# DESIGN OF A DIGITAL DISPLAY SYSTEM FOR MONITORING RADIATOR TEMPERATURE ON FOUR-WHEELED VEHICLES

I Made Wely Prayoga[1*], Yanse Arfinando Janis[2],
Jedithjah Naapia Tamedi Papia[3], Herotje Siwi[4],
Tammy Tinny Veisy Pangow[5]
[12345]Politeknik Negeri Manado, Indonesia
*Corresponding Author: welyprayoga83@gmail.com

**ABSTRACT**
Engine overheating can develop when radiator coolant temperature is not monitored adequately, while conventional dashboard indicators may provide limited numerical information. This study designed and evaluated an Arduino Uno-based digital display prototype for monitoring radiator coolant temperature in four-wheeled vehicles. The system integrated a DS18B20 temperature sensor, Arduino Uno, TM1637 driver, 3-digit 7-segment display, buzzer, and regulated power supply. Evaluation consisted of a three-point comparison against a digital thermometer and vehicle-scenario observations under idling, normal driving, and traffic-jam conditions with the air conditioning on. At reference temperatures of 30, 40, and 50°C, the sensor differed from the reference by 0–1°C, giving a mean absolute error of 0.33°C and a mean absolute percentage error of approximately 0.83%. Vehicle observations covered 32–94°C; the audible alarm remained inactive at 94°C because the programmed threshold was above 95°C. The findings demonstrate proof-of-concept feasibility for direct numerical coolant-temperature display under the reported conditions. However, the evidence does not establish universal vehicle applicability or superiority to factory indicators. Multi-vehicle calibration, repeated trials, quantitative response-time measurement, and durability testing are required before broader deployment.

**Keywords:** Arduino Uno, digital display, DS18B20, radiator coolant temperature, vehicle cooling system

## INTRODUCTION

Thermal management is a fundamental requirement for reliable internal-combustion-engine operation because the cooling system must reject sufficient heat while allowing the engine to remain within an efficient operating window. The radiator is a central heat exchanger in this process: hot coolant leaving the engine transfers heat to air flowing through the radiator core before the coolant returns to the engine. Reviews of automotive cooling circuits show that thermal performance depends on interacting coolant-flow, air-flow, radiator, fan, thermostat, and operating-condition effects rather than on temperature alone (Pang et al., 2012; Mukkamala, 2017). More recent reviews likewise emphasize that engine thermal-management performance is shaped by component coordination and control strategy, particularly as vehicle operating conditions vary dynamically (Liu et al., 2021). Consequently, temperature monitoring is not merely a display function; it is part of the information layer that allows abnormal thermal behavior to be recognized before severe overheating occurs.

The operating temperature of a vehicle is influenced by load, engine speed, ambient conditions, coolant properties, heat-exchanger characteristics, and the intervention of thermostats or cooling fans. Numerical and experimental studies of engine thermal management have therefore focused on more active and coordinated approaches to radiator and coolant control. Caresana et al. (2011) demonstrated the potential of smart thermal-management strategies for passenger vehicles, while Setlur et al. (2005), Salah et al. (2008), and Salah et al. (2009) examined nonlinear and hydraulically actuated control strategies for advanced cooling systems. Wang and Wagner (2015) later investigated nonlinear radiator-fan matrix control, and Castiglione et al. (2016) proposed a cooling-system control strategy intended to improve internal-combustion-engine thermal management. These studies represent more sophisticated control architectures than the present prototype, but they establish an important principle: useful thermal management depends on timely, interpretable temperature information and clearly defined control or warning logic.

Recent research has extended this system perspective. Haghighat et al. (2018) developed an intelligent cooling-system and control model for improved engine thermal management, and Shu et al. (2019) analyzed optimization of coupled vehicle thermal-management systems. Castiglione et al. (2020) further addressed opportunities for powertrain thermal-management improvement, while Syed and Wagner (2023) modeled and controlled a multiple-heat-exchanger thermal-management system for conventional and hybrid-electric vehicles. Although such studies often employ model-based or multi-component control methods, they also highlight a practical challenge relevant to simpler vehicles and retrofit contexts: temperature information must be acquired reliably and transformed into a form that a controller or driver can interpret. The present work addresses this narrower monitoring layer rather than attempting to reproduce the complexity of advanced thermal-control systems.

At the sensing level, digital temperature sensors and low-cost microcontrollers make it possible to construct compact monitoring devices that can be evaluated before a production-grade automotive implementation is attempted. Arduino-based platforms are widely used in engineering prototypes because they simplify sensor interfacing, data processing, and display control. In non-automotive environmental monitoring, Ali et al. (2016) demonstrated an open-source Arduino-based platform for long-term indoor environmental data collection, while Avallone et al. (2016) used Arduino-based multiplexing to control and record temperature profiles in a thermal-storage application. Pereira and Ramos (2022) evaluated low-cost Arduino-based temperature, relative-humidity, and carbon-dioxide sensors and showed why application-specific validation remains important even when low-cost platforms are convenient. These examples do not validate an automotive radiator monitor directly, but they support the broader engineering practice of pairing inexpensive sensing hardware with explicit calibration and application-specific testing.

