DESIGN AND PERFORMANCE EVALUATION OF A NETWORKED CONTROL SYSTEM BASED ON THE IOT CONCEPT AND ARDUINO HARDWARE PLATFORM

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Abstract: *The rapid development of communication networks and embedded computing has increased the demand for networked control systems capable of monitoring and controlling physical objects in real time. This article presents a software-hardware approach for designing an Arduino-based control system in accordance with the Internet of Things (IoT) concept. The proposed model combines sensors, actuators, an Arduino microcontroller, UART/SPI/I2C interfaces, Ethernet or Wi-Fi communication and TCP/UDP network protocols. A performance evaluation model is introduced using response time, packet delivery ratio, protocol overhead and control efficiency indicators. The analytical discussion shows that UDP-based control may provide faster response for lightweight real-time commands, while TCP remains useful for reliable data exchange. The results can be applied in educational laboratories, smart buildings, access control, environmental monitoring and small-scale automation systems.*

Keywords: *Internet of Things, Arduino, embedded control system, networked control, TCP, UDP, Ethernet, Wi-Fi, sensors, actuators.*

INTRODUCTION

Modern information and communication technologies are transforming control systems from isolated technical devices into network-connected intelligent units. In the uploaded research material, the IoT concept is described as a technological basis for connecting physical objects, places and devices to the internet for identification, monitoring and control. This idea is important because objects can exchange data, respond to changes and perform control commands without constant human intervention.

The purpose of this article is to develop a compact scientific model for designing and evaluating an Arduino-based networked control system. The focus is placed on practical engineering aspects: sensor data acquisition, microcontroller-based processing, network communication, command execution and performance assessment. Such a system can be used in smart homes, educational laboratories, security systems, environmental monitoring, telemedicine devices and small industrial automation tasks.

The relevance of the topic is determined by three factors. First, IoT-based systems require inexpensive and flexible hardware platforms. Second, control systems must operate through reliable communication channels such as Ethernet, Wi-Fi and serial interfaces. Third, performance evaluation is necessary because protocol selection directly affects delay, stability and control quality. Arduino is suitable for these tasks because it supports digital and analog inputs, embedded programming and a wide range of communication shields.

2. Related Work and Research Gap

The analyzed source emphasizes that modern control systems are increasingly organized through communication technologies and embedded devices. Microprocessors, microcontrollers, sensors, actuators and network interfaces form the hardware basis of such systems. Arduino is presented as a widely used platform due to its simple architecture, convenient programming environment and compatibility with Ethernet, Wi-Fi, Bluetooth, ZigBee, RFID and other modules.

However, many educational and practical Arduino projects are limited to demonstrating simple input-output operations. They often do not provide a systematic model that connects hardware architecture, communication protocols and measurable performance indicators. Therefore, the research gap addressed in this article is the need for a unified methodological framework for Arduino-based IoT control systems that includes both design logic and performance evaluation.

3. Proposed Arduino-Based IoT Control Architecture

The proposed architecture consists of four interacting layers: sensing layer, control layer, communication layer and application layer. The sensing layer receives information from analog and digital sensors. The control layer is implemented on the Arduino microcontroller and performs data preprocessing, decision logic and command generation. The communication layer provides Ethernet or Wi-Fi connectivity using TCP or UDP protocols. The application layer includes a monitoring dashboard, command interface and data journal.

The general workflow is organized as follows: sensor signal acquisition → signal conversion and filtering → control decision → network transmission → actuator command → feedback registration. This cycle corresponds to the structure of embedded control systems described in the source material, where sensors and communication interfaces are used to connect the control device with external objects.

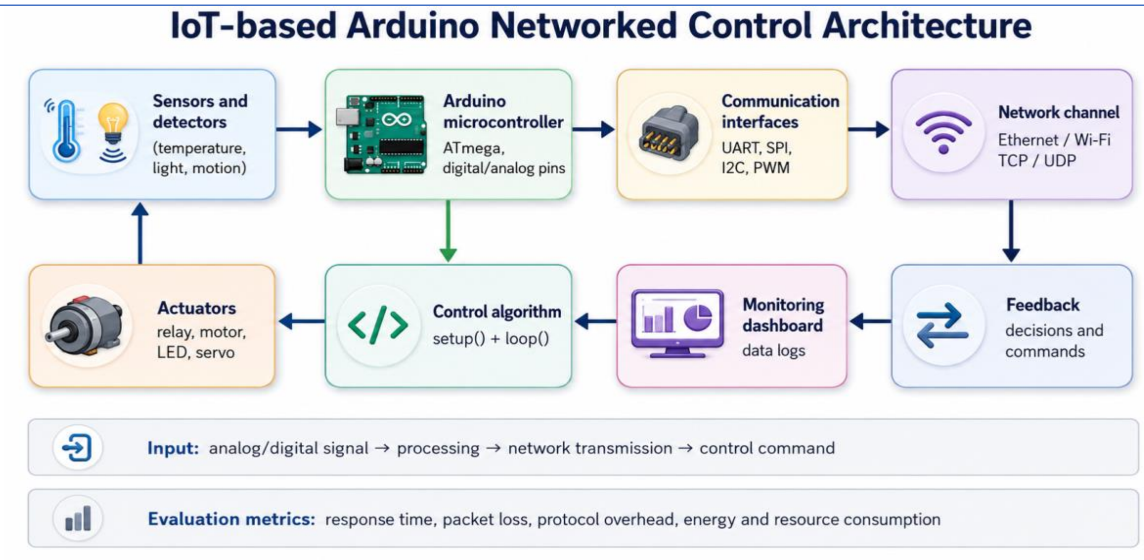

Figure 1. Arduino-based IoT networked control architecture.

