DESIGN OF A DIGITAL DISPLAY SYSTEM FOR FUEL CONSUMPTION MONITORING IN FOUR-WHEELED VEHICLES

Yohanis Prasetyo Dalekes[1*], Leonardo Frando Pasla[2],
Jedithjah Naapia Tamedi Papia[3], Alfred Noufie Mekel[4],
Tammy Tinny Veisy Pangow[5]
[12345]Politeknik Negeri Manado, Indonesia
*Corresponding Author: yohanisprasetyodalekes@gmail.com

ABSTRACT
Real-time fuel-consumption information can support more transparent evaluation of vehicle operating efficiency, but low-cost direct-flow prototypes require validation before vehicle deployment. This study designed and evaluated a digital display prototype using an Arduino Uno microcontroller, a YF-B6 Hall-effect water-flow sensor, an LM2596 voltage regulator, and a 20×4 I2C LCD. A prototype-development procedure covered literature review, workflow analysis, hardware and software design, bench sensor testing, system integration, and evaluation. During bench testing with water, one reported sensor reading was compared with each nominal reference volume from 1 to 5 L. Percentage error was calculated as |V_actual − V_sensor|/V_actual × 100. The sensor readings were 0.98, 1.96, 2.95, 3.93, and 4.91 L, producing errors of 2.00%, 2.00%, 1.67%, 1.75%, and 1.80%, respectively, with an average error of 1.84%. All pointwise errors were below the YF-B6 ±3% specification. The readings consistently under-reported the nominal volumes, indicating a systematic calibration bias that may be addressed through calibration correction. Because the prototype was tested with water rather than automotive fuel and was not validated on a moving vehicle, the results demonstrate bench-scale volumetric performance rather than final on-vehicle fuel-consumption accuracy. The system is therefore positioned as a low-cost proof of concept for subsequent fuel-compatible and on-vehicle validation.

Keywords: Arduino Uno, flow sensor, fuel consumption, real-time monitoring, YF-B6.

INTRODUCTION

Four-wheeled vehicles remain central to personal and commercial mobility, while fuel consumption directly affects operating cost, energy use, and environmental performance. Real-world studies consistently show that observed fuel consumption can diverge from certified or nominal values because vehicle characteristics, operating conditions, traffic, climate, and driver behavior interact during actual use (Wu et al., 2020; Zeng et al., 2021; Yang et al., 2022). Predictive studies based on vehicle technical parameters likewise demonstrate that fuel-consumption behavior cannot be represented adequately by a single static indicator (Ziółkowski et al., 2021). These findings strengthen the need for transparent, real-time or near-real-time monitoring methods that can provide vehicle users and technicians with direct information about fuel use under specific operating conditions.

Modern vehicles increasingly provide operational information through electronic control units (ECUs), controller area networks, and on-board diagnostic (OBD) interfaces. Electronic engine-control architectures integrate multiple sensor signals to regulate fuel and air delivery and to communicate operating conditions (Muzayyin et al., 2021). Recent research has combined on-board and remote sensors to estimate vehicle performance, emissions, driving behavior, and fuel consumption (Campos-Ferreira et al., 2023). Low-cost OBD-II interfaces have also been used to model fuel consumption with regression, decision-tree, and neural-network approaches (Rykała et al., 2023), while field studies have evaluated the usefulness of on-board fuel-consumption information under real driving conditions (Tapak et al., 2023; Rosero et al., 2024). Related work has used OBD variables and machine-learning models calibrated against high-precision fuel-flow measurements for instantaneous fuel-consumption estimation (Abediasl et al., 2024), and OBD data have also supported real-driving emissions estimation (Rivera-Campoverde et al., 2021). Collectively, this literature confirms the value of vehicle-level sensing while also emphasizing the importance of validating any estimated or broadcast fuel-consumption quantity against appropriate reference measurements.