The DS18B20 digital thermometer is particularly attractive for prototype temperature acquisition because it communicates through a 1-Wire interface and provides digital output without requiring a separate analog-to-digital converter at the sensing point. The manufacturer's datasheet specifies an operating range of approximately -55°C to +125°C and reports accuracy characteristics that make the device suitable for many general temperature-monitoring tasks (Maxim Integrated, 2019). Nevertheless, datasheet performance should not be treated as a substitute for system-level validation. Raldiartono et al. (2019) described a calibration approach for waterproof DS18B20 sensors using an Arduino data-acquisition system, while Rodríguez-Rama et al. (2026) emphasized calibration models, uncertainty, and reproducibility in metrological validation of low-cost DS18B20 sensors. Work comparing temperature-sensor implementations in other applied environments has similarly shown that sensor configuration, thermal contact, enclosure, and reference methodology can influence observed performance (Vega et al., 2020). These considerations motivate the use of a reference thermometer comparison in the present prototype, while also limiting the strength of claims that can be made from only three calibration points.

In automotive applications, sensing must ultimately be interpreted within the thermal behavior of the cooling system. Cheng et al. (2023), in a review of sensor applications in electric-vehicle thermal-management systems, underscored the importance of sensing for monitoring and control across thermal subsystems. Although electric-vehicle architectures differ from the radiator system considered here, the broader implication is transferable: sensor data become practically valuable when their acquisition, processing, presentation, and response logic are integrated into a coherent system. Likewise, experimental radiator studies show that heat-transfer performance may change with coolant formulation and operating conditions (Zubair et al., 2021), reinforcing the need to avoid treating a temperature threshold observed in one prototype context as a universal limit for all vehicles.

Within the more directly related prototype literature, microcontroller-based systems have been developed to monitor vehicle coolant or radiator conditions. Hervita et al. (2017) reported a radiator water-level monitoring system using fuzzy logic, and Arif et al. (2023) developed an early overheat-detection device based on coolant temperature. Other Arduino-based temperature-monitoring studies have emphasized straightforward numerical display and microcontroller integration (Fauzan et al., 2022; Rahman, 2020; Syahputra & Wijaya, 2023). The Arduino platform itself remains a practical prototyping environment for integrating digital inputs and outputs (Kadir, 2018). For compact display, the TM1637 driver can reduce microcontroller pin requirements while controlling a 7-segment numerical interface, an approach also discussed in related display-oriented prototyping work (Pratama & Setiawan, 2021). Power stability is also relevant because sensor and display behavior depend on an adequate regulated supply (Yuliana & Hidayat, 2021).

Despite these developments, a gap remains between demonstrating individual components and presenting an explicitly delimited, dashboard-oriented prototype whose claims are traceable to its reported tests. Prior literature establishes the feasibility of sensing, microcontroller processing, vehicle thermal monitoring, and increasingly sophisticated thermal-management control. However, a simple retrofit-oriented configuration still requires clear evidence concerning at least three practical functions: whether the temperature sensor agrees acceptably with a reference at tested points, whether numerical values can be displayed consistently across relevant setpoints, and whether the integrated device behaves coherently under basic vehicle-operating scenarios. The gap addressed here is therefore not the invention of a new sensing principle, but the integrated evaluation and transparent reporting of a low-complexity monitoring architecture.

The novelty of this study is deliberately modest. It lies in combining a DS18B20 sensor, Arduino Uno, TM1637-controlled 3-digit display, buzzer, and regulated power supply as a single radiator coolant-temperature monitoring prototype and evaluating that configuration through a three-point thermometer comparison, display verification, and three reported vehicle-operating scenarios. The study does not claim a new thermal-management theory, a new sensor, or a production-ready automotive safety system. Framing the contribution in this way is important because advanced thermal-control research demonstrates much broader capabilities than those assessed here (Wang & Wagner, 2015; Haghighat et al., 2018; Syed & Wagner, 2023). The value of the present study is instead as a proof-of-concept monitoring interface that makes numerical temperature information directly visible and incorporates a programmed audible threshold.

Accordingly, this study aims to design and evaluate a digital radiator coolant-temperature monitoring prototype for four-wheeled vehicles. The evaluation focuses on three questions: whether the prototype can present numerical temperature values through the TM1637-controlled display; how closely the DS18B20 readings agree with a reference digital thermometer at the three reported comparison points; and how the integrated system behaves during the reported idling, normal-driving, and traffic-jam operating scenarios. The interpretation is intentionally bounded by the available data so that conclusions remain proportionate to the evidence.

## METHOD

### Research Design and Prototype Architecture

The study used a prototyping approach in which needs identification, rapid planning, prototype construction, component integration, and evaluation were treated as sequential development activities. This approach was selected because the research objective was engineering-oriented: to construct a functioning monitoring prototype and examine whether its principal sensing, display, and warning functions operated as intended under the reported tests. The prototype was not evaluated as a production-ready automotive product, and no claim is made that it satisfies automotive qualification, electromagnetic-compatibility, environmental, or functional-safety standards. The research object was therefore the integrated monitoring device and its observed interaction with the vehicle cooling-system temperature; no human participants were recruited.

