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Design of Automotive Anti-flooding Device Based on Arduino Open-source Hardware

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Abstract: With the increasing frequency of car flooding accidents caused by climate change and inadequate urban drainage systems, this paper designs an automotive anti-flooding device and develops an interactive prototype using Arduino open-source hardware. Targeting users in flood-prone areas, low-lying roads, and underground parking lots, the design proposes a core structure of four foldable airbags, with an orange and black color scheme to enhance visibility and practicality. The prototype, built with an Arduino UNO development board, integrates a water level sensor and a servo module to monitor water levels in real-time and trigger an inflation mechanism. When the water level exceeds a 3 cm threshold, the device activates inflation within 0.5 seconds, effectively isolating the vehicle from water intrusion. Usability evaluations conducted through user interviews with 15 target users showed high recognition of the device's functionality and design, though improvements in installation and inflation efficiency are needed. This study provides a new approach to low-cost, high-response automotive anti-flooding technology, with future plans to test adaptability in complex environments and explore commercialization paths to enhance vehicle safety in waterlogged conditions.

1. Introduction

Due to climate change and urban drainage issues, car flooding incidents have become increasingly common, leading to significant property damage and safety hazards [1-2]. This project aims to design an automotive anti-flooding device using Arduino open-source hardware to address these challenges. By studying the causes and characteristics of car damage during flooding, the device is designed to sense surrounding water levels, provide timely alerts, and automatically lift the vehicle to prevent water intrusion. This innovation not only reduces property damage but also enhances vehicle safety and reliability, offering significant value to car owners.

2. Research Status At Home and Abroad

The automotive anti-flooding device is a critical safety equipment designed to prevent vehicle damage in flooding situations. In recent years, with the increase in climate change and extreme weather events, the incidence of vehicle flooding accidents has shown a gradual upward trend. Therefore, research and development of automotive anti-flooding devices are of significant

importance, and extensive research has been conducted both domestically and internationally in the design of such devices.

2.1 International research status

Firstly, in foreign countries, automotive manufacturers and research institutions in the United States and Europe have conducted some research on automotive anti-flooding devices. Their focus has primarily been on waterproof designs for vehicle electrical systems and engine components, as well as the design of evacuation and rescue systems for vehicles in flooding situations. For example, some U.S. automotive manufacturers have introduced waterproof designs in vehicle electronic control systems to enhance the survivability of vehicles in flooding conditions. Additionally, some European research institutions are exploring technologies related to automotive anti-flooding devices, with a focus on engine waterproofing and the self-protection capabilities of vehicles in flooding scenarios.

Abroad, research on automotive anti-flooding devices mainly concentrates on real-time water level monitoring, vehicle status monitoring, and alarm systems. As early as 2001, U.S. Patent US6266693B1 proposed a water level monitoring system [3], which uses ultrasonic sensors to monitor water levels in real time and transmits the data to a central processor for analysis. In 2012, U.S. Patent US20120068832A1 introduced a vehicle anti-flooding device [4], which employs multiple sensors to monitor vehicle status, water levels, and meteorological conditions in real time, thereby preventing vehicles from driving through flooded areas. In recent years, with the development of IoT and big data technologies, foreign research has gradually shifted its focus to intelligent anti-flooding systems. For instance, in 2017, South Korean Patent KR101738844B1 proposed an intelligent anti-flooding system that uses wireless communication modules to transmit water level monitoring data to the cloud in real time, allowing users to view water level information and receive alerts via a mobile app [5].

2.2 Domestic research status

In China, research on automotive anti-flooding devices has also made some progress. Compared to foreign countries, domestic research in this area started relatively late. Some automotive manufacturers and research institutions have conducted studies on vehicle waterproofing and anti-flooding devices. At the same time, universities and research institutes have also carried out experiments and research in this field, aiming to develop a simple yet effective automotive anti-flooding device to reduce vehicle damage in flooding situations.

A comparative analysis of several domestic competing products is shown in Table 1.

