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Solar Power Operated Adulterated Fuel Filtration and Moisture Detection System

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ABSTRACT :

Fuel contaminated with water, dust, or other foreign matter degrades engine performance, fuel economy, and component life, yet conventional fuel filters retain only suspended particles and give no indication of water in the fuel. This paper presents the design and implementation of a solar power operated prototype that combines preliminary moisture detection with physical fuel filtration. A 20 V, 50 W photovoltaic panel charges a 24 V, 15 Ah lithium-ion battery through a solar charge controller, and an LM2596 buck converter supplies the low-voltage electronics. An Arduino Uno reads a water-in-fuel (WIF) sensor and drives red and green LED indicators and a 16×2 LCD that report whether water has been detected, while a 24 V DC fuel pump moves fuel through an inline filter that retains suspended solid impurities. Moisture detection and filtration are treated as separate functions: the WIF sensor indicates water contamination only, and the system is not intended to identify chemical adulterants.

Index Terms Arduino, fuel adulteration, fuel filtration, moisture detection, solar photovoltaic, water contamination, water-in-fuel sensor.

I. Introduction

Fuel quality strongly influences combustion, engine efficiency, operational reliability, and the service life of engine components. Fuel can be contaminated by water, dust, dirt, and other foreign matter during storage, transportation, distribution, and handling. Adulteration, the mixing of unwanted or inferior substances with the original fuel, alters fuel properties and the combustion process, and may lead to lower efficiency, higher fuel consumption, increased emissions, and damage to engine parts [1], [2].

Among the forms of contamination, water is particularly important. It may enter fuel through improper storage, leakage, condensation, transportation, or inadequate handling, and it can interfere with combustion, promote corrosion of metallic parts, and affect fuel pumps, injectors, and other components of the fuel delivery system [3]. Detecting moisture in fuel is therefore a practical step towards protecting fuel-operated equipment.

Laboratory fuel analysis can provide detailed information on fuel properties, but it requires time, cost, and technical expertise. Basic fuel filters, in contrast, mainly remove suspended particles and do not identify water contamination or the chemical composition of the fuel [4]. A simple and economical prototype that combines moisture detection with filtration can support preliminary fuel contamination monitoring.

The work is further motivated by the supply of E20 ethanol-blended petrol in India, which may be used in vehicles manufactured in 2023 and earlier that were designed for E10 fuel; the project report states that nearly 80% of vehicles in India fall in this category. It should be noted that the present system detects water only and does not measure ethanol concentration.

Solar photovoltaic (PV) supply with battery storage allows such a system to operate independently of the vehicle electrical system; the integration of PV panels, batteries, and power converters in pumping applications is reviewed in [5]. This paper describes a prototype that integrates (i) a solar PV and battery power supply, (ii) Arduino-based moisture detection using a WIF sensor with LED and LCD indication, and (iii) inline physical filtration of suspended impurities. Section II states the problem, Section III reviews related work, Sections IV–VII describe the proposed system, its design, implementation, and working principle, and Sections VIII and IX are reserved for results and conclusions.

II. Problem Statement

Fuel contamination by moisture, dust, and other unwanted substances can reduce engine performance, fuel efficiency, and component life. Conventional filtration systems may not detect moisture or identify fuel adulteration, whereas advanced testing methods can be expensive. The objective of this work is to develop a low-cost, solar-powered system that detects moisture in fuel using a sensor and an Arduino and filters removable contaminants through a suitable filtration unit, thereby improving basic fuel quality monitoring.

The specific objectives are: (a) to supply the system from a PV panel and a rechargeable battery with suitable voltage regulation; (b) to detect water

in fuel using a WIF sensor interfaced with an Arduino Uno; (c) to indicate the detection status using red and green LEDs and an LCD; and (d) to pass the fuel through an inline filter that retains suspended solid impurities.

Scope: the system performs preliminary moisture detection and physical filtration. It is not a laboratory-level fuel analyser and does not identify every type of adulteration; changes in fuel composition, such as kerosene admixture or a change in ethanol concentration, would require additional suitable sensors and testing.