In parallel with OBD-based approaches, direct flow measurement remains relevant because it provides a physical measurement pathway that does not depend on the availability or interpretation of vehicle-specific diagnostic parameters. Tullah et al. (2020) developed a digital data-acquisition device for fuel-consumption and air-fuel-ratio analysis, whereas Dianastiti et al. (2023) developed a fuel flow meter for motorcycle-engine consumption measurement. Arifin et al. (2024) also reported an Arduino-based digital fuel indicator for motorcycles. At a more advanced metrological level, Büker et al. (2023) characterized a Coriolis flow meter for fuel-consumption measurements under realistic dynamic drive-cycle conditions and highlighted the effects of fuel density, viscosity, temperature, and transient flow. Direct measurements have likewise been used to verify the limitations of vehicle-broadcast fuel-consumption estimates (Gonder et al., 2017). Bond et al. (2023) showed that low-cost fuel-flow monitoring can be useful when sensing hardware, firmware, signal processing, and calibration are treated as an integrated measurement problem. These studies indicate that direct-flow architectures are technically meaningful, but their accuracy depends strongly on sensor suitability, calibration, test medium, and operating conditions.

Low-cost microcontroller platforms are widely used in proof-of-concept measurement systems because they can acquire sensor signals, execute real-time calculations, log data, and communicate with displays or networked peripherals. Arduino-based hardware has been applied to customizable laboratory sensing and data-acquisition systems (Goertzen et al., 2020), microcontroller-based flow-monitoring prototypes (Ardiliansyah et al., 2021), and open-source environmental flow-monitoring platforms (Guyard et al., 2025). Other low-cost flow and velocity studies demonstrate that inexpensive sensing platforms can provide useful measurements when calibration and validation are explicitly incorporated into system development (Harija et al., 2020; Catsamas et al., 2022; Ding et al., 2025). In the present system, the Arduino Uno acquires pulse signals from a Hall-effect flow sensor, calculates flow rate and accumulated volume, and communicates the resulting values to a local LCD. This architecture is attractive for a proof-of-concept monitor because sensing, processing, and display functions can be integrated with simple and accessible hardware.

Despite the growing literature on OBD-based estimation, fuel-flow instrumentation, and low-cost sensing, two gaps remain relevant to the present prototype. First, many recent vehicle-level studies rely on OBD, ECU, CAN, or factory on-board fuel-consumption information (Campos-Ferreira et al., 2023; Rykała et al., 2023; Abediasl et al., 2024), whereas several low-cost direct-flow prototypes focus on motorcycles or non-automotive applications (Dianastiti et al., 2023; Bond et al., 2023). Second, successful component integration is often emphasized more strongly than a transparent pointwise characterization of measurement error. The defensible novelty of the present study is therefore not the individual Arduino, sensor, or LCD components, but the integration of a low-cost direct-flow display prototype with an explicit 1-5 L bench error profile and identification of the direction of measurement bias. This positioning treats the system as an engineering proof of concept rather than as a validated automotive fuel-flow instrument.

Accordingly, this study aims to design and evaluate a digital display prototype for real-time flow and accumulated-volume monitoring using an Arduino Uno, a YF-B6 flow sensor, an LM2596 regulator, and a 20 x 4 I2C LCD. The study examines whether the integrated prototype can acquire pulse signals, convert them into flow and accumulated-volume information, display the information in real time, and achieve pointwise volumetric errors within the stated YF-B6 supplier specification during controlled bench testing. Because the validation medium is water rather than automotive fuel, the intended four-wheeled-vehicle application is treated as a development target rather than a validated deployment condition.

METHOD

Research Design

This study used a prototype-development design consisting of literature review, monitoring-workflow analysis, hardware design, software design, sensor testing, system integration, and performance evaluation. The development process was iterative in the engineering sense: hardware and software functions were checked during assembly, after which the integrated system was evaluated using the available volumetric test points. Contemporary flow-metrology studies emphasize that calibration and performance evaluation should distinguish steady from dynamic operating conditions and should use traceable reference procedures whenever quantitative accuracy claims are made (Ogheard et al., 2022; Batista et al., 2022). Figure 1 summarizes the development sequence applied in this study.

