# Embedded System (4343204) – Summer 2024 Solution

Milav Dabgar

June 21, 2024

## Question 1(a) [3 marks]

**Draw AVR status register.**

**Solution**

The AVR Status Register (SREG) contains information about the result of arithmetic operations and controls interrupts.
**Diagram:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| I | T | H | S | V | N | Z | C |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

- **I (bit 7)**: Global Interrupt Enable
- **T (bit 6)**: Bit Copy Storage
- **H (bit 5)**: Half Carry Flag
- **S (bit 4)**: Sign Flag (S = N⊕V)
- **V (bit 3)**: Two's Complement Overflow
- **N (bit 2)**: Negative Flag
- **Z (bit 1)**: Zero Flag
- **C (bit 0)**: Carry Flag

**Mnemonic**

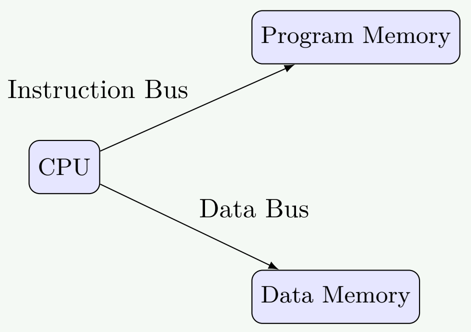
"I Take Health Seriously, Very Nice Zero Carry"

## Question 1(b) [4 marks]

**Explain Harvard Architecture in the AVR.**

**Solution**

Harvard Architecture in AVR separates program and data memory, allowing simultaneous access to both.
**Diagram:**



- **Program Memory**: Stores instructions in Flash memory
- **Data Memory**: Contains SRAM, registers, and I/O registers
- **Separate Buses**: Different buses for program and data
- **Parallel Access**: Can fetch instruction and access data simultaneously

**Mnemonic**

"Separate Places for Data And Programs"

## Question 1(c) [7 marks]

**Discuss real time operating system.**

**Solution**

Real-Time Operating System (RTOS) manages tasks with strict timing requirements, ensuring predictable response times.

**Table 1.** Key Features of RTOS

| **Feature** | **Description** |
|---|---|
| Task Scheduling | Prioritizes tasks based on urgency |
| Deterministic | Guaranteed response times for events |
| Preemptive | Critical tasks can interrupt lower priority ones |
| Memory Management | Efficient memory allocation without fragmentation |
| Low Latency | Minimal delay between event and response |
| Multitasking | Handles multiple tasks concurrently |

- **Task-based**: Divides program into independent tasks
- **Interrupt Handling**: Fast response to external events
- **Synchronization**: Provides semaphores and mutexes for task coordination
- **Resource Management**: Prevents resource conflicts
- **Small Footprint**: Optimized for limited hardware resources

**Mnemonic**

"Tasks Run On Strict Timelines"

## Question 1(c OR) [7 marks]

**Discuss criteria for choosing microcontroller for embedded system.**

**Solution**

Selecting the right microcontroller requires evaluating several key factors to match application requirements.

**Table 2.** Microcontroller Selection Criteria

| **Criterion** | **Considerations** |
|---|---|
| Processing Power | CPU speed, bit width (8/16/32-bit) |
| Memory | Flash, RAM, EEPROM sizes |
| Power Consumption | Sleep modes, operating voltage |
| I/O Capabilities | Number of ports, special functions |
| Peripherals | Timers, ADC, communication interfaces |
| Cost | Unit price, development tools cost |
| Development Support | Tools, documentation, community |

- **Application Needs**: Match controller to task complexity
- **Real-time Requirements**: Response time constraints
- **Environmental Factors**: Temperature, noise, vibration
- **Form Factor**: Physical size and packaging
- **Future Expansion**: Room for feature growth

