Description of the Fire Detection and Suppression Mechatronic Module System using a Sensitive Element

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Abstract: The design of a mechatronic module intended for early fire detection and automatic suppression is of significant importance. The structural scheme described in the article includes processes for rapid fire hazard detection, signal processing, and activation of the fire suppression mechanism. This article discusses the description, structure, and operating principles of the fire detection and suppression device.

Keywords: fire, sensitive element, mechatronic module, system, signals, temperature.

Introduction

Fire hazards represent one of the most pressing challenges in modern society, causing not only property damage but also posing significant risks to human lives. Systems designed for early fire detection and automatic suppression are of critical importance in minimizing these risks. Innovative approaches in the field of mechatronics, particularly systems utilizing sensitive elements and microcontrollers, provide effective solutions for ensuring fire safety. This article comprehensively examines the structure, operating principles, and characteristics of sensitive elements employed in a mechatronic module system designed for fire detection and suppression. The article aims to analyze the structural scheme of the system, which encompasses processes for rapid fire hazard detection, signal processing, and activation of automatic suppression mechanisms.
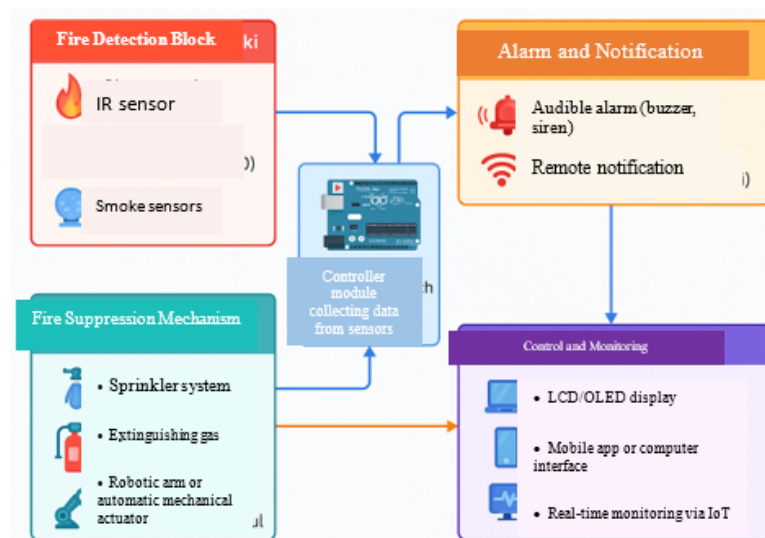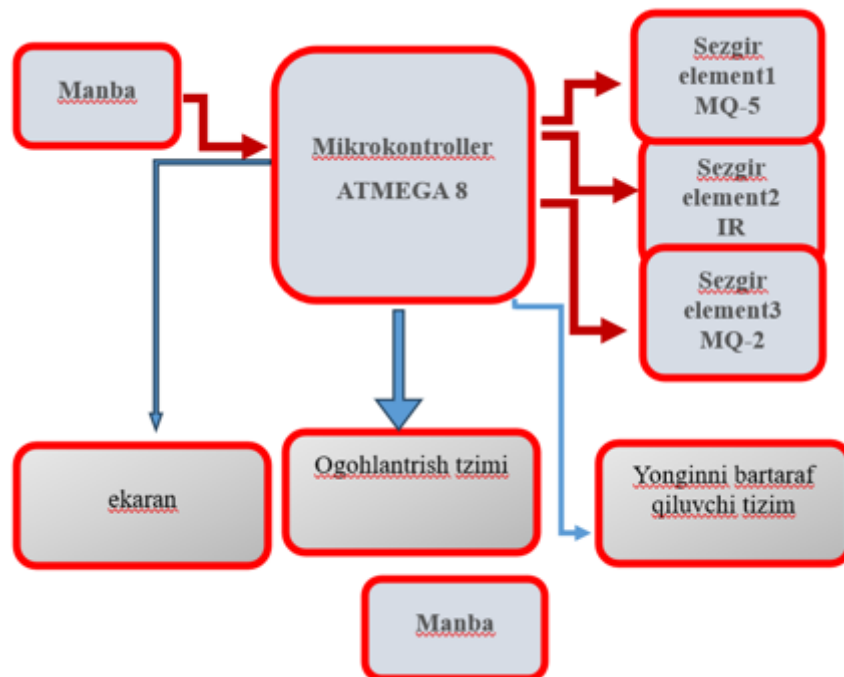
Main part

Figure 1. Description of the structural (component) scheme of the mechatronic module system for fire detection and suppression using a sensitive element

The structural scheme represents a mechatronic module designed for early fire detection and automatic suppression. The scheme includes processes for rapid fire hazard detection, signal processing, and activation of the fire suppression mechanism. The scheme depicts the main power source, the sensitive elements section, the warning section, and the fire suppression section.

