# Embedded System & Microcontroller Application (4351102) - Winter 2023 Solution

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## Question 1(a) [3 marks]

**Draw TIFR register and write its full name.**

**Solution**

**Full Name**: Timer/Counter Interrupt Flag Register
**TIFR Register Diagram:**

**Table 1.** TIFR Register

| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|
| OCF2 | TOV2 | ICF1 | OCF1A | OCF1B | TOV1 | OCF0 | TOV0 |

**Bit Descriptions:**
- **TOV0**: Timer0 Overflow Flag
- **OCF0**: Timer0 Output Compare Flag
- **TOV1**: Timer1 Overflow Flag

**Mnemonic**

"Timer Interrupts Flag Register"

## Question 1(b) [4 marks]

**Discuss data memory of ATmega32.**

**Solution**

**Data Memory Organization:**

**Table 2.** Data Memory Map

| Memory Type | Size | Address Range | Purpose |
|---|---|---|---|
| **General Purpose Registers** | 32 bytes | 0x00-0x1F | R0-R31 registers |
| **I/O Memory** | 64 bytes | 0x20-0x5F | Control registers |
| **Internal SRAM** | 2048 bytes | 0x60-0x85F | Variable storage |

- **General Purpose Registers**: Used for arithmetic operations and temporary storage.
- **I/O Memory**: Contains peripheral control and status registers.
- **Internal SRAM**: Used for stack, variables, and dynamic memory allocation.

**Mnemonic**

"General I/O SRAM Memory"

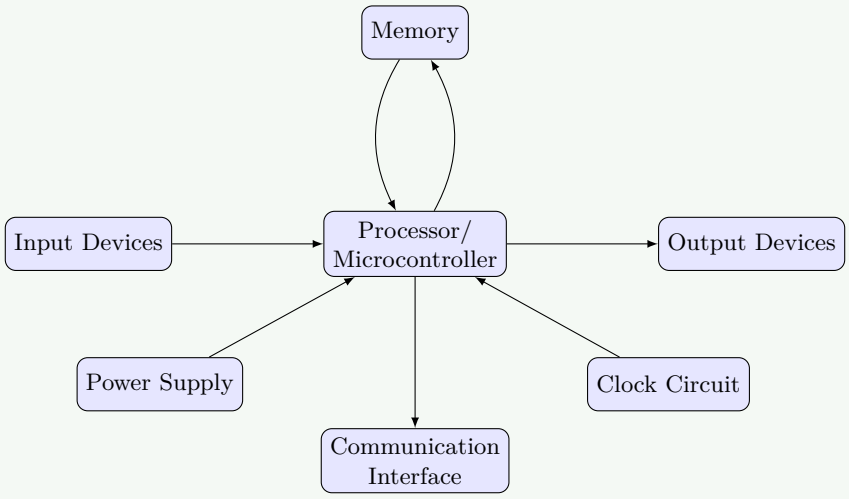
## Question 1(c) [7 marks]

**Draw and explain general block diagram of embedded system.**

**Solution**

**General Block Diagram:**

**Figure 1.** Embedded System Block Diagram




**Component Functions:**

**Table 3.** Component Functions

| Component | Function |
|---|---|
| **Processor** | Controls entire system operation |
| **Memory** | Stores program and data |
| **Input Devices** | Sensors, switches, keyboards |
| **Output Devices** | LEDs, displays, motors |
| **Communication** | UART, SPI, I2C interfaces |

**Characteristics:**

- **Real-time Operation**: System responds to inputs within defined time limits.
- **Dedicated Function**: Designed for specific applications.
- **Resource Constraints**: Limited memory, power, and processing capability.