Table 1: Competitive product analysis

name	representative product	feature	price /yuan	colour	advantage	shortcoming
plastic protective cover		the outer plastic can be used to isolate water, ensure the safety of the car, and the rope attached to the outer surface can be used for fixing	100-250	blue and white	easy to use, cheap, reusable, does not take up space, wide application	it has little effect in severe flood disasters and is difficult to be used twice
plastic insulating film		it can help the car isolate the rain and protect the use of electronic components	20-100	transparent	convenient, easy to use, can be carried with the car	can not be reused, easy to damage

inflatable air bag		the airbag will inflate in case of flooding and lift the car a certain height	800-900	blue, orange and white	strong flood resistance, can effectively ensure the safety of vehicles	expensive, difficult to recycle
car enclosure		it can ensure the isolation of the vehicle from the water and the drying of the protective elements on the terrain with high water level	200-450	black	it can be reused and has strong flood resistance, easy to use	inconvenient to carry, the price is expensive
independent parking hood		independent dustproof and waterproof car covers can be installed in the parking area to effectively protect the safety of vehicles	300-480	black transparent	easy to use after installation, multiple use, strong protection ability	the installation is difficult, the requirements for the site are high, and the technical requirements for the owner are high
engine technology		obtain water level information through big data, and report the autonomous starting vehicle to the owner in time	200000 - 300000	dark green	strong sense of technology, easy to use	expensive and not suitable for existing vehicles

3. Design of the Automotive Anti-Flooding Device

3.1 Design Positioning

3.1.1 User Positioning

Users in Rainy Regions: In areas with abundant rainfall and prolonged rainy seasons, an automotive flood prevention device is undoubtedly a valuable investment. When your car encounters standing water during a rainstorm without such a device, it could lead to a disaster. The automotive flood prevention device provides robust waterproof protection, ensuring your vehicle can safely navigate through the rainy season, avoiding property damage and travel safety risks.

Users in Low-Lying Flood-Prone Areas: In urban settings, certain low-lying areas or roads are prone to water accumulation during the rainy season, posing a serious threat to parked vehicles. The automotive flood prevention device offers essential protection for car owners in these areas, ensuring their vehicles remain safe throughout the rainy season.

Underground Parking Lot Users: Underground parking lot users are a key demographic for automotive flood prevention devices. Due to their unique location, underground parking lots often have inferior ventilation and drainage compared to above-ground lots, making them more susceptible to water accumulation during the rainy season. The automotive flood prevention device helps underground parking users prevent vehicle flooding, safeguarding their property.

3.1.2 Functional positioning

The core function of this automotive flood prevention device is to reduce the risk of vehicle damage in waterlogged or flooded environments through proactive protection and rapid response mechanisms. The specific functional designs are as follows:

1) Real-Time Water Level Monitoring and Intelligent Alert System

Utilizing high-precision water level sensors integrated with the Arduino platform, the system

continuously monitors the water level around the vehicle. When the detected water level exceeds a preset threshold (3 cm), the system immediately activates the inflation mechanism to prevent the vehicle from being submerged further.

2) Automatic Inflation and Lifting Mechanism

The device features four foldable airbags as its core components, controlled by a servo module to rapidly inflate via a high-pressure air pump. When the water level consistently exceeds the threshold, the system initiates the inflation process within 0.5 seconds. The inflated airbags form a unified buoyancy structure, lifting the vehicle above the water surface and effectively preventing water from entering critical components (e.g., the engine and electronic systems), thereby minimizing flood damage.

3) Emergency Response and User-Friendly Operation

The device supports a one-touch emergency activation mode, simplifying operations for sudden scenarios. Additionally, its modular design allows for quick disassembly and storage of components such as airbags and sensors, balancing daily portability with efficient deployment during emergencies.

Through the integration of these functions, the device not only achieves full-process automated control from alert to protection but also ensures stability in complex environments and user-friendly operation. This significantly enhances the limitations of traditional passive flood prevention devices, providing multi-layered protection for vehicle safety in waterlogged conditions.

3.2 Exterior Design

In terms of form, the automotive flood prevention device consists of four individual airbags. This design offers significant advantages: when not in use, the airbags can be folded for compact storage, greatly saving space and making it easy for car owners to store and carry. When needed, the four airbags can be quickly assembled to form a large airbag that surrounds and supports the vehicle, keeping it afloat on the water surface.