The sensitive elements section includes three types of sensitive elements: smoke, gas, and infrared sensors. It is known that smoke is an indicator of the onset of a flame. For the structural scheme, the MQ-2 smoke detection sensor was selected. The MQ-2 sensor is a versatile gas sensor capable of detecting alcohol, carbon monoxide, hydrogen, isobutene, liquefied petroleum gas, methane, propane, and smoke. It is popular among beginners due to its affordability and ease of use. The MQ-2 sensor operates based on the principle of resistance change in the presence of various gases. When the target gas interacts with the heated MOS (metal oxide semiconductor) material, it undergoes oxidation or reduction reactions that alter the resistance of the MOS material. Notably, the MQ-2 gas sensor can detect multiple gases but lacks the ability to distinguish between them, a common characteristic of most gas sensors. The sensor includes a built-in potentiometer that allows adjustment of the digital output (D0) threshold. When the gas concentration in the air exceeds a certain threshold, the sensor's resistance changes. This change in resistance is converted into an electrical signal that can be read by an Arduino board.
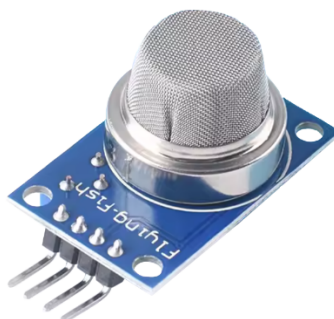

Figure 2. MQ-2 Smoke sensor.

The second sensitive element is the infrared (IR) sensor. It is appropriate to note that IR sensors are widely used in various industries due to their effectiveness in detecting heat, motion, or the presence of objects. Infrared sensors are applied in the following fields:

Medicine: IR thermometers are used for rapid body temperature measurement. Additionally, infrared imaging (thermography) is employed to detect inflammation or circulatory issues. IR thermometers measure body temperature through the forehead or ear in seconds, making them particularly useful for children or large-scale screenings (e.g., at airports during pandemics). They do not require hazardous materials like mercury thermometers, making them safer. Thermography identifies temperature differences on the body surface, aiding in the early detection of conditions such as inflammation (e.g., arthritis), circulatory issues, or breast cancer. Medical thermography serves as a non-invasive alternative to methods like X-rays. Recent research explores IR sensors for non-invasive glucose level measurement through the skin, which could be a significant breakthrough for diabetic patients. In rehabilitation, IR radiation is used in physiotherapy to generate heat, reduce muscle pain, and improve blood circulation.

Night Vision Cameras: IR cameras detect heat radiation in low-light conditions, enabling the visualization of objects and people. This is crucial for police, military, and security services.

Motion Sensors: IR sensors (e.g., passive infrared PIR sensors) detect motion in a room and are widely used in alarm systems and automatic lighting systems.

Fire Detection: IR sensors detect heat in the early stages of a fire, activating fire alarm systems.

Biometric Security: IR technology is used in facial recognition systems, particularly in low-light conditions, to identify facial features.

Remote Controls: IR signals are used in remote controls for TVs, air conditioners, audio systems, and some gaming consoles. They are simple, affordable, and reliable.

Smart Devices: IR sensors in smartphones and tablets provide remote control functionalities, such as universal remotes. Some IR touchscreens use infrared beams to detect touch, which is effective for large displays (e.g., interactive whiteboards).

Data Transmission: IR ports, once common in phones, were used for wireless data transfer and are still used in some specialized devices.

Temperature Monitoring: IR pyrometers or thermal cameras measure the temperature of machines, pipes, or products remotely in factories, helping prevent overheating.

Quality Control: IR sensors detect surface defects (e.g., cracks or uneven coatings) in products.

Energy Efficiency: IR imaging identifies heat losses in buildings, aiding in improving thermal insulation.

Automation: IR sensors detect products on conveyor belts, enabling sorting or packaging automation.

Night Vision Systems: IR cameras allow drivers to see people, animals, or obstacles in the dark, as seen in premium vehicles like BMW and Mercedes-Benz.

Autonomous Driving: IR sensors, in conjunction with LIDAR and radar, scan the environment and detect obstacles.

Passenger Monitoring: IR sensors monitor passengers' conditions (e.g., detecting a drowsy driver).

Climate Control: IR sensors measure passengers' body temperatures to adjust cabin climate.

Missile Guidance: IR sensors detect heat signatures (e.g., from aircraft or tank engines) to guide missiles.

Drones: IR cameras are used in drones for nighttime surveillance, search-and-rescue operations, and military reconnaissance.

Satellite Imaging: IR sensors monitor temperature changes on Earth's surface from space, aiding in weather forecasting and natural disaster detection.

Stealth Technologies: IR sensors detect enemy devices or reduce their infrared signatures.

Gas Leak Detection: IR sensors detect the infrared signatures of gases like methane or carbon dioxide, identifying leaks in the oil and gas industry.

Climate Research: IR spectroscopy measures greenhouse gases in the atmosphere, aiding in climate change analysis.

Forest Fire Detection: IR cameras on drones or satellites detect fire outbreaks in forests.