The hardware architecture consisted of a DS18B20 digital temperature sensor, an Arduino Uno microcontroller, a TM1637 display driver, a 3-digit 7-segment display, a buzzer, and an AMS1117-based regulated power-supply stage. The DS18B20 served as the primary temperature-acquisition component. The Arduino Uno received the sensor output, processed the numerical temperature value, and supplied the information to the display through the TM1637 module. A 4.7 kΩ pull-up resistor was used on the DS18B20 data line to support 1-Wire communication, consistent with the sensor's digital interface requirements (Maxim Integrated, 2019). The regulated supply provided the 5 V operating level required by the principal low-voltage components. The design choice reflects the common prototyping pattern in which sensing, processing, and output functions are modular but integrated through a single microcontroller (Ali et al., 2016; Avallone et al., 2016).

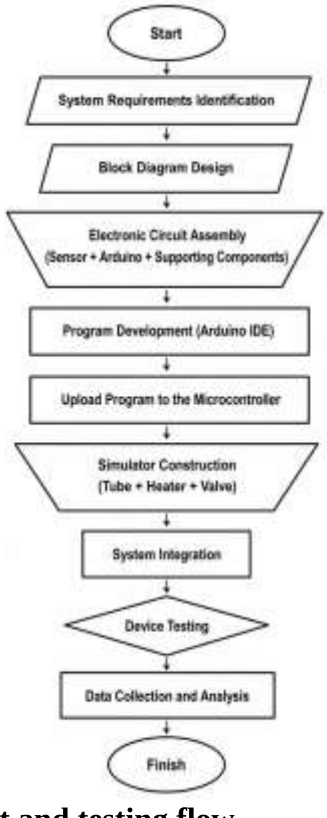


**Figure 1. Prototype development and testing flow**

**Research Object and Instrumentation**

The instrumentation reported in the study comprised the developed temperature-monitoring prototype and a digital thermometer used as the comparison reference. The available experimental record documents temperature comparison at 30°C, 40°C, and 50°C. It does not document the manufacturer, model, stated accuracy, traceability status, or calibration certificate of the reference thermometer. Likewise, the record does not specify the vehicle make and model, engine displacement, radiator design, coolant formulation, exact DS18B20 mounting geometry, ambient temperature, or electrical-noise conditions during vehicle testing. These details are not reconstructed or inferred because they were not reported in the source data. Their absence is treated as a reproducibility limitation rather than filled with assumptions.

The DS18B20 was selected because digital output reduces some of the signal-conditioning complexity associated with analog sensors. However, the use of a digital sensor does not eliminate measurement uncertainty. Sensor placement, thermal contact, local flow conditions, sensor encapsulation, response dynamics, and reference-instrument uncertainty can all affect the interpretation of a comparison result. Metrological work on low-cost digital sensors therefore emphasizes calibration design, uncertainty evaluation, and reproducibility rather than relying only on nominal sensor specifications (Raldiartono et al., 2019; Rodríguez-Rama et al., 2026). For this reason, the present three-point comparison is treated as an agreement check within a limited range and not as a comprehensive calibration certificate.

**Data Collection Procedure**

Primary data were obtained through direct testing of the prototype. First, DS18B20 readings were compared with the digital thermometer at the three reported reference temperatures of 30°C, 40°C, and 50°C. The paired readings were recorded and used to calculate absolute differences and summary error metrics. Second, display verification was performed at detected temperatures of 30°C, 45°C, 60°C, 75°C, and 90°C. At each point, the detected temperature, displayed value, and audible-alarm state were recorded. The programmed audible-alarm condition was defined as a temperature above 95°C; therefore, the alarm was expected to remain inactive at 90°C.

Vehicle-operating observations were then conducted under three reported conditions: a stationary idling engine for 15 min, normal-load driving over 10 km, and a 20-min traffic-jam simulation with the air conditioning on. The observed temperature range and cooling-system condition were recorded for each scenario. The study record does not state a sampling interval, number of repeated runs, route profile, vehicle speed distribution, load quantification, or standardized ambient condition. It also does not report a separate latency test, drift test, vibration test, or long-duration stability protocol. Consequently, terms such as 'instantaneous', 'highly responsive', or 'long-term stable' are not used as quantified performance claims in this revised report.

No coolant-level or pressure variable is included in the reported dataset. Earlier descriptions that could have been interpreted as assessing ultrasonic coolant-level sensing or pressure simulation are therefore excluded from the evaluated scope. This restriction aligns the objective, method, results, and conclusion with the actual evidence available for radiator coolant-temperature monitoring.

**Data Analysis**

Sensor agreement was summarized using absolute error, mean absolute error (MAE), and mean absolute percentage error (MAPE). For each comparison point, absolute error was calculated as $|T_{ref} - T_{sensor}|$. The mean absolute error was calculated as $MAE = \Sigma|T_{ref} - T_{sensor}|/n$, where Tref is the digital-thermometer reading, Tsensor is the DS18B20 reading, and n is the number of paired observations. Mean absolute percentage error was calculated as $MAPE = (100/n)\Sigma(|T_{ref} - T_{sensor}|/T_{ref})$. For the three reported pairs, the absolute differences were 0°C, 1°C, and 0°C. These values yield an MAE of 0.33°C and a MAPE of approximately 0.83%. No inferential statistical test is appropriate for the reported three-point descriptive comparison because repeated measurements and uncertainty estimates were not available.

