DESIGN AND IMPLEMENTATION OF MICROCONTROLLER-BASED EMBEDDED CONTROL SYSTEMS WITH ARDUINO

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ABSTRACT:

This article explores the design and development of embedded control systems using the Arduino platform. Embedded systems are widely used in modern electronic devices due to their flexibility, cost-effectiveness, and ability to control operations in real-time. Known for its simplicity and open-source ecosystem, the Arduino platform allows for rapid prototyping and efficient implementation of microcontroller-based solutions. In this article, we analyze the hardware and software aspects of Arduino-based embedded modules, including sensor integration, actuator control, and communication protocols.

Keywords: Embedded systems, Arduino variants, Arduino Uno R3, IoT, Automation, DFRobot RoMeo BLE.

INTRODUCTION:

Embedded systems have become ubiquitous in modern technology, playing a critical role in automation, control, and monitoring. Arduino, an open-source microcontroller platform, offers a practical solution for rapid prototyping and implementation of embedded control modules. This paper aims to analyze the functionality and real-world applications of such modules.

In 2005, Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, and David Mellis came up with an idea for an easy-to-use programmable device for interactive art design projects at the Interaction Design Institute Ivrea in Ivrea, Italy. The device needed to be simple, easy to connect to various things (such as relays, motors, and sensors), and easy to program. It also needed to be inexpensive to make it cost-effective for students and artists. They selected an AVR family of 8-bit microcontroller (MCU or µC) devices from Atmel and designed a self-contained circuit board with easy-to-use connections, wrote bootloader firmware for the microcontroller, and integrated it all into a simple development environment that used programs called "sketches." The result was Arduino[1].

Arduino is an open-source microcontroller that enables programming and interaction; it is programmed in C/C++ with an Arduino library to allow it to access the hardware. This allows for more flexible programmability and the ability to use electronics that can interface with Arduino. Because Arduino is open source, the plans for the circuits are available online for free to anyone who wants to use and create their own board based on the schematics, as long as they share what they create [2]. This allows for considerable customizability in projects; till date, users have built Arduinos of different sizes, shapes, and power levels to control their projects. Arduino is composed of two major parts:

The Arduino board, which is a piece of hardware you work on when you build your objects.

2. The Arduino IDE, which is a piece of software you run on your computer. You use the IDE to create a sketch (a small computer program) that you upload to the Arduino board.

Arduino is different from other platforms in the market because of the following features:

1. It is a multiplatform environment; it can run on Windows, Macintosh, and Linux.

2. It is based on a processing programming IDE, which is an easy-to-use development environment used by artists and designers.

3. You program it via a USB cable, not a serial port. This feature is useful, because many modern computers do not have serial ports.

4. It is open-source hardware and software—if you wish, you can download the circuit diagram, buy all the components, and make your own Arduino board, without paying anything to the makers of Arduino.

5. The hardware is cheap.

6. There is an active community of users, so there are many people who can assist you.

7. The Arduino project was developed in an educational environment, and is therefore, great for newcomers to get things working quickly

Owing to these special features, there are many potential applications:

- Real-world monitoring
- Automated weather station
- Lightning detection
- Sun tracking for solar panels
- Background radiation monitor

- Automatic wildlife detector
- Home or business security system
- Small-scale control
- Small robots
- Model rockets
- Model aircrafts
- Quadrotor UAVs
- Simple CNCs for small machine tools
- Small-scale Automation
- Automated greenhouse
- Automated aquarium
- Laboratory sample shuttle
- Precision thermal chamber
- Automated electronic test system
- Performance Art
- Dynamic lighting control
- Dynamic sound control
- Kinematic structures
- Audience responsive artwork.

Arduino Variants

Arduino is rapidly becoming one of the most popular microcontrollers used in robotics. There are many different types of Arduino microcontrollers that differ not only in design and features, but also in size and processing capabilities. However, there are only two models that use completely different chips: the Standard and the Mega. The Standard is the basic Arduino that uses the Atmega8/168/328 chip, whereas the Mega is a different Arduino board with more I/O pins and uses the beefier Atmega1280 chip. The makers of Arduino also developed software that is compatible with all Arduino microcontrollers. The software, also called “Arduino,” can be used to program any of the Arduino microcontrollers by selecting them from a drop-down menu. Being open source, and based on C, Arduino users are not necessarily restricted to this software, and can use a variety of other software to program their microcontrollers. There are many additional manufacturers who use open-source schematics provided by Arduino to make their own boards (either identical to the original, or with variations to add to the functionality), e.g., DFRobot. In this chapter, the Arduino Uno R3 and DFRobot Romeo BLE boards are introduced [3-5].

