DEVELOPMENT OF A SENSOR MONITORING AND REMOTE CONTROL MODEL BASED ON THE ARDUINO HARDWARE PLATFORM

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Abstract: *The rapid development of embedded systems and the Internet of Things has increased the demand for compact software-hardware solutions that can collect sensor data, transmit it through communication networks and control physical devices remotely. This article proposes a sensor monitoring and remote control model based on the Arduino hardware platform. The model integrates analog and digital sensors, the ATmega328 microcontroller, UART, I2C, SPI and PWM interfaces, Wi-Fi/Ethernet communication modules, a monitoring dashboard and actuator control. The study systematizes the functional blocks of the proposed system, describes the algorithmic sequence of data acquisition and remote control, and presents mathematical indicators for evaluating response time, sensor accuracy, packet delivery and monitoring efficiency. The results show that Arduino can be used not only as an educational prototyping board, but also as a compact embedded node for smart rooms, environmental monitoring, access control, laboratory automation and small-scale IoT systems.*

Keywords: *Arduino, sensor monitoring, remote control, embedded system, Internet of Things, microcontroller, UART, I2C, SPI, PWM, Wi-Fi, Ethernet.*

INTRODUCTION

The expansion of digital technologies has created new opportunities for observing physical objects in real time, collecting information from sensors and controlling devices from a distance. In this process, the Internet of Things concept plays a central role because it connects physical objects, sensors, microcontrollers, communication modules and software platforms into a unified information environment. As a result, monitoring and control systems are no longer limited to local electronic circuits; they are becoming network-oriented embedded systems capable of exchanging data and reacting to changing conditions.

The source material used for this article describes IoT as a telecommunication technology that enables objects, places and devices to be connected to the Internet, identified, monitored and controlled. It also emphasizes that modern control systems are based on microcontrollers, sensors, actuators and communication interfaces. These ideas make it possible to develop simple, inexpensive and flexible monitoring-control solutions based on the Arduino hardware platform.

The purpose of this article is to develop a software-hardware model of a sensor monitoring and remote control system based on Arduino and to justify the criteria for evaluating its efficiency. The practical value of the proposed model is that it can be used in educational laboratories, smart rooms, access control, environmental monitoring, small automation projects and experimental Internet of Things applications.

2. Related Approaches and Research Gap

Modern control systems are increasingly considered as embedded intelligent nodes that exchange data through communication networks. In such systems, sensor devices detect the state of an object or environment, a microcontroller processes the incoming information, a communication module transfers the result to a monitoring panel, and actuators execute control commands when required. This architecture is especially important for applications where physical processes must be observed continuously and decisions must be made quickly.

The Arduino platform is convenient for educational and applied projects because it includes analog and digital input-output pins, UART, SPI and I2C interfaces, and PWM outputs for controlling actuators. However, many practical Arduino-based works remain at the level of reading a single sensor or switching an LED. In these cases, the complete monitoring cycle, network data transmission quality, actuator response and system efficiency are not always evaluated in an integrated way.

The research gap addressed in this article is the lack of a compact methodological model that combines sensor acquisition, signal preprocessing, interface selection, network transmission, dashboard visualization and actuator control into one coherent remote monitoring cycle. Therefore, this article interprets sensor monitoring and remote control as a full software-hardware chain rather than as a set of separate electronic experiments.

3. Proposed Software-Hardware Model

The proposed model consists of five main functional blocks: the sensor block, the Arduino microcontroller block, the communication interface block, the monitoring dashboard and the actuator block. The sensor block measures physical parameters such as temperature, humidity, light, motion, distance or other environmental indicators. The Arduino block converts incoming signals into a digital form, filters them, compares them with threshold values and generates a control decision. The communication block transfers information through Wi-Fi, Ethernet or Bluetooth. The monitoring dashboard displays the system status to the user, while the actuator block executes the corresponding physical action.

Sensor Monitoring and Remote Control Model Based on Arduino

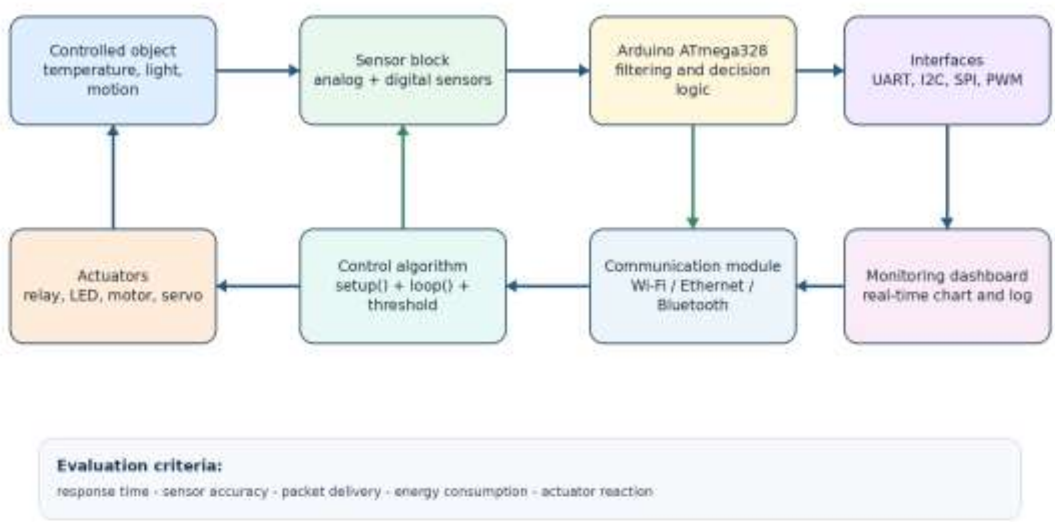

Figure 1. Arduino-based sensor monitoring and remote control model.