Vehicle-scenario data were analyzed descriptively by reporting the observed temperature ranges and the associated cooling-system or alarm state. Display-verification results were also summarized descriptively as agreement between the detected and displayed values at the five test setpoints. The interpretation distinguishes directly observed behavior from inferred engineering significance. In particular, the data support functional numerical display and limited pointwise agreement, but they do not establish universal accuracy across the full DS18B20 range, validated response time, reliability over extended operation, or comparative superiority over factory-installed dashboard indicators.

### Ethical and Safety Considerations

The work involved engineering-device and vehicle testing and did not recruit or intervene with human research participants. Human-subject informed consent was therefore not applicable to the reported study. The available record does not document a formal institutional vehicle-testing safety protocol, hazard analysis, or data-retention procedure. This absence is reported transparently. Future vehicle trials should document safe sensor installation, electrical isolation, secure routing of wiring, driver-distraction controls, test-route procedures, emergency stopping criteria, and data-recording practices, particularly if the prototype is evaluated during extended road operation.

## RESULTS AND DISCUSSION

### Prototype Integration and Functional Verification

The completed prototype integrated the DS18B20 as the radiator-temperature sensor, the Arduino Uno as the processing unit, the TM1637 as the display driver, a 3-digit 7-segment display as the numerical interface, a buzzer as the audible warning output, and an AMS1117-based power-regulation stage. Figure 2 illustrates the reported circuit configuration. The architecture is intentionally low in complexity: one digital sensor provides the primary measured variable, the microcontroller performs the logic and formatting, and the display provides an explicit numerical output. This differs from advanced thermal-management systems that coordinate multiple heat exchangers, actuators, pumps, fans, and optimization objectives (Shu et al., 2019; Syed & Wagner, 2023). The comparison is important because the present contribution should be judged as a monitoring interface rather than as an integrated thermal-control platform.

The choice of a numerical display addresses a practical information-design issue. Conventional dashboard temperature indicators often communicate temperature indirectly through a needle position, segmented zone, or warning lamp, whereas a numerical display makes the measured value immediately explicit. The present study did not conduct a head-to-head human-factors or response-time comparison with a factory gauge, so it cannot demonstrate that the prototype is safer, faster, or superior. Its supported contribution is narrower: the device displayed numerical temperature values at the tested points and incorporated an audible threshold above 95°C. This evidence is consistent with the feasibility of Arduino-based sensing and display integration reported in related prototype studies (Fauzan et al., 2022; Rahman, 2020; Syahputra & Wijaya, 2023).

The power and communication design also reflects standard embedded-prototype practice. The DS18B20's 1-Wire interface allows temperature data to be read digitally, while the TM1637 uses a compact clock/data interface to drive the multi-digit display. The regulated 5 V supply is operationally important because unstable power can affect microcontroller and peripheral behavior. Prior local work on Arduino supply stability has similarly highlighted the role of voltage regulation in maintaining system operation (Yuliana & Hidayat, 2021). Nevertheless, the present study did not measure input-voltage transients, automotive load-dump conditions, alternator noise, electromagnetic interference, or regulator thermal behavior. Accordingly, electrical robustness in a production vehicle remains unverified.

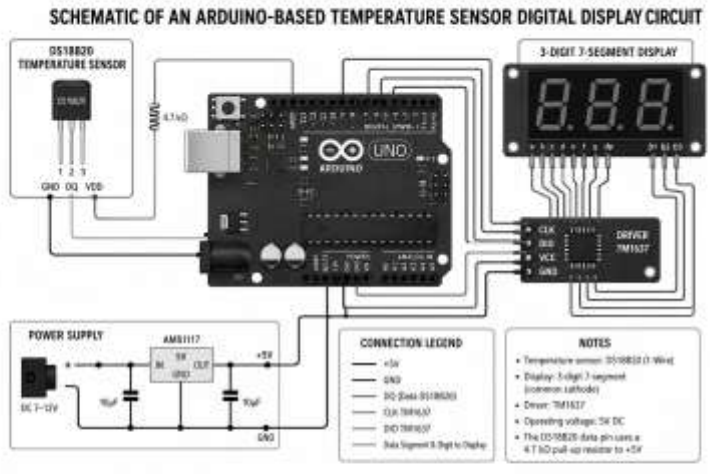


**Figure 2. Electronic circuit of the radiator temperature-monitoring prototype**

## Vehicle-Operating Scenario Performance

**Table 1. Vehicle-operating scenario test results**

| Test Conditions | Duration/Distance | Temperature Read | Cooling System Condition |
|---|---|---|---|
| Stationary (Idling) Engine | 15 min | 32–85°C | Normal; radiator fan activated at 85°C |
| Driving (Normal Load) | 10 km | 82–88°C | Stable; temperature varied with thermostat operation |
| Traffic Jam Simulation (A/C On) | 20 min | 88–94°C | Safe in the reported test; alarm remained inactive below the >95°C threshold |

Table 1 summarizes the three reported vehicle-operating scenarios. During stationary idling for 15 min, the displayed coolant temperature increased from 32°C to 85°C, and radiator-fan activation was observed at 85°C. During normal-load driving over 10 km, the reported temperature range was 82–88°C, with temperature variation described in relation to thermostat operation. The traffic-jam simulation with the air conditioning on produced the highest observed range, 88–94°C. At 94°C the audible alarm remained inactive because the programmed threshold was above 95°C. These observations show that the integrated prototype produced differentiated numerical readings as vehicle operating conditions changed.