**Mnemonic**

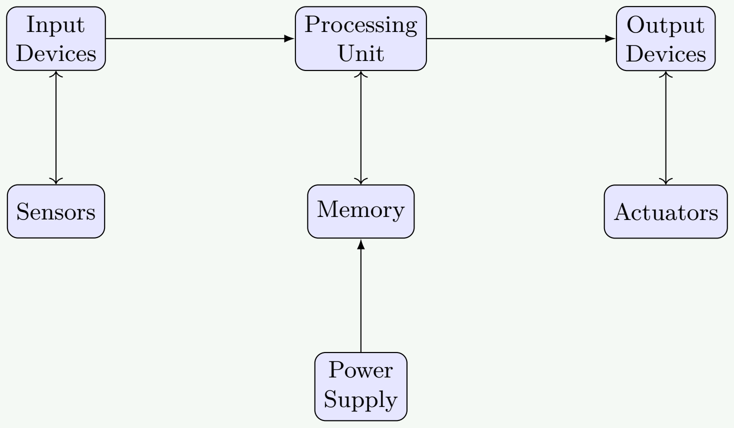
"Power, Memory, I/O, Peripherals, Cost"

## Question 2(a) [3 marks]

**Define embedded system and draw its general block diagram.**

**Solution**

An embedded system is a dedicated computer system designed for specific functions within a larger mechanical or electrical system.
**Diagram:**



- **Processing Unit**: Microcontroller/microprocessor
- **Memory**: Stores program and data
- **Input/Output**: Interfaces with external world

**Mnemonic**

"Processing Memory I/O Power"

## Question 2(b) [4 marks]

**List I/O registers associated with each port.**

**Solution**

AVR microcontrollers have three primary registers for controlling each I/O port.

**Table 3.** I/O Port Registers

| Register | Function | Description |
|---|---|---|
| PORTx | Data Register | Sets output values or pull-ups |
| DDRx | Data Direction Register | Sets pin direction (1=output, 0=input) |
| PINx | Port Input Pins | Reads actual pin status |

- **x represents**: A, B, C, D (port letter)
- **Additional Special**: Some ports have PCMSK (Pin Change Mask) registers

**Mnemonic**

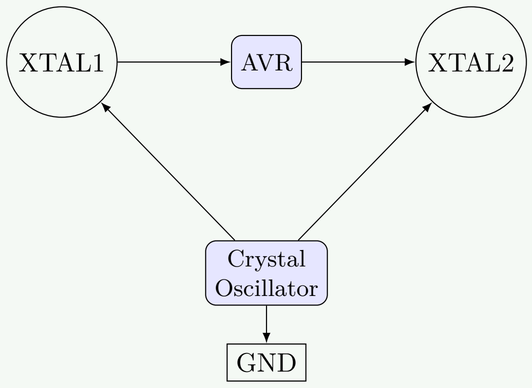
"Direction, Data, Pin reading"

## Question 2(c) [7 marks]

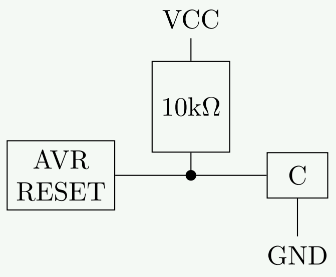
**Explain clock and reset circuit for AVR.**

**Solution**

The clock and reset circuits ensure proper initialization and timing of AVR operations.
**Clock Circuit Diagram:**



**Reset Circuit:**



- **Clock Source**: External crystal, RC oscillator, or internal oscillator
- **Crystal**: Provides accurate timing (1-16 MHz)
- **Reset Pin**: Active-low input for system restart
- **Power-on Reset**: Automatic reset when power applied
- **Brown-out Detection**: Reset if voltage drops below threshold

**Mnemonic**

"Crystal Oscillates, Reset Ensures Start"

## Question 2(a OR) [3 marks]

**Write characteristics of embedded system.**

**Solution**

Embedded systems have unique characteristics that distinguish them from general-purpose computers.