III. Literature Review

A. Fuel Adulteration Detection

Felix *et al.* [1] and Harkare [2], [7] address the detection of fuel adulteration through variations in fuel quality, emphasising the need for reliable and economical monitoring. Kamani *et al.* [6] combine a circular-slotted refractive index sensor with machine-learning optimisation to detect changes in fuel properties. Kakaei *et al.* [8] use an electronic nose to classify pure and adulterated fossil fuel samples from vapour characteristics through sensor responses and pattern recognition. Saxena *et al.* [9] estimate diesel purity in real time from density measurement with temperature compensation using load cells and a temperature sensor.

B. Water-in-Fuel Detection

Uche and Augustine [3] present a low-cost detector that exploits the electrical conductivity of water: two conductive probes identify water in non-polar hydrocarbon fuel, and a 555 timer IC and a microcontroller drive audible and visual alarms. Kılıç *et al.* [10] studied the response of WIF sensors in diesel fuel and found that sensitivity depends on the electrical conductivity of the water and its mixing ratio. Macioszek and Sobczyński [11] estimate the moisture content of commercial diesel using impedance spectroscopy, indicating the potential for non-destructive, on-site monitoring.

C. Fuel Filtration and Water Separation

Johnson [4] discusses how changing fuel compositions and engine technologies affect filtration requirements. Song *et al.* [12] report a dual-layer filter medium of hydrophilic and hydrophobic kapok fibres for separating water from diesel, and Arouni *et al.* [13] show that the water-separation performance of surface-modified PBT filter materials depends on fuel composition, surface wettability, and surfactants. These studies indicate that conventional filters have limits and that the filter medium must be selected for the contaminant of concern.

D. Solar-Powered Systems

Gevorkov *et al.* [5] review PV-powered pumping systems, covering panels, batteries, converters, and pumps, together with maximum power point tracking, energy storage, and control techniques. Onep and Ninsiima [14] model a solar-powered water treatment system that combines filtration with real-time monitoring.

The reviewed works largely treat detection, filtration, and solar power individually. The present work integrates a solar supply, a WIF-based moisture indication, and inline filtration in one prototype, using low-cost, readily available components.

IV. Proposed System

A. System Overview

The proposed system comprises four subsystems, shown in the block diagram of Fig. 1: (1) a solar power subsystem (PV panel, charge controller, battery, and buck converter); (2) a control and sensing subsystem (Arduino Uno and WIF sensor); (3) a fuel-handling subsystem (fuel inlet, fuel pump, sensing chamber, inline filter, and outlet through fuel hose); and (4) an indication subsystem (red and green LEDs and a 16×2 LCD). A toggle switch provides manual ON/OFF control, and a fuse protects the power circuit.

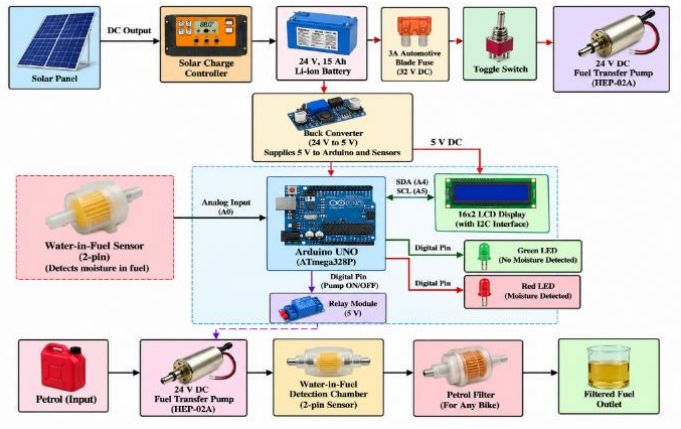


Fig. 1. Block diagram of the solar power operated fuel filtration and moisture detection system.

B. Moisture Detection versus Filtration

Moisture detection and fuel filtration are separate functions performed by different components (Table I). The WIF sensor only indicates whether water is detected; it does not clean the fuel. The inline filter retains suspended solid particles; it does not detect water and does not necessarily remove dissolved water or chemical adulterants.