The observed pattern is thermally plausible, but the study design does not permit causal attribution to individual components. Radiator and engine temperatures reflect the balance among heat generation, coolant circulation, thermostat state, radiator air flow, fan operation, and ambient conditions (Pang et al., 2012; Liu et al., 2021). Under idling or congested traffic, ram-air flow through the radiator is limited and fan assistance becomes more important, whereas normal driving can increase air flow through the heat exchanger. Advanced thermal-management studies have examined such interactions explicitly through nonlinear fan control and coordinated cooling strategies (Wang & Wagner, 2015; Haghighat et al., 2018). The present measurements are too limited to evaluate these control dynamics quantitatively, but the scenario data demonstrate that the prototype can present temperature changes during distinct operating contexts.

The traffic-jam observation deserves especially cautious interpretation. A maximum reported value of 94°C was below the prototype's programmed audible-alarm threshold, so the inactive buzzer was consistent with the implemented logic. However, the study does not establish that 95°C is a universally appropriate over-temperature threshold for all engines or coolant systems. Acceptable temperature ranges and fan-control points can differ with engine calibration, pressure cap, coolant composition, thermostat specification, radiator design, and manufacturer strategy. Experimental radiator research further shows that thermal performance can change with coolant formulation and heat-transfer conditions (Zubair et al., 2021). Therefore, the 95°C value should be understood as the prototype's programmed test threshold, not as a general automotive safety limit.

The scenario results also clarify what the system does not do. The prototype does not actively regulate fan speed, coolant flow, thermostat position, or engine load. By contrast, studies such as Setlur et al. (2005), Salah et al. (2008), Castiglione et al. (2016), and Castiglione et al. (2020) investigate active or optimized thermal-management control. The present system functions as a monitoring and warning interface. That distinction is relevant to practical deployment: an informative display can support driver awareness, but it cannot substitute for a validated engine-control strategy or correct a mechanical cooling-system fault.

### Sensor Agreement and Calibration Evidence

**Table 2. Three-point comparison between the reference digital thermometer and DS18B20 sensor**

| No. | Digital Thermometer (°C) | DS18B20 Sensor (°C) | Difference (°C) |
|---|---|---|---|
| 1 | 30 | 30 | 0 |
| 2 | 40 | 39 | 1 |
| 3 | 50 | 50 | 0 |

Table 2 presents the three reported reference comparisons. At 30°C, the digital thermometer and DS18B20 both indicated 30°C. At 40°C, the reference indicated 40°C and the DS18B20 indicated 39°C, producing a 1°C absolute difference. At 50°C, both devices indicated 50°C. The mean absolute error across these three points was therefore 0.33°C. Using the reference value as the denominator at each point, the percentage errors were 0%, 2.50%, and 0%, which yield a MAPE of approximately 0.83%. This calculation is directly traceable to the values shown in the table and replaces less transparent accuracy claims.

The small differences observed at the three points are encouraging for proof-of-concept use, but they should not be equated with a full metrological validation. The comparison covers only 30–50°C, whereas the vehicle observations extended to 94°C. The study did not report repeated observations at each calibration point, reference-instrument uncertainty, sensor-to-reference stabilization time, thermal-bath homogeneity, or traceability. Calibration studies of DS18B20 devices demonstrate why these details matter: Raldiartono et al. (2019) used a controlled oil-bath approach for sensor calibration, while Rodríguez-Rama et al. (2026) explicitly addressed calibration models, uncertainty, and reproducibility. Thus, the present MAPE describes agreement for three reported pairs; it does not validate the sensor across the entire automotive operating range.

This distinction also affects interpretation of the manufacturer's accuracy specification. The DS18B20 datasheet provides nominal performance characteristics (Maxim Integrated, 2019), but system-level accuracy depends on more than the sensing element. Installation geometry can create thermal lag or local-temperature bias, and waterproof packaging can alter response characteristics. Evidence from applied sensor-assessment research shows that low-cost temperature measurement requires context-specific verification rather than simple transfer of datasheet claims (Vega et al., 2020; Pereira & Ramos, 2022). For automotive radiator monitoring, future calibration should therefore include additional points spanning the expected operating range, repeated measurements, uncertainty reporting, and documentation of sensor mounting and reference instrumentation.

Even within these limitations, the three-point agreement provides useful engineering information. A prototype that displays large unexplained offsets at basic setpoints would require redesign before vehicle testing. Here, the observed pointwise differences were no greater than 1°C, which supports proceeding to broader validation. The appropriate conclusion is consequently one of preliminary agreement, not certified accuracy. This wording maintains alignment between evidence and claim while preserving the practical significance of the result.