**Table 4.** Embedded System Characteristics

| Characteristic | Description |
|---|---|
| Single-Function | Dedicated to specific tasks |
| Real-time | Predictable response times |
| Resource Constrained | Limited memory, power, processing |
| Reliability | Must operate continuously without fail |
| Reactive | Responds to environmental changes |

- **Long Life**: Often operates for years without intervention
- **Often Hidden**: Integrated within larger systems

**Mnemonic**

"Single, Real-time, Resource-limited, Reliable"

## Question 2(b OR) [4 marks]

**Discuss the role of DDRx in outputting and inputting data.**

**Solution**

DDRx (Data Direction Register) configures each pin of port x as either input or output.

**Table 5.** DDRx Role in I/O Operations

| DDRx Value | PORTx Value | Mode | Function |
|---|---|---|---|
| 0 | 0 | Input | High-impedance mode |
| 0 | 1 | Input | Pull-up enabled |
| 1 | 0 | Output | Output low (0V) |
| 1 | 1 | Output | Output high (VCC) |

- **Direction Control**: 1 = output, 0 = input
- **Pin-specific**: Each bit controls individual pin
- **Initial State**: Default is input (all 0s)

**Mnemonic**

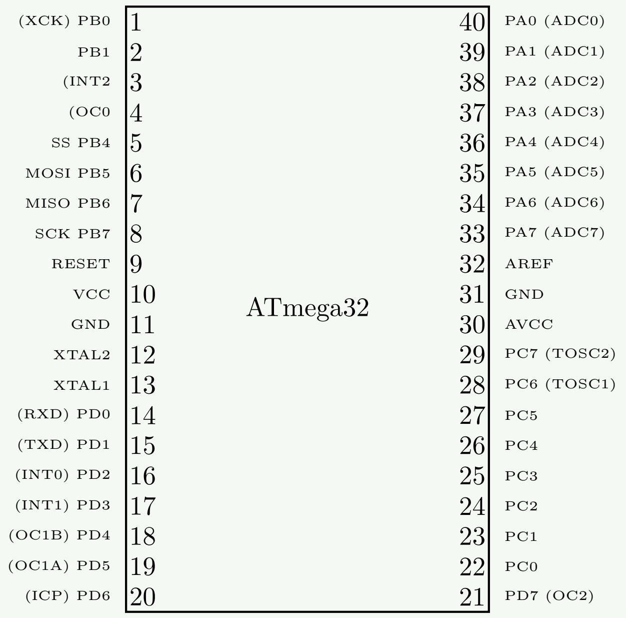
"Direction Determines Data flow"

## Question 2(c OR) [7 marks]

**Draw and explain ATmega32 pin diagram.**

**Solution**

ATmega32 is a popular 8-bit AVR microcontroller with 40 pins providing various functionalities.
**Diagram:**



- **Port A (PA0-PA7)**: 8-bit bidirectional port with ADC inputs
- **Port B (PB0-PB7)**: 8-bit port with SPI, timers, and external interrupts
- **Port C (PC0-PC7)**: 8-bit bidirectional port with TWI support
- **Port D (PD0-PD7)**: 8-bit port with USART, external interrupts, and PWM
- **Power/Ground**: VCC, GND, AVCC, AREF
- **Clock**: XTAL1/XTAL2 for external oscillator
- **Reset**: Active-low reset input

**Mnemonic**

"ABCD Ports Around Power Clock Reset"

## Question 3(a) [3 marks]

**Explain Program Counter (PC) register for ATmega32.**

**Solution**

Program Counter (PC) is a 16-bit register that tracks the address of the next instruction to execute.
**Diagram:**

| | |
|---|---|
| PC High | PC Low |
| 15:8 | 7:0 |

- **Function**: Points to next instruction in program memory
- **Size**: 16-bit (can address up to 64K words)
- **Auto-increment**: Automatically increments after instruction fetch
- **Jump Control**: Modified by branch and jump instructions

**Mnemonic**

"Points to Code Execution"