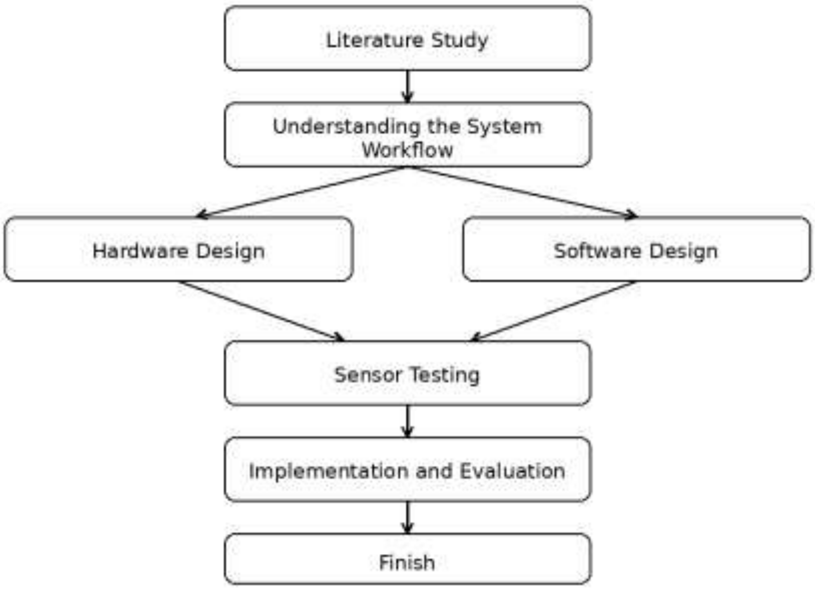

Figure 1. Research Method Stages

Literature and Problem Identification

Figure 2. YF-B6 Water-Flow Sensor

Software Logic and Calculation Procedure

Programming was performed in the Arduino IDE using C/C++-style Arduino syntax. During operation, a pulse counter is incremented whenever the sensor generates a pulse. Let N denote the number of pulses counted during an elapsed interval Δt (s). Pulse frequency is calculated as $f = N/\Delta t$ (Hz). For the YF-B6 supplier relationship used in this study, $f = 6.6Q$, where Q is flow rate in L/min; therefore $Q = f/6.6$ (HESTORE Hungary Kft., n.d.). Incremental volume is calculated as $\Delta V = Q(\Delta t/60)$, and accumulated volume is obtained by summing ΔV over successive intervals. This explicit calculation sequence improves computational reproducibility and follows the general principle that low-cost sensor outputs should be converted through documented calibration relationships rather than treated as inherently accurate measurements (Villanueva et al., 2023; Ding et al., 2025).

The device-operation logic is presented in Figure 5 in the Results and Discussion section. The flowchart follows the same computational sequence described above and uses consistent terminology for pulse counting, frequency conversion, flow-rate calculation, accumulated volume, and LCD output.

Bench Sensor Testing and Error Analysis

Sensor performance was evaluated using water as the test medium because the YF-B6 is specified as a water-flow sensor. The available test record contains one reported sensor reading at each nominal reference-volume point of 1, 2, 3, 4, and 5 L. No replicate measurements or repeated-trial statistics are available; consequently, the analysis is restricted to pointwise measurement error and the consistency of the error direction across the five volumes. The make, model, resolution, and traceability status of the reference measuring vessel were not documented and are therefore treated as methodological limitations. This conservative interpretation is consistent with contemporary low-cost sensor studies that emphasize device-specific calibration, reference comparison, and validation before field deployment (Ding et al., 2025; Villanueva et al., 2023).

For each test point, the absolute volume difference was calculated as $|V\_actual - V\_sensor|$. Percentage error was calculated using $\text{Error}\ (\%) = |V\_actual - V\_sensor|/V\_actual \times 100$. The mean percentage error was calculated as the arithmetic mean of the five pointwise percentage-error values. The stated acceptance reference for this prototype was the YF-B6 supplier specification of $f = 6.6Q$ with an accuracy of $\pm 3\%$ under its specified measurement conditions (HESTORE Hungary Kft., n.d.). Because the bench test used water, the comparison is interpreted only as a check against the sensor specification and not as evidence of certified automotive-fuel measurement accuracy.

Evaluation Scope and Safety Boundary

The quantitative evaluation in this study is limited to the reported volumetric sensor error. Functional integration was also observed in the sense that Arduino Uno received sensor pulses and the LCD displayed processed information during bench operation. However, no quantitative tests were reported for display refresh rate, transient response, supply-voltage variation, electromagnetic interference, vibration, temperature cycling, leakage, or dynamic on-vehicle operation. Therefore, terms such as “stable,” “optimal,” and “vehicle-ready” are avoided unless they refer specifically to the observed bench functionality. In addition, the YF-B6 is not presented as a fuel-certified sensor; actual-fuel compatibility and vehicle installation require separate safety and materials validation.