TABLE I

FUNCTIONAL DISTINCTION BETWEEN DETECTION AND FILTRATION

Aspect	Moisture detection	Fuel filtration
Component	WIF sensor with Arduino Uno	Inline fuel filter with fuel pump
Purpose	Indicate presence or absence of water	Retain suspended solids (dust, dirt, rust)
Output	Red/green LED and LCD status	Filtered fuel at the outlet
Limitation	Water-related contamination only; other adulterants (e.g., kerosene, ethanol content) not identified	Depends on filter medium, pore size, contaminant; dissolved water and chemical adulterants not necessarily removed

V. System Design and Methodology

A. Solar Supply, Storage, and Charge Control

A 20 V, 50 W PV panel is the primary energy source. It feeds a solar charge controller rated for 12 V/24 V systems (5 A–10 A), which regulates charging of a 24 V, 15 Ah lithium-ion battery and protects it against overcharging. The nominal battery energy is 360 Wh (24 V × 15 Ah); the energy actually available depends on the load, conversion losses, and usable battery capacity. The charge controller must be compatible with the lithium-ion chemistry, charging voltage, and current limits of the battery. The battery allows operation in low sunlight and independently of the vehicle battery.

B. Voltage Regulation and Protection

An LM2596 buck converter steps the 24 V battery voltage down to a regulated 5 V for the Arduino Uno, the LCD, and the 5 V relay module, provided the total current stays within the converter capacity. Its output is adjustable through an onboard potentiometer and is measured before the loads are connected. A fuse protects the circuit against excessive current, and a toggle switch connects or disconnects the supply.

C. Control and Sensing

The Arduino Uno (ATmega328P, 5 V logic, 16 MHz) is the main controller. It reads the output of the WIF sensor and determines whether water is detected. The sensor's compatibility with the fuel type, its operating voltage, and its output signal must be verified against its datasheet before wiring. The connection diagram is shown in Fig. 2.

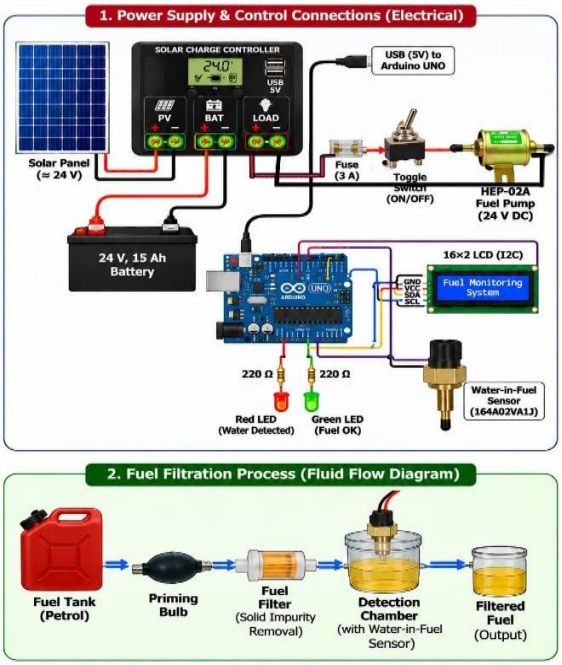


Fig. 2. Circuit and connection diagram of the proposed system.

D. Fuel Path and Indication

Fuel enters the inlet through the fuel hose and is moved by the fuel pump into the sensing chamber, where the WIF sensor monitors it for water. The fuel then passes through the inline filter, which retains suspended solid impurities, and flows to the outlet. Moisture detection therefore precedes filtration in the flow path. The green LED indicates that no water is detected, the red LED indicates detected water, and the LCD displays the corresponding status message. The overall operating sequence is shown in the flowchart of Fig. 3.