### Display Verification and Alarm Logic

**Table 3. Display verification and alarm-state observations**

| No. | Detected Temperature (°C) | Display Screen | System Response |
|---|---|---|---|
| 1 | 30 | 30 | Displayed correctly; alarm inactive |
| 2 | 45 | 45 | Displayed correctly; alarm inactive |
| 3 | 60 | 60 | Displayed correctly; alarm inactive |
| 4 | 75 | 75 | Displayed correctly; alarm inactive |
| 5 | 90 | 90 | Displayed correctly; alarm inactive (<95°C threshold) |

Table 3 summarizes display verification at detected temperatures of 30°C, 45°C, 60°C, 75°C, and 90°C. At each setpoint, the numerical value shown on the display matched the detected temperature recorded for the test. The alarm remained inactive at all five points. This was expected at 90°C because the audible threshold was programmed above 95°C. The revised reporting therefore uses one consistent interpretation across the abstract, method, results, and conclusion: 90°C is a verified display point, not an alarm-trigger point, and 94°C in the vehicle test likewise remained below the programmed audible threshold.

The display results support functional value presentation but do not quantify temporal responsiveness. No sampling-frequency log, timestamped transition record, step-response test, or latency measurement was reported. Descriptions such as 'instantaneous' or 'without perceptible delay' would therefore exceed the evidence. A more defensible statement is that the display updated consistently with the tested temperature values during observation. This distinction follows good measurement practice because responsiveness is a measurable performance characteristic and should be supported by timing data rather than by qualitative impression alone.

The alarm logic also illustrates the difference between prototype functionality and safety validation. A buzzer can provide a salient secondary output when a programmed condition is met, but selecting an automotive warning threshold requires application-specific engineering justification. Advanced vehicle thermal-management research treats temperature thresholds and actuator decisions as part of a larger control problem involving model behavior, thermal inertia, and operating constraints (Salah et al., 2009; Wang & Wagner, 2015). In future iterations, alarm logic should be based on the specific engine manufacturer's acceptable coolant-temperature range or a validated thermal model, and it may be useful to distinguish advisory, warning, and critical states rather than relying on a single generic threshold.

**Relation to Previous Thermal-Management and Monitoring Studies**

The findings can be positioned at the intersection of low-cost embedded monitoring and automotive thermal-management research. On one side, advanced studies demonstrate the benefits of coordinated cooling control and system-level optimization (Caresana et al., 2011; Haghighat et al., 2018; Shu et al., 2019; Syed & Wagner, 2023). On the other side, Arduino-oriented studies demonstrate that low-cost controllers can integrate sensors, process measurements, and present useful data in compact prototypes (Ali et al., 2016; Avallone et al., 2016; Pereira & Ramos, 2022). The present prototype does not compete with advanced control systems; instead, it applies the accessibility of embedded prototyping to a narrowly defined automotive monitoring task.

Compared with prior radiator-oriented local studies, the contribution is primarily in explicit integration and evidence alignment. Hervita et al. (2017) focused on radiator fluid-level monitoring using fuzzy logic, while Arif et al. (2023) addressed early overheating detection through coolant temperature. The present design focuses only on temperature because that is the variable supported by the available dataset. It combines numerical display, a programmed buzzer threshold, three-point reference comparison, and observations in three operating scenarios. This narrower scope avoids conflating temperature monitoring with coolant-level detection and makes the reported results easier to audit against the stated objective.

The sensor-validation component also distinguishes the work from purely descriptive hardware assembly. A common weakness of prototype reports is to infer accuracy from component specifications without comparing the assembled system with a reference. Here, even though the three-point comparison is limited, the paper reports the actual paired values and calculates MAE and MAPE from them. This approach is consistent with the broader emphasis on validation in low-cost sensing research (Raldiartono et al., 2019; Rodríguez-Rama et al., 2026). The next step should be to expand the calibration range and uncertainty analysis rather than to add unsupported claims of precision.

From a transferability perspective, the architecture is potentially adaptable because the principal components are widely available and the logic is conceptually simple. However, transferability of architecture is not equivalent to generalizability of performance. Vehicle type, engine displacement, radiator geometry, coolant type, thermostat calibration, sensor placement, ambient temperature, electrical noise, vibration, and heat exposure could all affect performance. Sensor literature in automotive thermal management reinforces that sensing must be evaluated within the operating environment in which it will be used (Cheng et al., 2023). Therefore, the present prototype should be viewed as a platform for further testing rather than as a validated universal device for all four-wheeled vehicles.

**Limitations and Practical Implications**

Several limitations constrain the interpretation of the findings. First, the reference comparison used only three temperature points and did not include repeated trials, reference-instrument uncertainty, or a traceable calibration procedure. Second, the available study record does not specify vehicle make/model, engine displacement, radiator and coolant characteristics, exact sensor mounting, ambient temperature, sampling interval, or route standardization. Third, the vehicle observations were limited to one set of idling, normal-driving, and traffic-jam conditions as reported, without a repeated-trial count. Fourth, the study did not quantify response time, sampling frequency, drift, long-duration stability, vibration tolerance, water/heat exposure, electromagnetic susceptibility, or automotive power-transient resilience. Fifth, no direct performance comparison with a factory-installed gauge was conducted. These limitations mean that the prototype's current evidence is functional and exploratory rather than qualification-grade.