As shown in Figure 1，in terms of color scheme, the device uses warning orange (HEX: #EA8F36) and tech black (HEX: #313131) to enhance visual recognition. Orange is a highly visible color that allows rescue personnel and other road users to quickly spot the vehicle in complex environments such as standing water, improving vehicle visibility and safety. Black, on the other hand, conveys a sense of reliability and stability, while also being dirt-resistant, making it suitable for scenarios involving mud or water.

The overall exterior design features streamlined contours and rounded edges to reduce wind resistance and prevent scratches to the vehicle body. The rounded shape not only better conforms to the vehicle's contours, providing more stable support and protection, but also effectively avoids scratches or damage during installation and use, offering comprehensive protection for the vehicle.

Fig. 1 Exterior design of the automotive anti-flooding device

3.3 Material Selection

The choice of materials for the automotive flood prevention device is critical to its performance and reliability. The airbag components are made of high-strength, wear-resistant, and airtight chloroprene rubber. Chloroprene rubber exhibits excellent water resistance, effectively withstanding prolonged immersion in water and preventing material degradation or air leakage in humid environments. Its high strength allows it to bear the weight of the vehicle and various external forces during flotation, ensuring structural stability. Additionally, its superior wear resistance minimizes damage from contact with the ground or debris, extending the device's lifespan.

The main tubing of the four-way connector is constructed from PA66-GF30 (30% glass fiber-reinforced nylon), with a temperature resistance range of -40 ℃ to 120 ℃, capable of enduring frequent pneumatic impacts. The connection ports are fitted with silicone rubber sealing rings (Shore hardness 50±5), ensuring airtightness and adaptability to vehicle vibrations.

The high-pressure gas storage tank is precision-cast from aerospace-grade aluminum alloy (6061-T6), with a pressure resistance rating of ≥30 MPa, reducing weight by 40% compared to traditional steel tanks. The interior of the tank is nickel-plated to prevent gas corrosion and is certified under the ISO 11439 safety standard.

Furthermore, the connecting components and structural framework are made of lightweight yet high-strength aluminum alloy. The aluminum alloy's light weight avoids adding excessive load to the vehicle, ensuring normal driving performance. At the same time, its high strength guarantees the structural stability of the entire device during use, supporting the vehicle and resisting water flow impacts, ensuring reliable operation of the flood prevention device.

3.4 Structural Design

The structural design of the automotive flood prevention device emphasizes stability, airtightness, and user-friendly operation. The overall structure is based on four individual airbags as the primary support components, each equipped with independent inflation and deflation valves. The inflation valve is connected to the inflation module and features a one-way valve design, ensuring gas flows only into the airbag, enabling rapid inflation while preventing gas backflow, thereby improving inflation efficiency and airbag stability. The deflation valve allows for easy gas release after use, facilitating storage.

At the connection points of the airbags, high-strength nylon fabric straps are used for binding. These straps exhibit high tensile strength, capable of withstanding the significant tension generated when the airbags are inflated, ensuring the stability of the combined large airbag structure. Additionally, reinforced patches are added at the connection points to further enhance reliability, preventing airbag separation during use.

As shown in Figure 2，to achieve better waterproofing, the waterproof barrier at the vehicle's undercarriage features a foldable and retractable design. When the device is activated, the barrier quickly deploys and tightly adheres to the ground, forming an effective waterproof shield. When not in use, it retracts beneath the vehicle, avoiding interference with normal driving. For door and window sealing, rubber sealing strips are used, installed tightly along the edges through specially designed grooves to ensure effective isolation from external water sources under various conditions.

Moreover, the device includes a fixing structure compatible with the vehicle chassis, secured via bolts or clips to firmly attach the flood prevention device to the chassis, preventing displacement during use，as shown in Figure 3.