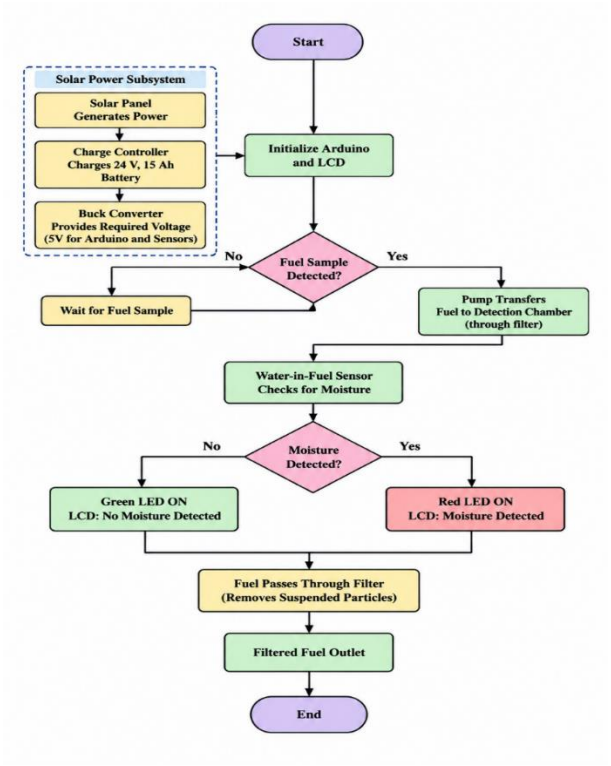


Fig. 3. Flowchart of system operation.

E. Safety Considerations

Because petrol is flammable, the fuel pump, hose, and relay must be suitable for fuel service: the pump's voltage, current rating, and material must be compatible with petrol, the hose must be petrol-compatible and leak-free, and the relay connections must be protected from fuel vapour. Proper electrical isolation and secure, insulated wiring reduce the risk of short circuits and loose contacts.

VI. Hardware and Software Implementation

A. Hardware Implementation

The components and ratings used in the prototype are listed in Table II. The relay module is available to switch the fuel pump from a low-power control signal, so that the Arduino does not carry the load current. Thicker insulated wires are used for the battery and pump circuits and jumper wires for low-current signal connections. The assembled prototype is shown in Fig. 4.

TABLE II

COMPONENT SPECIFICATIONS

S.No.	Component	Rating / specification	Qty.
1	Solar panel	20 V, 50 W	1
2	Solar charge controller	12 V/24 V system, 5 A–10 A	1
3	Battery	24 V, 15 Ah lithium-ion	1
4	Arduino Uno	5 V operating logic	1
5	Water-in-fuel sensor	Ashok Leyland, Part No. 164A02VA1J	1
6	Fuel pump	24 V DC	1
7	Fuel filter	Inline fuel filter	1
8	LCD display	16 × 2, 5 V	1
9	Toggle switch	9 A, 250 V AC	1

S.No.	Component	Rating / specification	Qty.
10	Relay module	5 V DC	1
11	Fuel hose	Petrol-compatible tubing	1
12	Buck converter (LM2596)	Output voltage: 5 V and 4.1 V	1
13	Connecting wires	Single-core wires	As req.
14	Green and red LEDs	2 V, 10–20 mA	2
15	Resistors	220 Ω (listed as voltage-divider resistors)	2

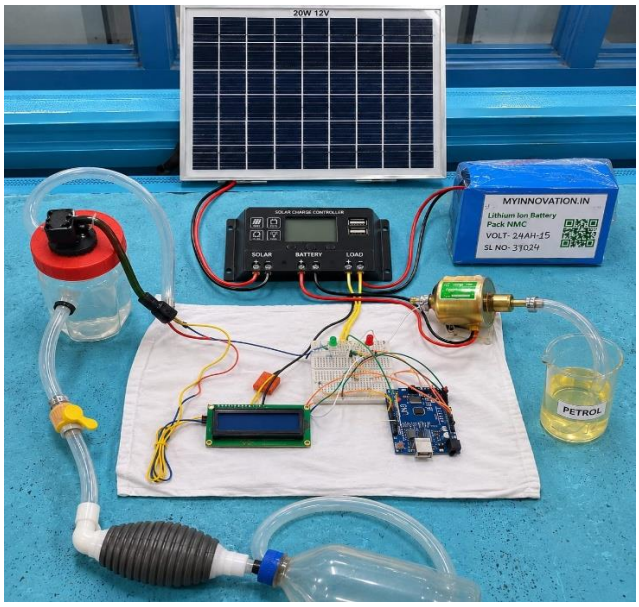


Fig. 4. Hardware prototype of the solar power operated fuel filtration and moisture detection system.