## Question 3(b) [4 marks]

**Write an AVR C program to read the content of location 0x005F of EEPROM into PORTB.**

**Solution**

**Listing 1.** Read EEPROM to PORTB

```c
#include <avr/io.h>
#include <avr/eeprom.h>

int main(void)
{
    // Set PORTB as output
    DDRB = 0xFF;

    // Read from EEPROM location 0x005F and output to PORTB
    PORTB = eeprom_read_byte((uint8_t*)0x005F);

    while(1) {
        // Main loop
    }
    return 0;
}
```

- **DDRB = 0xFF**: Configure all PORTB pins as outputs
- **eeprom_read_byte()**: AVR library function to read EEPROM
- **while(1)**: Infinite loop to maintain output

**Mnemonic**

"Direction, Read EEPROM, Output to Port"

## Question 3(c) [7 marks]

**Draw and explain TCCR0 register in detail.**

**Solution**

Timer/Counter Control Register 0 (TCCR0) controls the operation of Timer/Counter0.
**Diagram:**

| FOC0 | WGM00 | COM01 | COM00 | WGM01 | CS02 | CS01 | CS00 |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

**Table 6.** TCCR0 Bits Function

| **Bit(s)** | **Name** | **Function** |
|---|---|---|
| 7 | FOC0 | Force Output Compare |
| 6,3 | WGM01:0 | Waveform Generation Mode |
| 5,4 | COM01:0 | Compare Match Output Mode |
| 2,1,0 | CS02:0 | Clock Select |

- **WGM01:0**: Selects Normal, CTC, or PWM modes
- **COM01:0**: Defines OC0 pin behavior on compare match
- **CS02:0**: Sets clock source and prescaler (1, 8, 64, 256, 1024)

**Mnemonic**

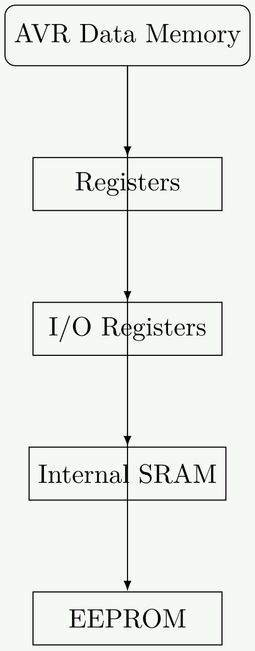
"Forcing Waveforms, Comparing, Selecting Clock"

## Question 3(a OR) [3 marks]

**Explain AVR data memory.**

**Solution**

AVR data memory consists of multiple sections for different types of data storage.
**Diagram:**



- **Registers**: 32 general-purpose registers (R0-R31)
- **I/O Memory**: Special function registers for peripherals
- **SRAM**: Internal RAM for variables (volatile)
- **EEPROM**: Non-volatile memory for persistent data

**Mnemonic**

"Registers I/O SRAM EEPROM"

## Question 3(b OR) [4 marks]

**Write an AVR C program to store 'G' into location 0x005F of EEPROM.**

**Solution**

**Listing 2.** Write to EEPROM

```c
#include <avr/io.h>
#include <avr/eeprom.h>

int main(void)
{
    // Store character 'G' to EEPROM location 0x005F
    eeprom_write_byte((uint8_t*)0x005F, 'G');

    while(1) {
        // Main loop
    }
    return 0;
}
```

- **eeprom_write_byte()**: AVR library function to write to EEPROM
- **'G'**: ASCII value 71 (0x47) stored in EEPROM
- **0x005F**: Target EEPROM address
- **while(1)**: Infinite loop after writing

**Mnemonic**

"Write Once, Remember Forever"

## Question 3(c OR) [7 marks]

### Draw and explain TIFR register in detail.

**Solution**

Timer/Counter Interrupt Flag Register (TIFR) holds flags that indicate timer events.
**Diagram:**

| – | – | – | – | – | OCF2 | TOV2 | TOV0 |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