Fig. 2 Structural diagram of the automotive anti-flooding device

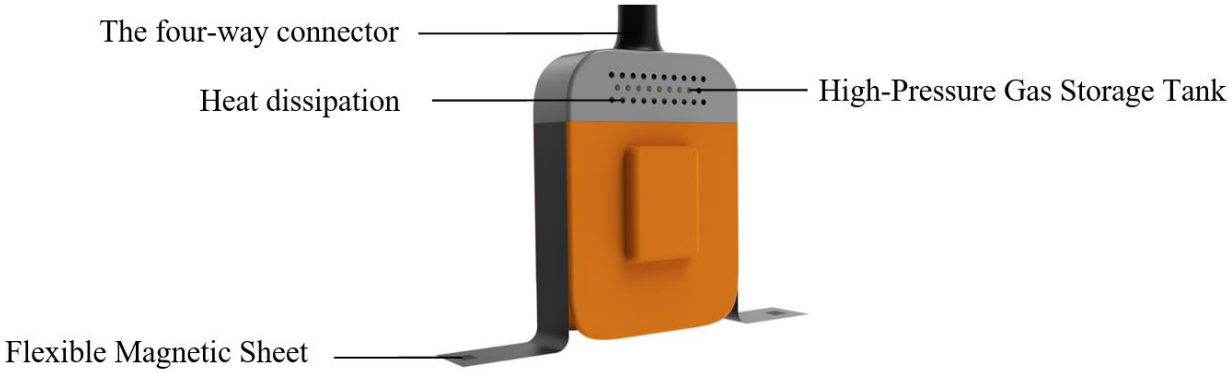

Fig. 3 Modular airbag storage body structure diagram

3.5 Usage Process Design

Initial Setup and Installation:

After parking the vehicle, take out the prepared flood prevention device and identify the left, right, front, and rear modules. Connect them via the four-way tube and position them near the center of the vehicle's underside. This setup aims to prepare for sudden weather changes, ensuring the vehicle sustains minimal damage in complex environments.

Activation and Triggering:

Once installed, the device automatically enters standby mode. The water level sensor continuously monitors the water level beneath the chassis. When the water level exceeds the preset threshold (3 cm), the Arduino control center sends a pulse signal to the servo within 0.5 seconds, triggering the high-pressure gas valve to open.

Airbag Deployment:

High-pressure gas is distributed through the four-way tube to inflate the four airbags at a rate of ≥30 L/s. The airbags fully deploy within 5 seconds. The left and right airbags extend at a 90° angle to the sides of the vehicle, while the front and rear airbags conform to the vehicle's contours, forming a closed waterproof barrier.

Storage and Maintenance:

After the water recedes, the owner manually opens the airbags' deflation valves. The airbags rapidly deflate through bidirectional valves, and then fold along preset lines into the device's cavity,

where they are automatically secured by flexible magnetic structures. Given the complexity of flood conditions, timely maintenance is essential. After use, clean the device promptly, replace or refill the high-pressure gas storage tank to ensure sufficient gas supply, and perform necessary maintenance to guarantee safety and integrity for the next use.

The entire usage process is designed to be simple and user-friendly, ensuring that in emergency flooding situations, the owner can quickly and effectively activate the device to protect the vehicle.

4. Prototype Design of an Automotive Anti-Flooding Device Based on the Arduino Open-Source Platform

4.1 Overall Design Plan

This design centers around the Arduino UNO development board, utilizing analog input interfaces to acquire water level data and a servo module to control the inflation of the anti-flooding device. This enables the automatic prevention of vehicle flooding. The workflow is illustrated in Figure 4. The interactive prototype of the anti-flooding device is shown in Figure 5.