RESULTS AND DISCUSSION

Prototype Architecture and Functional Realization

The prototype integrated an Arduino Uno R3, a YF-B6 flow sensor, an LM2596 DC–DC step-down module, a 20×4 I2C LCD, jumper wiring, and a computer running Arduino IDE for program development. The system architecture follows a straightforward signal chain: fluid movement produces sensor pulses, the microcontroller converts the pulse frequency into flow and accumulated-volume values, and the LCD presents the processed information. The voltage regulator provides a regulated supply from the nominal vehicle-battery source used in the intended architecture.

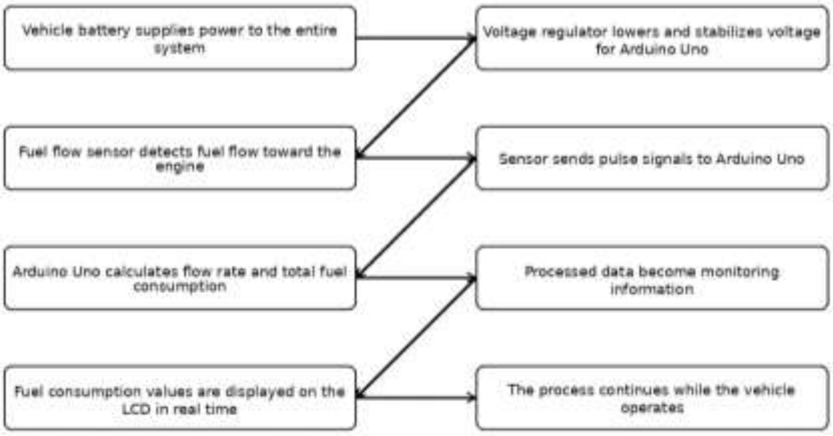

Figure 3. Mechanism of the System Work

Figure 3 illustrates the functional sequence from the power supply and sensor input to data processing and display. The diagram represents the intended operating mechanism of the prototype. The present evaluation validates the sensing-and-display concept on the bench; it does not demonstrate complete operation in a moving four-wheeled vehicle.

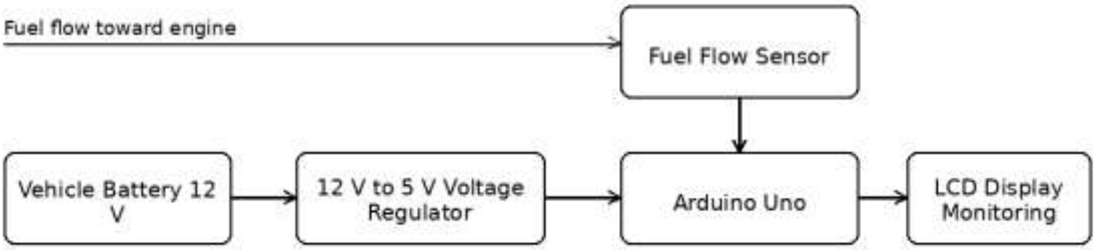

Figure 4. Block Diagram of the Monitoring System

YF-B6 Technical Specification

Table 1 presents the YF-B6 characteristics traceable to the supplier specification used in this study. The documentation identifies the YF-B6 as a Hall-effect water-flow meter with a nominal 5 V supply, 5-12 V operating range, maximum stated pressure of 1.75 MPa, the relationship f = 6.6Q, and stated accuracy of ±3% (HESTORE Hungary Kft., n.d.). These specifications are used only as the bench-test comparison criterion and are not interpreted as automotive-fuel certification.

Table 1. Technical Specifications of the YF-B6 Sensor

Parameter	Specification
Sensor model	YF-B6 water-flow sensor
Working principle	Hall effect
Nominal voltage	5 VDC
Operating voltage	5–12 VDC
Maximum pressure	1.75 MPa
Frequency relationship	f = 6.6Q, where Q is in L/min
Stated accuracy	±3%
Connection	3 wires: V+, signal, GND
Thread size	G3/4

Device Operation Flow

The operation flow is shown in Figure 5. After initialization, the microcontroller counts pulses over an elapsed interval, calculates pulse frequency and flow rate, updates accumulated volume, and displays the values. The cycle continues while the system remains active. The figure uses the same terminology and computational sequence described in the Method section.