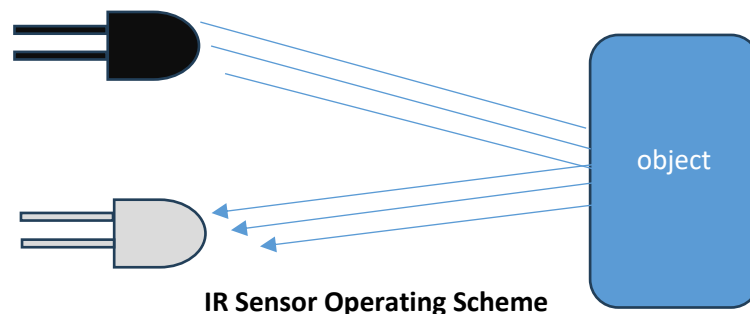**Water Quality**: IR sensors monitor water pollution levels or temperature changes.

Smart Homes: IR sensors detect human presence in a room, automatically controlling lighting, air conditioning, or heating systems to save energy.

Security Systems: IR sensors in home alarm systems detect motion.

Smart Kitchen Appliances: IR sensors monitor food temperature in ovens or microwaves.

Voice Assistant Integration: IR sensors work with smart speakers or IoT devices, detecting human presence to activate music or lighting.

An infrared (IR) sensor is an electronic device that detects infrared radiation from objects. These sensors sense infrared light at various wavelengths and convert it into electrical signals. This capability allows them to detect and identify target objects. The primary function of an IR sensor is to receive infrared radiation, convert it into an electrical signal, and use this signal to interpret information about the environment or objects within its range. IR sensors are versatile and widely used in fields such as proximity detection, contrast detection, and obstacle counting. Proximity sensors are common in smartphones and robotics for obstacle avoidance systems. In smartphones, these sensors detect when a user's face is close to the screen, disabling the display to prevent accidental touches. In robotics, proximity sensors help robots detect nearby objects and navigate without collisions. Accurate distance detection enables precise interaction and control.
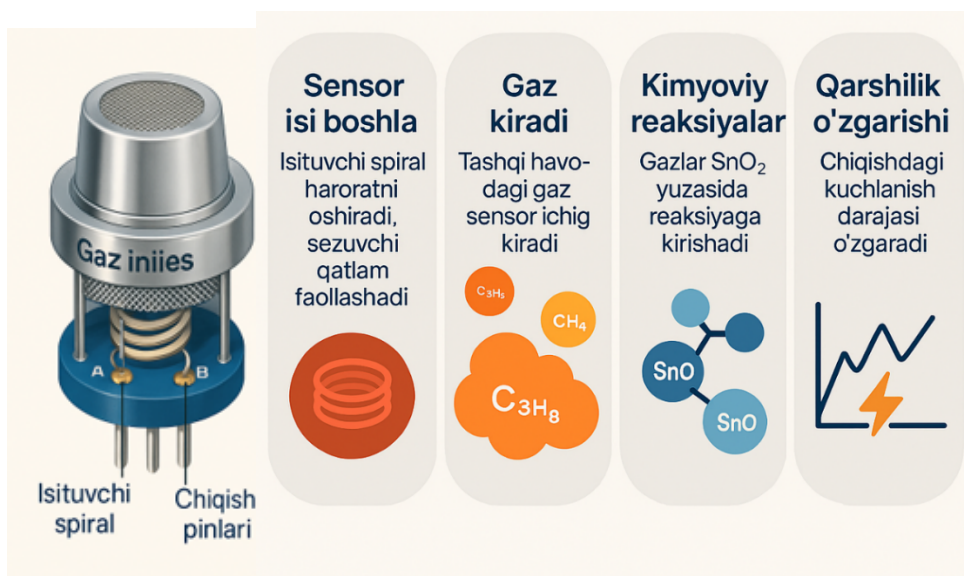

IR Sensor Operating Scheme

The operating principle of an infrared (IR) sensor relies on two main components: the transmitter circuit and the receiver circuit. These components together form the basic structure of an IR sensor, often referred to as an optocoupler or optical coupler.

Figure 3. MQ-5 Gas sensor.

The third sensitive element is the MQ-5 gas detection sensor. This device is widely used to detect natural gas and liquefied petroleum gas. It is highly suitable for the project being developed. The gas-sensing material used in the MQ-5 sensor is tin dioxide (SnO2), which has low conductivity in clean air. When combustible gas is present in the environment, the sensor's conductivity increases with the rising concentration of combustible gas in the air. The MQ-5 gas sensor is highly sensitive to butane, propane, and methane and can account for methane and propane. This sensor is an affordable option capable of detecting various combustible gases, particularly natural gas, making it suitable for multiple applications.

MQ-5 Gaz Sensor Operating Scheme

Conclusion

The mechatronic module system developed for fire detection and suppression is regarded as a significant advancement in modern safety technologies. The smoke, gas, and infrared sensitive elements utilized in this system ensure high efficiency in early fire hazard detection. The mechanism, controlled by the Arduino platform, guarantees the system's automated operation and rapid response. The presented structural scheme and the operating principles of the sensitive elements establish a robust foundation for the practical application and further development of this system. In the future, enhancements such as the integration of artificial intelligence algorithms or the addition of supplementary sensitive elements could improve the system's accuracy and functionality. This approach not only enhances fire safety but also contributes to the advancement of safety systems across various industries.

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