Arduino Uno R3

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. Central to the Arduino interface board, shown in Fig. 1 is an onboard microcontroller [6].

Specifications of the Arduino UNO R3 are as follows:

- Microcontroller: ATmega328
- Operating Voltage: 5 V
- Input Voltage (recommended): 7–12 V
- Input Voltage (limits): 6–20 V
- Digital I/O Pins: 14 (of which 6 provide PWM outputs)
- Analog Input Pins: 6
- DC Current per I/O Pin: 40 mA
- DC Current for 3.3 V Pin: 50 mA
- Flash Memory: 32 KB of which 0.5 KB is used by the bootloader
- SRAM: 2 KB (ATmega328)
- EEPROM: 1 KB (ATmega328)
- Clock Speed: 16 MHz (Fig. 1.2)

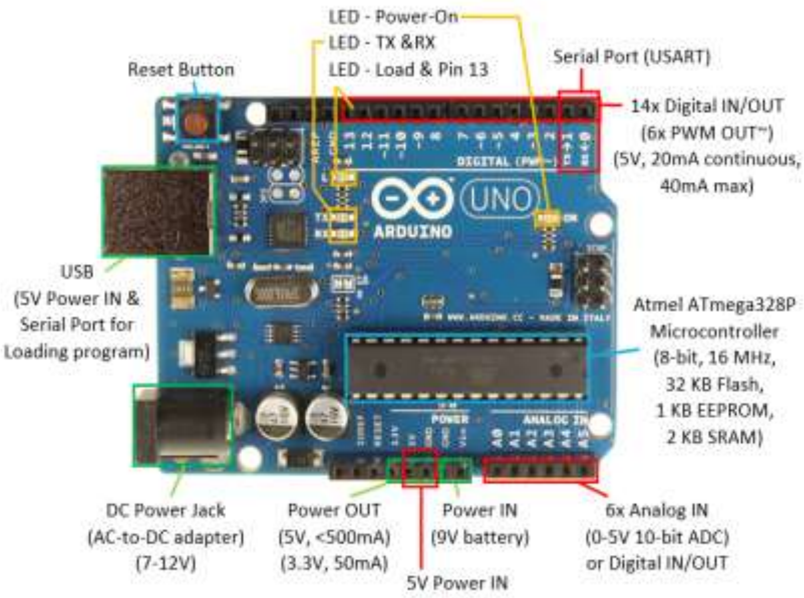

Fig. 1 Arduino UNO interface board.

The Arduino Uno pinout is printed in the silkscreen in the top section. While this pinout is a good start, it is not a comprehensive guide. At first, you mainly use the pins in the female headers at the edge of the board (top and bottom in the photo), as well as the USB, and maybe the power Tx and Rx are serial UART pins used for RS-232 and USB communications I2C is another serial communications method that uses a bidirectional data line (SDA) and a clock line (SCL) SPI is another serial communications method that uses one line for the master to transmit (MOSI—Master Out Slave In), another for the master to receive (MISO), and a third as a clock (SCK) A/D, the Analog to Digital input, converts an analog voltage into a digital representation PWM (Pulse Width Modulator) is used to create a square wave with a specific duty cycle (high time vs low time) ICSP is the In Circuit Serial Programming—another way to program the processor Vcc is the voltage supplied to the processor (+5VDC regulated from a higher input voltage) 3.3VDC is a regulated voltage (from the higher input voltage) for peripherals requiring that voltage—50 mA maximum [8].

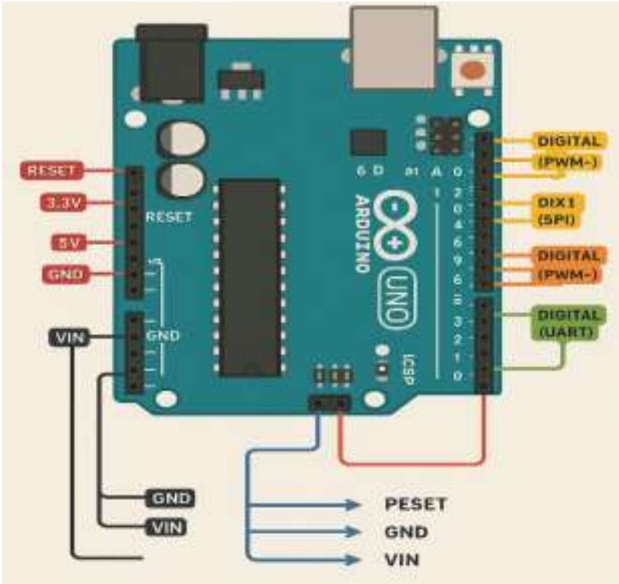

Fig.2. Arduino Uno R3 pinout diagram

IOREF provides a voltage reference so shields can select the proper power source

AREF is a reference

INPUT voltage used by the A/Ds

GND is the ground reference

RESET resets the processor (and some peripherals).