The practical implication is nevertheless meaningful at the prototype level. The device demonstrates a low-complexity route for presenting radiator coolant temperature numerically on a compact display while maintaining a separate audible-warning output. For educational laboratories, engineering prototyping, or early-stage retrofit development, such an architecture can provide a clear platform for investigating sensor placement, calibration, display design, and warning logic. The open and modular character of Arduino-based development can facilitate iterative changes, as demonstrated broadly in low-cost monitoring research (Ali et al., 2016; Pereira & Ramos, 2022). However, installation in operational vehicles should proceed only after application-specific electrical, environmental, mechanical, and safety validation.

Future research should use a substantially stronger test protocol. Calibration should cover more points across the expected coolant-temperature range, with repeated measurements and a reference instrument whose accuracy and traceability are documented. Vehicle evaluation should report the vehicle and engine specification, coolant type, sensor position, ambient conditions, sampling frequency, test duration, and repeat count. Quantitative response-time testing should apply controlled temperature steps or synchronized reference logging. Environmental testing should assess vibration, moisture, heat cycling, electrical noise, and supply-voltage transients. Finally, multi-vehicle testing would allow researchers to determine whether the same sensor placement and warning logic remain appropriate across different cooling-system configurations. These steps would move the system from proof of concept toward defensible automotive application.

## CONCLUSION

This study designed and evaluated a low-complexity Arduino Uno-based prototype for numerical monitoring of radiator coolant temperature in four-wheeled vehicles. The prototype integrated a DS18B20 sensor, TM1637-controlled 3-digit display, buzzer, and regulated power supply. At the three reported comparison points, DS18B20 readings differed from the reference digital thermometer by 0–1°C, yielding an MAE of 0.33°C and a MAPE of approximately 0.83%. In the reported vehicle scenarios, displayed temperatures ranged from 32°C to 94°C; the alarm remained inactive at 94°C because the programmed audible threshold was above 95°C. Display verification also showed agreement between detected and displayed values at 30, 45, 60, 75, and 90°C. These findings support proof-of-concept feasibility for direct numerical temperature presentation and basic warning logic under the tested conditions. They do not demonstrate universal accuracy across the full operating range, validated response time, superiority over factory-installed indicators, or applicability to all vehicle types. Broader calibration, repeated measurements, documented uncertainty, multi-vehicle trials, and electrical, environmental, durability, and safety testing are required before the prototype can be considered ready for general automotive deployment.

## REFERENCES

Ali, A. S., Zanzinger, Z., DeBose, D., & Stephens, B. (2016). Open source building science sensors (OSBSS): A low-cost Arduino-based platform for long-term indoor environmental data collection. *Building and Environment, 100*, 114–126. https://doi.org/10.1016/j.buildenv.2016.02.010

Arif Kurnia, Surapati, A., & Agustian, I. (2023). Rancang bangun alat pendeteksi dini over heat mesin kendaraan melalui suhu air pendingin. *Jurnal Teknologi Universitas Muhammadiyah Jakarta*, *15*(1).

Avallone, E., Cunha, D. G., Padilha, A., & Scalon, V. L. (2016). Electronic multiplex system using the Arduino platform to control and record the data of the temperatures profiles in heat storage tank for solar collector. *International Journal of Energy and Environmental Engineering, 7*, 391–398. https://doi.org/10.1007/s40095-016-0217-1

Caresana, F., Bilancia, M., & Bartolini, C. M. (2011). Numerical method for assessing the potential of smart engine thermal management: Application to a medium-upper segment passenger car. *Applied Thermal Engineering, 31*(16), 3559–3568. https://doi.org/10.1016/j.applthermaleng.2011.07.017

Castiglione, T., Perrone, D., Algieri, A., & Bova, S. (2020). A contribution to improving the thermal management of powertrain systems. *SAE International Journal of Engines, 13*(1), 35–48. https://doi.org/10.4271/03-13-01-0003

Castiglione, T., Pizzonia, F., & Bova, S. (2016). A novel cooling system control strategy for internal combustion engines. *SAE International Journal of Materials and Manufacturing*, *9*(2), 294–302. https://doi.org/10.4271/2016-01-0226

Cheng, A., Xin, Y., Wu, H., Yang, L., & Deng, B. (2023). A review of sensor applications in electric vehicle thermal management systems. *Energies*, *16*(13), 5139. https://doi.org/10.3390/en16135139

Fauzan, R., Nugroho, D., & Prasetyo, A. (2022). Perancangan sistem monitoring suhu digital menggunakan display 7-segment dan Arduino Uno. *Jurnal Elektronika dan Instrumentasi*, *14*(1), 55–63.

Haghighat, A. K., Roumi, S., Madani, N., Bahmanpour, D., & Olsen, M. G. (2018). An intelligent cooling system and control model for improved engine thermal management. *Applied Thermal Engineering*, *128*, 253–263. https://doi.org/10.1016/j.applthermaleng.2017.08.102

Hervita, D., Taqwa, A., & Rose, M. M. (2017). Sistem monitoring level air radiator kendaraan dengan metode fuzzy. *Jurnal Elektro dan Telekomunikasi Terapan*, *4*(1), 485. https://doi.org/10.25124/jett.v4i1.995

Kadir, A. (2018). *Panduan praktis mempelajari aplikasi mikrokontroler dan pemrogramannya menggunakan Arduino*. Andi Publisher.