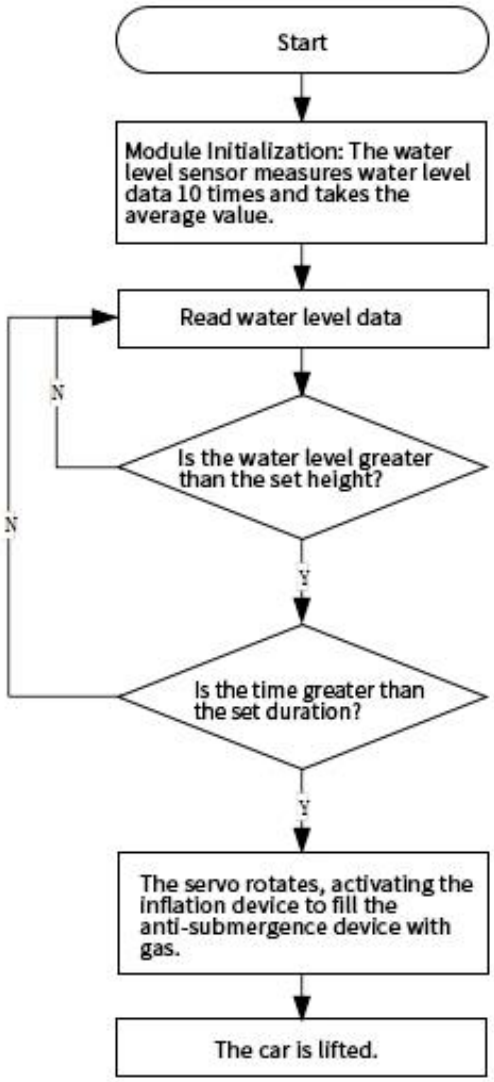

Fig. 4 Anti-Flooding Device Workflow Diagram

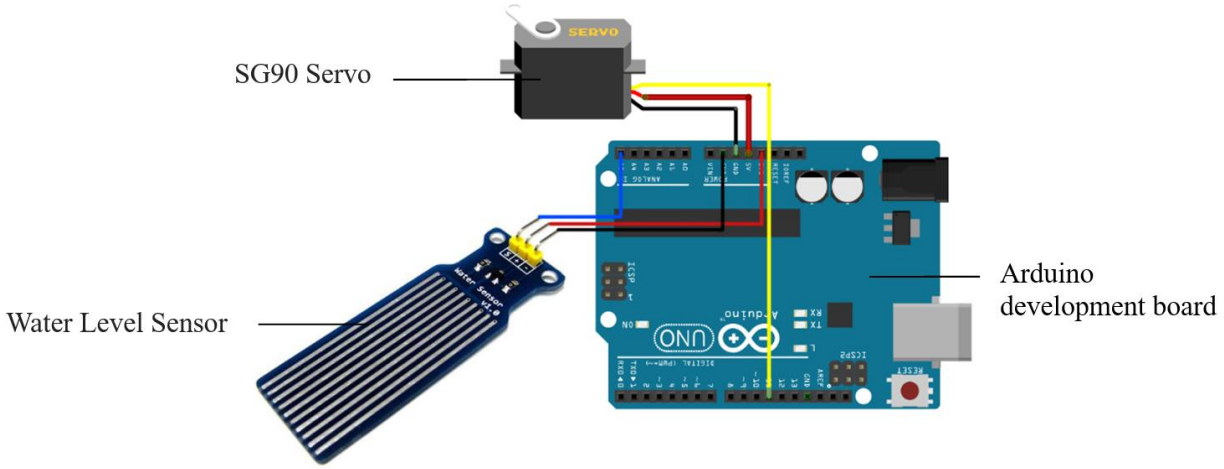

Fig. 5 Structure diagram of automobile flood protection device

4.2 Arduino Open-Source Platform

Arduino is an open-source electronics platform, consisting of two main components: the Arduino development board and the Arduino Integrated Development Environment (Arduino IDE). There are various models of Arduino development boards, and this study uses the Arduino UNO version. It features 14 digital input/output pins (6 of which can be used as PWM outputs), can be connected to a computer via a USB interface, and allows users to write code in the Arduino IDE and upload it to the Arduino board[6-7].

4.3 Water Level Sensor

The DFRobot water level sensor (range: 0-5 cm, accuracy: ±0.2 cm) is employed. The water level sensor module is primarily used to monitor in real-time whether the vehicle is submerged. It converts water level information into analog signals, and the output analog values can be directly read by the Arduino board, achieving the function of water level detection. As shown in Figure 4, the S pin of the water level sensor is connected to the A5 pin of the Arduino board, which sends water level height data to the Arduino board.