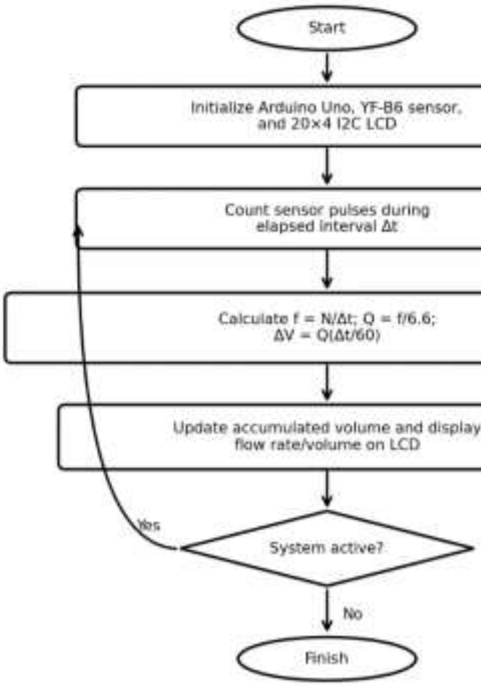

Figure 5. Flowchart of Device Operation

Conceptual Circuit and Deployment Layout

Figure 6 presents the conceptual fuel-flow and electronic integration of the prototype using the YF-B6 sensor. The diagram separates the intended fluid path from the electronic signal and power paths. The fluid-path portion is conceptual because actual-fuel compatibility and on-vehicle validation were not evaluated in this study; therefore the figure should not be interpreted as a recommendation for direct installation of the tested water-flow sensor in an automotive fuel line.

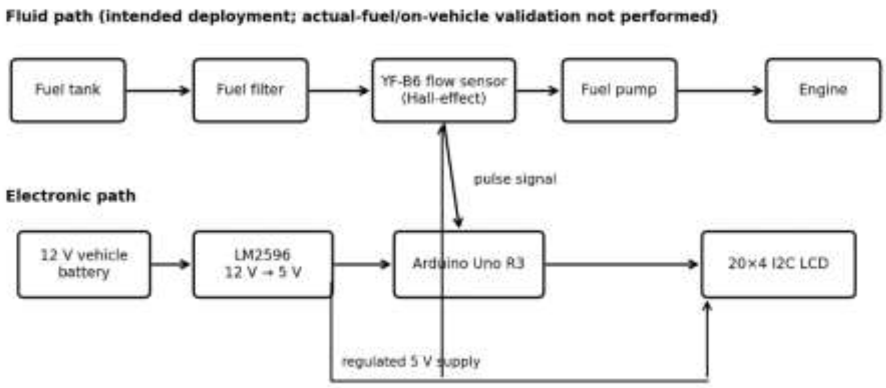

Figure 6. Conceptual Fuel-Flow and Electronic Integration Using the YF-B6

Volumetric Test Results

The reported bench-test data are presented in Table 2. At every nominal volume, the YF-B6 reading was slightly lower than the corresponding actual volume. The absolute differences ranged from 0.02 L at the 1 L point to 0.09 L at the 5 L point.

Table 2. YF-B6 Water-Flow Sensor Test Results

No.	Actual Volume (L)	Sensor Volume (L)	Difference (L)	Error (%)
1	1.00	0.98	0.02	2.00
2	2.00	1.96	0.04	2.00
3	3.00	2.95	0.05	1.67
4	4.00	3.93	0.07	1.75
5	5.00	4.91	0.09	1.80

The percentage errors ranged from 1.67% to 2.00%, and the arithmetic mean of the five reported errors was 1.84%. All five pointwise values were below the cited ±3% YF-B6 specification. The test therefore supports the narrower conclusion that, under the reported water-bench conditions, the sensor produced pointwise volumetric errors within the stated supplier tolerance.

The error direction is also informative. The sensor under-reported the reference volume at all five test points. This pattern is consistent with a systematic negative measurement bias rather than a mixture of positive and negative deviations. A plausible engineering explanation is that the nominal pulse-to-flow constant does not perfectly represent the particular test arrangement or that transient pulse losses occur as flow starts and stops. Nevertheless, the present data do not isolate the physical cause of the bias; pressure stability, air bubbles, rotor mechanics, flow profile, and calibration conditions remain possible contributors. Because only one reported observation is available at each test point, the data should be described as showing a consistent pointwise error pattern, not as demonstrating statistical repeatability or precision.