Arduino supports several important interfaces for control system design. UART is useful for short-range serial communication and for modules such as Bluetooth or Wi-Fi. SPI provides faster communication and is often used for Ethernet, RFID and SD-card modules. I2C is convenient for connecting sensors such as temperature, humidity, light and motion sensors. PWM outputs are used for controlling motors, servos and LED intensity. This combination allows the platform to be adapted to different monitoring and control scenarios.

4. Algorithm and Mathematical Performance Model

The control algorithm is based on the classical Arduino program structure: setup() initializes the ports, libraries and network parameters, while loop() continuously reads sensors, processes data, sends status information and executes commands. In simplified form, the algorithm can be expressed as follows:

Step 1: initialize sensor pins, communication interface and control parameters. Step 2: read sensor values. Step 3: normalize or classify the input condition. Step 4: generate a control command. Step 5: send data to the monitoring system using TCP or UDP. Step 6: activate the actuator and record feedback.

The response time of the networked control system can be represented by Eq. (1):

$$T\_response = T\_sensor + T\_processing + T\_network + T\_actuator \qquad (1)$$

where T_sensor is the sensor reading time, T_processing is the Arduino processing time, T_network is the network transmission delay and T_actuator is the actuator activation time.

The packet delivery ratio is calculated by Eq. (2):

$$PDR = (N\_received \,/\, N\_sent) \times 100\% \qquad (2)$$

where N_sent is the number of transmitted packets and N_received is the number of successfully received packets. The generalized control efficiency indicator is given in Eq. (3):

$$E = PDR / (T\_response + \alpha O\_protocol + \beta C\_resource) \quad (3)$$

In Eq. (3), O_protocol denotes protocol overhead, C_resource represents resource consumption, while α and β are weighting coefficients selected according to the system scenario. A higher E value indicates better control performance.

5. Results and Analytical Discussion

A scenario-based comparison was prepared to evaluate how communication technologies influence the operation of Arduino-based control systems. The comparison reflects the logical conclusion of the uploaded research material: UDP may be more efficient for fast command exchange, while TCP provides stronger delivery control and session reliability.

Table 1. Analytical comparison of Arduino-based network control scenarios.

Scenario	Protocol / channel	Average response	Reliability	Engineering interpretation
Wired reliable control	TCP + Ethernet	Medium	Very high	Suitable for logs, configuration and important status messages
Wired real-time command	UDP + Ethernet	Low	High	Suitable for short repetitive commands and fast actuator control
Flexible wireless monitoring	TCP + Wi-Fi	Medium to high	High	Useful when cable installation is difficult but reliability is required

Mobile lightweight control	UDP + Wi-Fi	Low to medium	Medium to high	Useful for fast IoT commands, but packet loss must be monitored

The comparison shows that protocol selection should depend on the functional purpose of the system. If the system controls access, switching devices or actuators that receive frequent short commands, UDP can reduce delay because it has lower protocol overhead. If the system transmits configuration files, event journals or critical confirmation messages, TCP is more appropriate because it supports ordered delivery and retransmission mechanisms.

The uploaded source also notes that Ethernet and Wi-Fi have different practical advantages. Ethernet can provide stable communication in fixed installations, but cable infrastructure may limit deployment flexibility. Wi-Fi is more convenient for mobile, distributed and hard-to-wire objects, although wireless interference and signal quality must be considered. Therefore, hybrid design is recommended: Ethernet for fixed control nodes and Wi-Fi for flexible sensor or actuator modules.

6. Scientific Novelty and Practical Value

The scientific novelty of the article is the integration of Arduino-based embedded control principles with IoT communication architecture and measurable performance indicators. The model does not consider Arduino only as a training board; instead, it treats it as a practical embedded node that participates in a networked control cycle.

The practical value lies in the possibility of using the proposed model in educational laboratories and applied engineering projects. Students can learn how sensors, microcontrollers, communication interfaces and network protocols work together. Engineers can use the model as a preliminary design scheme for small automation systems, access control devices, smart rooms, greenhouse monitoring, laboratory equipment monitoring and other IoT tasks.

The proposed approach is also useful for choosing the communication protocol. By measuring response time, packet delivery ratio and resource consumption, developers can decide whether TCP, UDP, Ethernet or Wi-Fi is more suitable for a particular control scenario.

7. Conclusion

This article proposed an Arduino-based networked control system model developed according to the Internet of Things concept. The system includes sensors, actuators, Arduino microcontroller logic, UART/SPI/I2C/PWM interfaces, Ethernet or Wi-Fi communication and TCP/UDP protocol options. A mathematical model for performance evaluation was presented using response time, packet delivery ratio and generalized control efficiency.

The analytical discussion shows that UDP can be preferable for lightweight real-time commands due to lower delay and protocol overhead, while TCP is useful for reliable data exchange. Ethernet is suitable for fixed and stable systems, whereas Wi-Fi increases deployment flexibility. Future work should include large-scale experimental testing, cybersecurity analysis, energy consumption measurement and development of a web-based dashboard for real-time monitoring.

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