**Table 7.** TIFR Bits Function

| Bit | Name | Function |
|---|---|---|
| 0 | TOV0 | Timer/Counter0 Overflow Flag |
| 1 | TOV2 | Timer/Counter2 Overflow Flag |
| 2 | OCF2 | Output Compare Flag 2 |
| 3-7 | – | Reserved bits |

- **TOV0**: Set when Timer0 overflows, cleared when ISR executes
- **TOV2**: Set when Timer2 overflows
- **OCF2**: Set when Timer2 compare match occurs
- **Flag Clearing**: Write '1' to bit to clear flag

**Mnemonic**

"Timers Overflow, Comparisons Flag"

## Question 4(a) [3 marks]

### Write different ways of generating delay in AVR.

**Solution**

AVR microcontrollers offer multiple methods to generate time delays.

**Table 8.** Delay Generation Methods

| Method | Description | Precision |
|---|---|---|
| Software Loops | CPU cycles counting | Low |
| Timer Interrupts | Hardware timers with ISR | High |
| Timer Polling | Hardware timers with flag checking | Medium |
| Delay Functions | Library functions (_delay_ms/_delay_us) | Medium |

- **Software**: Simple but affected by optimizations
- **Hardware**: More accurate but requires timer setup
- **Library**: Convenient but limited to constant values

**Mnemonic**

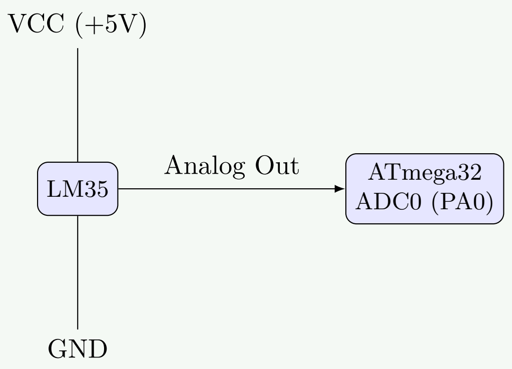
"Loops, Interrupts, Polling, Functions"

## Question 4(b) [4 marks]

### Draw and explain interfacing of LM35 with ATmega32.

**Solution**

LM35 is a temperature sensor that outputs an analog voltage proportional to temperature.
**Circuit Diagram:**



- **Connection**: LM35 output to ADC0 (PA0) of ATmega32
- **Scaling**: 10mV/°C output (0°C = 0V, 25°C = 250mV)
- **ADC Setup**: Configure ADMUX to select ADC0
- **Calculation**: Temperature = (ADC_value × 5 × 100) / 1024

**Mnemonic**

"Analog Voltage Converts Temperature"

## Question 4(c) [7 marks]

### Explain interfacing of MAX7221 with ATmega32 in detail.

**Solution**

MAX7221 is an LED display driver IC that connects to AVR using SPI communication.
**Circuit Diagram:**

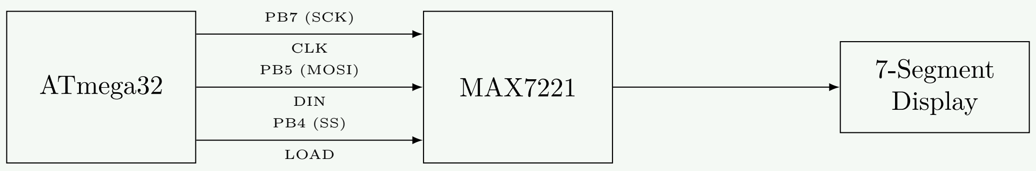


**Table 9.** Connections and Functionality

| ATmega32 Pin | MAX7221 Pin | Function |
|---|---|---|
| PB7 (SCK) | CLK | Serial Clock |
| PB5 (MOSI) | DIN | Data Input |
| PB4 (SS) | LOAD | Chip Select |