In the model, the UART interface is used for short-distance serial communication and for working with certain wireless modules. The I2C interface is appropriate when several sensors must be connected to the same bus. The SPI interface is used for high-speed modules such as Ethernet, RFID or SD-card devices. PWM outputs are used to control relays, LEDs, motors and servo mechanisms. Such an architecture makes the system adaptable to different real environments and allows the designer to expand the system step by step.

The general operation of the system follows a repeated cycle. First, the sensor value is acquired. Second, the microcontroller checks whether the value is valid and filters possible noise. Third, the value is transmitted to a local or remote monitoring panel. Fourth, if the value exceeds a predefined threshold, the system generates a control command for the actuator. Finally, the result is stored in the log and the next measurement cycle begins.

4. Algorithmic and Mathematical Evaluation Model

The Arduino-based monitoring system is programmatically organized around the setup() and loop() functions. The setup() stage initializes ports, libraries, sensors and communication modules. The loop() stage continuously reads sensor data, processes the value, transmits the result to the monitoring panel and generates a control signal when necessary.

To remove the influence of different measurement units, the sensor value can be normalized as follows:

$$S\_norm = (S\_i - S\_min) / (S\_max - S\_min) \qquad (1)$$

Here, S_i is the current sensor value, S_min and S_max are the minimum and maximum boundary values, and S_norm is the normalized indicator. The control decision can be expressed by the following rule:

$$u(t) = 1, \text{ if } S\_norm >= theta; \quad u(t) = 0, \text{ if } S\_norm < theta \qquad (2)$$

In Eq. (2), theta is the control threshold and u(t) is the control signal sent to the actuator. The total response time of the system is determined by the sum of the main technological delays:

$$T\_response = T\_sensor + T\_processing + T\_network + T\_actuator \qquad (3)$$

To evaluate monitoring efficiency, packet delivery, sensor accuracy and reaction quality can be integrated into one indicator:

$$M = (A\_sensor * P\_delivery * R\_reaction) / (T\_response + C\_resource) \qquad (4)$$

Here, A_sensor is sensor measurement accuracy, P_delivery is the successful packet delivery rate, R_reaction is actuator reaction quality, and C_resource represents the resource consumption of the microcontroller and communication module. A higher value of M indicates a more efficient monitoring and remote control configuration.

5. Results and Analytical Discussion

The proposed model can be applied with different interface and sensor configurations. Table 1 presents a comparative analysis of common technical variants used in Arduino-based monitoring systems. The comparison is methodological and scenariobased; it is intended to show which configuration is appropriate for a specific technical task.

Table 1. Comparative analysis of Arduino-based sensor monitoring configurations.

Configuration	Main interface	Application case	Advantage	Limitation
Analog sensor + Arduino	Analog pins	Temperature, light or humidity monitoring	Simple connection and low cost	High sensitivity to noise
I2C sensor network	I2C	Connecting multiple sensors to one bus	Saves pins and is easy to extend	Distance and addressing limitations
RFID or Ethernet module	SPI	Access control and network monitoring	Fast data exchange	More complex programming
Wireless monitoring	UART / Wi-Fi	Observation of remote objects	No cable infrastructure required	Signal quality depends on the environment
Actuator control	PWM / digital pin	Servo, relay, LED and motor control	Convenient real-time reaction	Power circuit requires protection

The table shows that interface selection directly depends on the functional purpose of the project. For simple measurement tasks, analog pins may be sufficient. For multi-sensor systems, I2C is more efficient because it saves input-output pins. For fast data exchange and network connection, SPI-based Ethernet or RFID modules are more appropriate. Wireless monitoring is useful for remote objects, but it requires continuous control of signal stability and packet delivery quality.

When implementing the system in real conditions, additional factors must also be considered. These include stable power supply, sensor calibration, network security, packet loss, actuator wear and error handling. Therefore, a practical Arduino-based monitoring system should not consist only of program code; it must also include hardware protection, backup power, data logging, validation of sensor values and a mechanism for processing abnormal situations.

6. Scientific Novelty and Practical Value

The scientific novelty of the article is that the Arduino hardware platform is interpreted not only as a separate microcontroller board, but as an embedded Internet of Things node that combines sensor monitoring, communication interfaces, decision logic and actuator control. The proposed model links sensor signal acquisition, digitization, decision-making, communication and feedback into a single control cycle.

The practical value of the proposed approach is related to its simplicity, modularity and low cost. On the basis of this model, understandable laboratory stands can be created for students, small automation objects can be monitored, smart room devices can be developed, and access control or remote observation systems can be implemented. The modular structure also allows the model to be extended by adding a web dashboard, a database, mobile notifications, cybersecurity modules and energy-saving modes.

7. Conclusion

This article developed a software-hardware model of a sensor monitoring and remote control system based on the Arduino hardware platform.

The proposed model integrates sensors, an Arduino microcontroller, UART/I2C/SPI/PWM interfaces, Wi-Fi or Ethernet communication modules, a monitoring dashboard and actuators.

Mathematical indicators were proposed for sensor normalization, control decision generation, response time calculation and integrated monitoring efficiency evaluation.

The analysis shows that Arduino is an effective solution for creating compact sensor monitoring systems because of its low cost, modularity, interface diversity and simple programming environment.

Future work should focus on integrating the model with a web panel, database storage, mobile application, cybersecurity mechanisms, cloud services and energy-efficient operating modes.

Such improvements can transform the proposed model into a more complete IoT-based remote monitoring and control platform.

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