The systematic under-reading provides a practical basis for future calibration. A correction relationship should be estimated from a larger dataset containing repeated measurements over the intended operating range and should then be checked using an independent validation dataset. Flow-metrology research shows that calibration quality depends on reference traceability, measurement uncertainty, and the ability to represent unsteady as well as steady flow conditions (Ogheard et al., 2022; Batista et al., 2022). Low-cost sensor studies likewise show that calibration is often device-specific and that environmental or operating conditions can influence performance (Ding et al., 2025; Villanueva et al., 2023). The present five-point record is therefore sufficient to identify the direction and approximate magnitude of bias, but not to establish a robust correction model.

Comparison with Previous Studies and Scholarly Contribution

The present prototype occupies a different position from several recent vehicle-monitoring approaches. Campos-Ferreira et al. (2023) combined on-board and remote sensing for integrated vehicle and driver monitoring, while Rykała et al. (2023) modeled fuel consumption using a low-cost OBD-II interface. Tapak et al. (2023) evaluated on-board fuel-consumption-meter information in field testing, Rosero et al. (2024) used OBD data to assess fuel efficiency under real traffic conditions, and Abediasl et al. (2024) trained machine-learning models using OBD variables with fuel-flow measurements as the reference. Rivera-Campoverde et al. (2021) similarly demonstrated the analytical value of OBD data for real-driving emissions estimation. These approaches are relevant to vehicle-level monitoring but rely primarily on diagnostic or built-in vehicle information rather than the simple direct pulse-flow architecture examined here.

Direct flow measurement introduces a different set of engineering trade-offs. Tullah et al. (2020) reported a digital device for real-time fuel-consumption data acquisition, Dianastiti et al. (2023) developed a motorcycle fuel flow meter, and Arifin et al. (2024) developed an

Arduino-based digital fuel indicator. Bond et al. (2023) demonstrated the importance of integrating sensing hardware, signal processing, firmware, and calibration in a low-cost fuel-flow monitoring system. At higher metrological performance, Büker et al. (2023) characterized a Coriolis fuel flow meter across realistic dynamic profiles, densities, viscosities, and temperatures, while Gonder et al. (2017) showed why vehicle-broadcast fuel rates should be checked against precise instrumentation. The contribution of the present study is therefore a transparent low-cost integration example with explicit 1-5 L pointwise errors and observed bias direction, not a claim of equivalence to fuel-rated laboratory or automotive flow instrumentation.

The average error of 1.84% should not be interpreted as evidence that the prototype is more accurate than other published systems because the technologies, test media, reference procedures, operating ranges, and deployment conditions differ substantially. Real-world fuel-consumption studies show substantial variation between nominal, modeled, broadcast, and measured values (Wu et al., 2020; Zeng et al., 2021; Yang et al., 2022). Accordingly, the 1.84% value is meaningful only as an internal benchmark for the present water-bench configuration. Its most useful implication is that all five observations fall below the cited supplier tolerance and exhibit the same under-reading direction, which can guide the design of a more rigorous calibration experiment.

The distinction between accuracy, bias, precision, and repeatability is important for this dataset. Accuracy is discussed here in terms of the absolute percentage difference between each reported sensor value and the corresponding nominal reference volume. Bias refers to the direction of the deviation; all five readings were lower than the reference values, so the observed bias is negative. Precision and repeatability, by contrast, require repeated observations under the same or closely controlled conditions. Because the available table contains one reported reading at each volume, the manuscript cannot estimate within-condition variability and therefore does not use the five different-volume observations as a substitute for replicate trials. This revision directly narrows the interpretation to what the data can demonstrate.

A future calibration protocol should separate calibration from validation. Repeated measurements across the operating range should first be used to estimate a correction relationship against a traceable reference, after which an independent dataset should be used to test whether the correction generalizes. Reporting mean absolute error, signed bias, standard deviation, maximum absolute error, confidence or uncertainty measures, and reference-instrument specifications would permit a substantially stronger assessment. Calibration research on both primary flow standards and low-cost sensors demonstrates the importance of reference quality, independent validation, and controlled testing across relevant operating conditions (Ogheard et al., 2022; Ding et al., 2025). For an automotive application, the matrix should also include transient flow because fuel demand changes dynamically with engine speed, load, acceleration, and operating state (Büker et al., 2023; Abediasl et al., 2024).