- **SPI Mode**: Master mode, MSB first
- **Initialization**: Set decode mode, intensity, scan limit
- **Data Transfer**: Send address byte followed by data byte
- **Multiplexing**: Can drive up to 8 digits
- **Brightness Control**: 16 levels through intensity register

**Mnemonic**

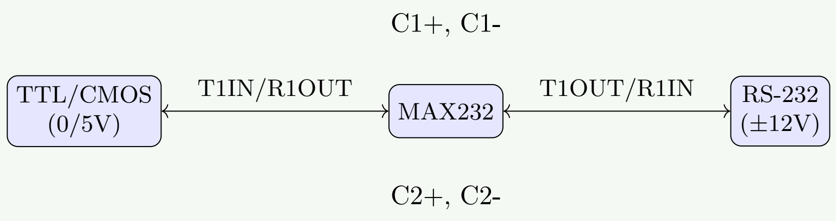
"Send Clock Data Load Display"

## Question 4(a OR) [3 marks]

### Explain MAX232 line driver.

**Solution**

MAX232 is an IC that converts TTL/CMOS logic levels to RS-232 voltage levels for serial communication.
**Diagram:**



- **Voltage Conversion**: TTL (0/5V) to RS-232 (±12V)
- **Charge Pumps**: Uses capacitors to generate required voltages
- **Applications**: Serial communication with PC, modems
- **Bidirectional**: Handles both transmit and receive signals

**Mnemonic**

"TTL To RS-232 Conversion"

## Question 4(b OR) [4 marks]

### Explain ADMUX register.

**Solution**

ADC Multiplexer Selection Register (ADMUX) controls analog input channel selection and result format.
**Diagram:**

| REFS1 | REFS0 | ADLAR | – | MUX3 | MUX2 | MUX1 | MUX0 |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Table 10. ADMUX Bit Functions

| Bits | Name | Function |
|---|---|---|
| 7:6 | REFS1:0 | Reference Selection |
| 5 | ADLAR | ADC Left Adjust Result |
| 3:0 | MUX3:0 | Analog Channel Selection |

- **REFS1:0**: Select voltage reference (AREF, AVCC, Internal)
- **ADLAR**: Result alignment in ADC registers
- **MUX3:0**: Select input channel (ADC0-ADC7)

**Mnemonic**

"Reference, Alignment, Multiplexer"

## Question 4(c OR) [7 marks]

**Discuss Two Wire serial Interface (TWI) in AVR.**

**Solution**

Two Wire Interface (TWI) is AVR's implementation of I$^2$C protocol for communication with peripheral devices.
**Diagram:**

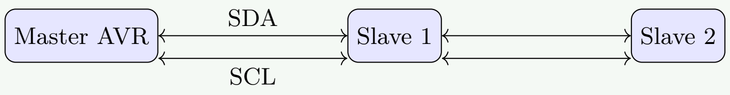


Table 11. TWI Characteristics

| Feature | Description |
|---|---|
| Pins | SCL (Serial Clock) and SDA (Serial Data) |
| Speed | Standard (100kHz), Fast (400kHz) |
| Addressing | 7-bit or 10-bit device addressing |
| Operation | Master or Slave mode |
| Bus Structure | Multi-master, multi-slave |

- **Bidirectional**: Both devices can transmit and receive
- **Registers**: TWBR, TWCR, TWSR, TWDR, TWAR
- **ACK/NACK**: Acknowledgment for reliable transfers
- **Start/Stop**: Special conditions to begin/end transmission
- **Common Uses**: EEPROM, RTC, sensors, displays

**Mnemonic**

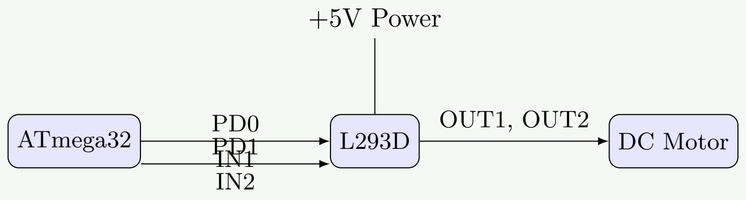
"Serial Clock And Data Transfers"