B. Software Implementation

The control program is developed in the Arduino IDE and uploaded to the Arduino Uno after selecting the board and serial port. It uses the Wire and LiquidCrystal_I2C libraries to drive the 16×2 LCD at I²C address 0x27. The pin assignments are given in Table III.

TABLE III

ARDUINO UNO PIN ASSIGNMENT

Signal	Pin	Configuration
WIF sensor input	D4	INPUT_PULLUP
Red LED	D3	Output
Green LED	D5	Output
LCD (16×2)	I²C	Address 0x27

At start-up the program initialises the LCD and backlight, configures the pins, displays “Fuel Monitoring” for two seconds, and clears the display. In the main loop, the digital state of the sensor pin is read every 500ms. A LOW level is interpreted as water detected: the red LED is switched ON, the green LED OFF, and the LCD shows a water-detected message. A HIGH level is interpreted as no water detected: the red LED is switched OFF, the green LED ON, and the LCD shows “FUEL OK / No Water Found”. The sketch reproduced in the project report controls only the LCD and the two LEDs.

VII. Working Principle

Sunlight incident on the PV panel is converted into electrical energy, which the charge controller regulates to charge the 24 V lithium-ion battery. The battery supplies the system through the buck converter, which provides the regulated 5 V rail for the Arduino Uno, LCD, and relay module.

When the system is switched on, the fuel pump draws fuel from the inlet through the fuel hose into the sensing chamber. The WIF sensor monitors the fuel for water and sends its output to the Arduino, which evaluates it according to the programmed detection criterion. If water is detected, the red

LED lights and the LCD shows a water-detected message; otherwise the green LED lights and the LCD shows that no water was found. Because the sensor is polled continuously, the indication follows the sensor state.

After the sensing stage, the fuel flows through the inline filter, where suspended solid impurities such as dust, dirt, and rust particles are retained, and then through the hose to the outlet. The WIF sensor indicates water-related contamination only and cannot, on its own, identify other adulterants such as kerosene or a change in ethanol concentration. Likewise, the filter removes particulate contamination but does not necessarily remove dissolved water or chemical adulterants.

VIII. Conclusion

This paper presented the design and implementation of a solar power operated prototype that combines preliminary moisture detection with physical filtration of petrol. The system is powered by a 20 V, 50 W photovoltaic panel, a solar charge controller, and a 24 V, 15 Ah lithium-ion battery, with an LM2596 buck converter supplying the low-voltage electronics. An Arduino Uno reads a water-in-fuel sensor and reports the result through red and green LEDs and a 16×2 LCD, while a fuel pump moves the fuel through an inline filter that retains suspended solid impurities. In tests with petrol, the system displayed “WATER DETECTED” with the red LED glowing when water was present, and “FUEL OK / No Water Found” with the green LED glowing when water was absent. [[Optional: add one sentence on the filtration observation and one on solar charging or battery operation, using your measured results.]] The two functions of the prototype are separate. The sensor indicates the presence of water only, and the filter removes suspended solid particles only. The system does not identify other adulterants, such as kerosene or changes in ethanol concentration, and its performance applies only to the conditions tested. Future work may include sensors better suited to fuel composition analysis, advanced water-separation techniques, automatic filtration control, and a digital display of sensor readings.

B. Future Scope

The project report identifies the following possible improvements: incorporating sensors better suited to fuel composition analysis, advanced water-separation techniques, automatic filtration control, and a digital display of sensor readings.

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