Liu, H., Wen, M., Yang, H., Yue, Z., & Yao, M. (2021). A review of thermal management system and control strategy for automotive engines. *Journal of Energy Engineering, 147*(2), 03121001. https://doi.org/10.1061/(ASCE)EY.1943-7897.0000743

Maxim Integrated. (2019). *DS18B20 programmable resolution 1-wire digital thermometer datasheet*. Maxim Integrated Products.

Mukkamala, Y. S. (2017). Contemporary trends in thermo-hydraulic testing and modeling of automotive radiators deploying nano-coolants and aerodynamically efficient air-side fins. *Renewable and Sustainable Energy Reviews, 76*, 1208–1229. https://doi.org/10.1016/j.rser.2017.03.106

Pang, S. C., Kalam, M. A., Masjuki, H. H., & Hazrat, M. A. (2012). A review on air flow and coolant flow circuit in vehicles' cooling system. *International Journal of Heat and Mass Transfer, 55*(23–24), 6295–6306. https://doi.org/10.1016/j.ijheatmasstransfer.2012.07.002

Pereira, P. F., & Ramos, N. M. M. (2022). Low-cost Arduino-based temperature, relative humidity and CO2 sensors—An assessment of their suitability for indoor built environments. *Journal of Building Engineering, 60*, 105151. https://doi.org/10.1016/j.jobe.2022.105151

Pratama, Y., & Setiawan, H. (2021). Analisis kinerja modul display TM1637 pada sistem monitoring digital berbasis Arduino. *Jurnal Teknologi dan Sistem Komputer, 9*(3), 120–127.

Rahman, F. (2020). Perancangan sistem monitoring suhu real-time menggunakan Arduino Uno. *Jurnal Ilmiah Teknik Elektro, 8*(2), 88–95.

Raldiartono, Saleh, Y. A., Roihan, I., & Harinaldi. (2019). A simple method for calibration of temperature sensor DS18B20 waterproof in oil bath based on Arduino data acquisition system. *AIP Conference Proceedings, 2062*, 020006. https://doi.org/10.1063/1.5086553

Rodríguez-Rama, J. A., Presa Madrigal, L., Marín Lázaro, A., Maroto Lorenzo, J., García Laso, A., Costafreda Mustelier, J. L., & Martín-Sánchez, D. A. (2026). Metrological validation of low-cost DS18B20 digital temperature sensors using the TH-001 procedure: Calibration models, uncertainty, and reproducibility. *Metrology, 6*(1), 21. https://doi.org/10.3390/metrology6010021

Salah, M. H., Frick, P. M., Wagner, J. R., & Dawson, D. M. (2009). Hydraulic actuated automotive cooling systems—Nonlinear control and test. *Control Engineering Practice, 17*(5), 609–621. https://doi.org/10.1016/j.conengprac.2008.10.016

Salah, M. H., Mitchell, T. H., Wagner, J. R., & Dawson, D. M. (2008). Nonlinear-control strategy for advanced vehicle thermal-management systems. *IEEE Transactions on Vehicular Technology, 57*(1), 127–137. https://doi.org/10.1109/TVT.2007.901892

Setlur, P., Wagner, J. R., Dawson, D. M., & Marotta, E. E. (2005). An advanced engine thermal management system: Nonlinear control and test. *IEEE/ASME Transactions on Mechatronics, 10*(2), 210–220. https://doi.org/10.1109/TMECH.2005.844707

Shu, G., Hu, C., Tian, H., Li, X., Yu, Z., & Wang, M. (2019). Analysis and optimization of coupled thermal management systems used in vehicles. *Energies, 12*(7), 1265. https://doi.org/10.3390/en12071265

Syahputra, D., & Wijaya, R. (2023). Implementasi Arduino Uno pada sistem monitoring temperatur digital. *Jurnal Rekayasa Elektronika, 12*(1), 15–24.

Syed, Z. A., & Wagner, J. R. (2023). Modeling and control of a multiple-heat-exchanger thermal management system for conventional and hybrid electric vehicles. *Designs, 7*(1), 19. https://doi.org/10.3390/designs7010019

Vega, F. A. O., Ríos, A. P. M., Saraz, J. A. O., Quiroz, L. G. V., & Damasceno, F. A. (2020). Assessment of black globe thermometers employing various sensors and alternative materials. *Agricultural and Forest Meteorology, 284*, 107891. https://doi.org/10.1016/j.agrformet.2019.107891

Wang, T., & Wagner, J. R. (2015). Advanced automotive thermal management—Nonlinear radiator fan matrix control. *Control Engineering Practice, 41*, 113–123. https://doi.org/10.1016/j.conengprac.2015.04.004

Yuliana, S., & Hidayat, T. (2021). Pengaruh stabilitas tegangan pada sistem mikrokontroler Arduino menggunakan regulator AMS1117. *Jurnal Elektronika Dasar dan Telekomunikasi, 6*(1), 41–48.

Zubair, M. M., Seraj, M., Faizan, M., Anas, M., & Yahya, S. M. (2021). Experimental study on heat transfer of an engine radiator with TiO2/EG-water nano-coolant. *SN Applied Sciences, 3*, 434. https://doi.org/10.1007/s42452-021-04441-7