## Question 5(a) [3 marks]

**Draw circuit diagram to interface DC motor with ATmega32 using L293D motor driver.**

**Solution**

L293D provides bidirectional drive current for controlling DC motors with microcontrollers.
**Circuit Diagram:**



- **Control Pins**: PD0, PD1 control motor direction
- **Driver Power**: Separate for logic and motor
- **H-Bridge**: Enables forward/reverse operation
- **Enable Pin**: Can be used for PWM speed control

**Mnemonic**

"Direction Control Through Bridge"

## Question 5(b) [4 marks]

**Write features of on chip ADC in ATmega32.**

**Solution**

ATmega32 features a versatile analog-to-digital converter for measuring analog signals.

**Table 12.** ATmega32 ADC Features

| **Feature** | **Specification** |
|---|---|
| Resolution | 10-bit |
| Channels | 8 single-ended inputs |
| Conversion Time | 65-260 $\mu$s |
| Reference Voltage | AREF, AVCC, or 2.56V internal |
| Accuracy | $\pm$2 LSB |
| Conversion Modes | Single and Free Running |
| Input Range | 0V to VREF |

- **Successive Approximation**: Conversion technique
- **Multiplexer**: Selects among 8 input channels
- **Interrupt**: Optional interrupt on completion
- **Sampling Rate**: Up to 15 KSPS at maximum resolution

**Mnemonic**

"Multiple Channels, Ten-bit Resolution"

## Question 5(c) [7 marks]

**Explain Smart Irrigation System.**

**Solution**

Smart Irrigation System automates watering based on environmental conditions using microcontroller technology.
**Diagram:**

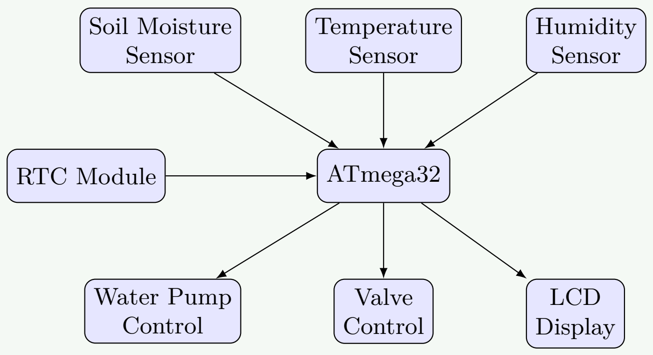


**Table 13.** System Components

| **Component** | **Function** |
|---|---|
| Soil Moisture Sensor | Measures water content in soil |
| Temperature/Humidity | Monitors environmental conditions |
| Water Pump | Delivers water when needed |
| Valves | Controls water flow to different zones |
| LCD Display | Shows system status |
| RTC Module | Tracks time for scheduled irrigation |

- **Adaptive Control**: Adjusts watering based on conditions
- **Water Conservation**: Uses only necessary amount of water
- **Remote Monitoring**: Optional WiFi/GSM connectivity
- **Data Logging**: Records moisture levels and watering events
- **Battery Backup**: Ensures operation during power outages

**Mnemonic**

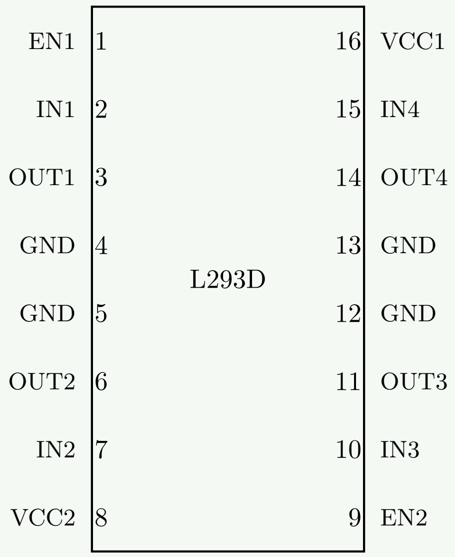
"Sense Moisture, Control Water Automatically"