2. DFRobot RoMeo BLE

The DFRobot Romeo BLE All-in-one Microcontroller (ATMega 328) is an all-in-one Arduino-compatible microcontroller specifically designed for robotic applications. It benefits from the Arduino open-source platform; it is supported by thousands of open-source codes, and can easily be expanded with your Arduino-compatible shields. This robot controller uses an Atmel ATmega328p as the main microcontroller. It comes preprogrammed with an Arduino bootloader for compatibility with the user-friendly Arduino Uno platform. A secondary Texas Instruments CC2540 microcontroller handles the BLE Bluetooth Low Energy communication services. It comes preprogrammed with a firmware that supports transparent serial over Bluetooth and an AT command interpreter. Both microcontrollers are full programmable. The Romeo robot controller contains a built in L298 dual channel motor driver chip. This motor driver can be used to drive two 5–23 V DC motors at up to 2 amps. Screw terminals are provided for connecting two motors and an external motor power supply [9].

The Romeo BLE microcontroller board also has a large number of pin headers to simplify connections to your robot project. A full set of 3-pin analog and digital GPIO headers provide access to signal, voltage, and ground lines at each connection to simplify wiring arrangements.

The digital GPIO headers can also be used to drive servos and a screw terminal can provide an external servo power supply. A full set of Arduino Uno compatible headers allow you to choose from a large number of Arduino-compatible shields for expansion. A triplet of I2C connectors is also provided. Additional features include five optional user push buttons, a reset button, and a number of LED status indicators to assist with diagnostics [10].The optional user buttons are conveniently wired to a single analog input. They can be enabled or disabled via a slider switch (Fig.3).

Fig.3. DFRobot RoMeo BLE

Specifications of the RoMeo BLE are as follows:

• Microcontroller: ATmega328P

• Bootloader: Arduino UNO

• Onboard BLE chip: TI CC2540

• 14 Digital I/O ports

• 6 PWM Outputs (Pin11, Pin10, Pin9, Pin6, Pin5, Pin3)

• 8 10-bit analog input ports

• 3 I2Cs • Two way H-bridged motor driver with 2A maximum current

• 5 Buttons • Power Supply Port: USB or DC2.1

• External Power Supply Range: 5–23 V

• DC output: 5 V/3.3 V

• Auto sensing/switching external power input

• Size: 94 mm 80 mm.

RESULTS

The prototype embedded systems designed using Arduino successfully demonstrated the feasibility of implementing low-cost, modular automation solutions. These results demonstrate that Arduino-based embedded systems can perform efficiently in both controlled and dynamic environments.

DISCUSSION

The results validate the suitability of Arduino as a core platform for embedded system design in prototyping and small-scale automation projects. The modular nature of Arduino allows for rapid development and ease of integration with a wide variety of sensors and actuators.

One key observation is that while Arduino is not designed for high-speed processing tasks, it excels in applications requiring moderate control, real-time monitoring, and simple decision-making. This makes it particularly effective for smart home devices, educational robotics, and environmental monitoring systems.

Limitations include the limited processing power and memory, which can restrict scalability for complex systems. However, these constraints can be overcome through optimization techniques or by migrating to more powerful Arduino-compatible boards (e.g., Arduino Mega or ESP32) when needed.

Overall, the study illustrates that Arduino provides an accessible entry point for embedded system development, supporting innovation in both academic and industrial settings.

Conclusion

The design and practical application of embedded systems using the Arduino platform were studied. Arduino is an inexpensive, open-source, and user-friendly development environment that allows you to quickly and efficiently create various control and automation systems.

The modular architecture of Arduino boards, compatibility with a wide range of sensors and actuators, and the availability of extensive software libraries make it an ideal tool for both beginners and experienced engineers.

Practical experiments have shown that Arduino-based systems are reliable in real-time data acquisition, processing, and signal transmission. In addition, their software flexibility allows them to quickly adapt to various embedded system requirements.

In conclusion, designing embedded systems with Arduino is of great importance in modern education, industry, and innovation. This technology not only bridges the gap between theoretical knowledge and real-world applications, but also serves as a powerful tool for prototyping and implementing new ideas.

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