4.4 Servo Module

The SG90 servo (torque: 1.6 kg·cm, response time: 0.1 s) is used. The servo module is mainly responsible for controlling the inflation of the anti-flooding device. When the water level exceeds the preset height and duration, the servo begins to rotate, activating the inflation module to rapidly fill the anti-flooding device with gas, enabling the vehicle to float on the water surface.

4.5 Arduino Control Code Design

The Arduino programming is implemented using the Arduino IDE software. The complete program is as follows:

```
#include <Servo.h>
Servo servo;
const int SENSOR_PIN = A5;
const int SERVO_PIN = 11;
float baseline = 0.0;  // Dynamic reference value
```

```
void setup() {
  servo.attach(SERVO_PIN);
  Serial.begin(9600);
  calibrateSensor();  // Automatic power-on calibration
}

void loop() {
  float level = getWaterLevel();
  if (level > 5.0) {          // Primary inflation threshold
    servo.write(90);
    activatePump(500);    // Inflatable 500ms
  } else if (level > 3.0) {   // Warning threshold
    triggerAlarm();
  }
}

void calibrateSensor() {
  // Collect 10 times of data and take the average value as the benchmark
  for (int i=0; i<10; i++) {
    baseline += analogRead(SENSOR_PIN);
    delay(100);
  }
```

5. Usability Evaluation of the Design Proposal

Usability focuses on the user experience, considering the ease of use, efficiency, and user satisfaction of the product in real-world applications. Given that the current stage of this design proposal cannot produce a physical prototype, a pre-built Arduino interactive prototype was used to conduct the usability evaluation. The evaluation metrics primarily included functional usability, operational convenience, and aesthetic design. Expert interviews were employed to gather feedback, providing precise insights into the strengths and weaknesses of the proposal.

For this evaluation, 15 car owners from different regions with extensive driving experience were invited. The participants included users from areas prone to heavy rainfall, low-lying flood-prone zones, and those who frequently use underground parking lots, ensuring the evaluation results are broadly representative. Before the evaluation, the car owners were provided with a detailed introduction to the design principles, functional features, and operational procedures of the device, ensuring they had a comprehensive understanding of it. During the evaluation, the car owners personally operated the Arduino interactive prototype, simulating various flooding scenarios. After the operation, one-on-one in-depth interviews were conducted to collect their feedback.

Most car owners agreed that the device's functional positioning was accurate, effectively meeting their needs for vehicle protection in specific scenarios and significantly reducing the risk of vehicle submersion. In terms of aesthetic design, the orange and black color scheme and the smooth, rounded shape received widespread praise for being both eye-catching and preventing scratches on the vehicle body.

However, some car owners pointed out areas for improvement. For example, the installation process was somewhat cumbersome, which could affect efficiency in emergency situations. Additionally, the inflation time needed to be further reduced to enhance the device's ability to respond to sudden flooding incidents. Based on the comprehensive evaluation results, the design proposal

shows significant potential in preventing vehicle submersion. However, it still requires optimization and refinement based on user feedback to continuously improve the user experience. The specific scores are shown in Table 2.

Table 2: User Evaluation Feedback Statistics

Evaluation Dimension	Average Score	Key Suggestions
Functional Usability	4.7	Optimize alarm threshold sensitivity
Operational Convenience	3.8	Simplify the airbag installation process
Aesthetic Design	4.5	Maintain the orange and black color scheme

6. Conclusion

This study focuses on the issue of vehicle submersion and developed an interactive prototype of an automotive anti-flooding device based on Arduino open-source hardware, achieving significant phase-specific results. During the design phase, the target user groups were precisely identified, including users from areas prone to heavy rainfall, low-lying flood-prone zones, and underground parking lots. The targeted functional design and reasonable selection of structure and materials laid a solid foundation for the practicality of the device.

Through practical verification, the prototype system built around the Arduino UNO development board, combined with the water level sensor and servo module, effectively achieved real-time water level monitoring and automatic control of the anti-flooding device. The usability evaluation conducted using the Arduino-based interactive prototype, along with actual user feedback, provided profound insights into the device design. In particular, the feedback highlighted areas for improvement in operational convenience and inflation efficiency, offering a solid foundation for future optimization efforts.

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