## Question 5(a OR) [3 marks]

### Draw and explain pin diagram of L293D motor driver IC.

**Solution**

L293D is a quadruple half-H driver IC used for controlling motors and other inductive loads.
**Diagram:**



- **VCC1 (Pin 16)**: Logic supply voltage (5V)
- **VCC2 (Pin 8)**: Motor supply voltage (4.5V-36V)
- **EN1/EN2**: Enable inputs (can be PWM for speed control)
- **IN1-IN4**: Logic inputs to control direction
- **OUT1-OUT4**: Outputs to connect motors
- **GND**: Ground connections

**Mnemonic**

"Enable, Input, Output, Power"

## Question 5(b OR) [4 marks]

**List registers associated with ADC in AVR.**

**Solution**

AVR's ADC system uses several registers to control its operation and store results.

**Table 14.** ADC Registers

| Register | Function | Description |
|---|---|---|
| ADMUX | Multiplexer | Channel selection and reference options |
| ADCSRA | Control & Status | Control bits and flags |
| ADCH | Data High | High byte of conversion result |
| ADCL | Data Low | Low byte of conversion result |
| SFIOR | Special Function | ADC trigger source selection |

- **ADMUX**: Channel and reference selection
- **ADCSRA**: Enable ADC, start conversion, prescaler
- **ADCH/ADCL**: Result registers (10-bit value)
- **SFIOR**: Auto-trigger sources (Timer, External)

**Mnemonic**

"Multiplexer Controls And Delivers Results"

## Question 5(c OR) [7 marks]

### Explain IoT based home automation system.

**Solution**

IoT home automation connects household devices to the internet for remote monitoring and control.
**Diagram:**

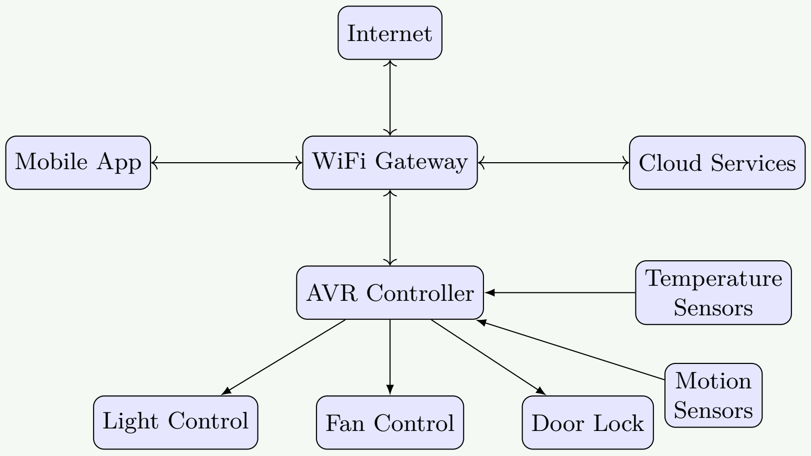


**Table 15.** System Components

| **Component** | **Function** |
|---|---|
| Controller | Processes sensor data and commands |
| Sensors | Monitor environmental conditions |
| Actuators | Control appliances and systems |
| Communication | WiFi/Ethernet/Bluetooth connectivity |
| Gateway | Connects local network to internet |
| Mobile App | User interface for remote control |

- **Remote Access**: Control home from anywhere
- **Scheduling**: Automate device operation based on time
- **Voice Control**: Integration with digital assistants
- **Energy Monitoring**: Track power consumption
- **Security**: Alerts for unusual activities
- **Scene Setting**: One-touch control of multiple devices

**Mnemonic**

"Connect, Control, Automate, Monitor"