The direct-flow architecture has both a conceptual advantage and a practical disadvantage relative to OBD-based estimation. Its conceptual advantage is that the measurement originates from a dedicated physical flow sensor rather than from diagnostic parameters whose availability and interpretation can vary among vehicle implementations. Its practical disadvantage is that an inline sensor becomes part of the fluid-delivery path and therefore introduces requirements for pressure drop, sealing, chemical compatibility, vibration resistance, and safety. Studies using fuel-rated flow meters under laboratory and real-world driving conditions illustrate the level of instrumentation control required for credible direct fuel measurement (Büker et al., 2023; Abediasl et al., 2024). The present prototype demonstrates the signal-processing concept, but water-bench evidence cannot be extrapolated directly to fuel-line deployment.

Practical Significance, Transferability, and Limitations

The prototype has practical value as a low-cost instructional and engineering proof of concept for demonstrating how sensor pulses can be converted into real-time flow and accumulated-volume information. Similar open-source and low-cost sensing studies show that accessible hardware can support measurement, experimentation, and field monitoring when calibration, documentation, and performance boundaries are explicit (Goertzen et al., 2020; Harija et al., 2020; Catsamas et al., 2022; Guyard et al., 2025). Transfer to an operational vehicle would nevertheless require verified fuel compatibility, appropriate flow and pressure range, installation orientation, leak prevention, vibration and temperature qualification, electromagnetic and electrical protection, stable power supply, and calibration under transient engine demand. These deployment conditions cannot be inferred from static water-volume testing.

A particularly important limitation is the test medium. The YF-B6 is specified as a water-flow sensor, while gasoline and diesel differ from water in density, viscosity, lubricity, volatility, chemical compatibility, and safety requirements. Fuel-flow metrology studies specifically characterize instruments across fuel type, temperature, dynamic flow, density, and viscosity because these variables influence measurement performance (Büker et al., 2023). The present study therefore does not recommend direct installation of the tested YF-B6 in an automotive fuel line. Subsequent development should use a sensor explicitly rated for the intended fuel or establish verified material compatibility and safety before controlled fuel testing and on-vehicle validation.

The experimental record has additional limitations. Only five nominal volume points were reported, one reading was available at each point, and the reference measuring instrument and its resolution were not documented. The study also did not quantify dynamic response, display latency, electrical stability, temperature effects, vibration resistance, long-duration drift, or on-road performance. These limitations restrict generalization of the 1.84% mean error to the specific reported water-bench conditions. Future work should use repeated measurements, a traceable reference flow/volume instrument, calibration and validation datasets, multiple flow rates, fuel-compatible hardware, and controlled on-vehicle testing. Data logging and Internet of Things connectivity can be added after the measurement chain itself has been validated.

System Realization

During bench realization, Arduino Uno, the YF-B6 sensor, the LM2596 module, and the 20×4 I2C LCD were integrated so that sensor pulses could be processed and the resulting flow/volume information could be displayed. The available observations support a statement of functional integration: the components communicated and produced displayed measurement values during the reported tests. Because no quantitative reliability or dynamic-response metrics were recorded, the revised manuscript does not characterize the complete system as “optimal” or statistically “stable.” Instead, the system is described as functionally operational under the specific bench conditions reported.

CONCLUSION

This study designed and bench-evaluated a digital display prototype that integrates an Arduino Uno, a YF-B6 Hall-effect water-flow sensor, an LM2596 regulator, and a 20×4 I2C LCD for real-time flow and accumulated-volume monitoring. Across the five reported water-volume test points from 1 to 5 L, the pointwise error ranged from 1.67% to 2.00%, with an average of 1.84%, and all values were below the cited ±3% YF-B6 specification. The sensor consistently under-reported the nominal volume, revealing a systematic calibration bias that should be addressed in subsequent calibration work. The findings support the prototype as a functional bench-scale proof of concept, but they do not establish repeatability, fuel compatibility, or on-vehicle fuel-consumption accuracy because only one reported reading was available at each test point, the reference instrument was not documented, water was used as the test medium, and dynamic vehicle conditions were not evaluated. Future development should use a fuel-rated flow sensor, repeated measurements with a traceable reference instrument, calibration and independent validation, and controlled actual-fuel and on-vehicle tests before adding advanced functions such as data logging or IoT connectivity.

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