**Mnemonic**

"Processor Memory Input Output Communication"

**OR**

## Question 1(c) [7 marks]

**Define real time operating system and explain its characteristics.**

**Solution**

**Definition**: **Real Time Operating System (RTOS)** is an operating system that guarantees response within specified time constraints for critical tasks.
**Characteristics:**

**Table 4.** RTOS Characteristics

| Characteristic | Description |
|---|---|
| **Deterministic** | Predictable response times |
| **Multitasking** | Multiple tasks execution |
| **Priority-based** | High priority tasks first |
| **Minimal Latency** | Fast interrupt response |

**Key Concepts:**
- **Hard Real-time**: Missing deadline causes system failure.
- **Soft Real-time**: Performance degrades if deadline missed.
- **Task Scheduling**: Preemptive priority-based scheduling ensures critical tasks run first.

**Mnemonic**

"Deterministic Multitasking Priority Minimal"

## Question 2(a) [3 marks]

**Write Criteria for choosing microcontroller for embedded system.**

**Solution**

**Selection Criteria:**

**Table 5.** Selection Criteria

| Criteria | Importance |
|---|---|
| **Processing Speed** | Match application requirements |
| **Memory Size** | Sufficient ROM/RAM |
| **I/O Pins** | Adequate peripheral interfaces |
| **Power Consumption** | Battery life consideration |
| **Cost** | Budget constraints |
| **Development Tools** | Compiler, debugger availability |

**Mnemonic**

"Speed Memory I/O Power Cost Tools"

## Question 2(b) [4 marks]

**Discuss Harvard Architecture in the AVR.**

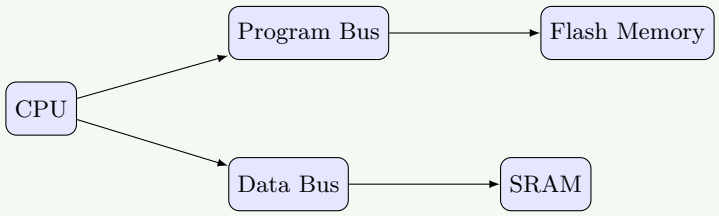
**Solution**

**Harvard Architecture Features:**

**Table 6.** Harvard Architecture

| Feature | Description |
|---|---|
| **Separate Buses** | Program and data have independent buses |
| **Simultaneous Access** | Can fetch instruction and access data simultaneously |
| **Different Memory Types** | Flash for program, SRAM for data |

**Figure 2.** Harvard Architecture




- **Advantage**: Higher performance due to parallel access.
- **16-bit Instructions**: Most instructions execute in single clock cycle.

**Mnemonic**

"Separate Simultaneous Different Performance"

## Question 2(c) [7 marks]

**Discuss different ways of connecting clock sources to the AVR.**

**Solution**

**Clock Sources:**

**Table 7.** Clock Source Types

| Clock Source | Frequency Range | Application |
|---|---|---|
| **External Crystal** | 1-16 MHz | High accuracy applications |
| **External RC** | 1-8 MHz | Cost-effective solution |
| **Internal RC** | 1-8 MHz | Default, no external components |
| **External Clock** | Up to 16 MHz | Synchronized systems |

**Clock Selection via Fuse Bits:**

- **CKSEL3:0**: Bits determine clock source.
- **CKDIV8**: Bit divides clock by 8.
- **SUT1:0**: Bits set startup time.

**Descriptions:**

- **Crystal Oscillator**: Most stable, requires external crystal and capacitors.
- **RC Oscillator**: Less accurate but cheaper.
- **Internal Oscillator**: Factory calibrated, temperature dependent.

**Mnemonic**

"Crystal RC Internal External"

**OR**

# Question 2(a) [3 marks]

**Write size of code ROM, SRAM and EEPROM, Number of I/O pins, ADC and Timers for ATmega32.**

**Solution**

**ATmega32 Specifications:**

**Table 8.** Device Specifications

| Specification | ATmega32 |
|---|---|
| **Flash ROM** | 32 KB |
| **SRAM** | 2 KB |
| **EEPROM** | 1 KB |
| **I/O Pins** | 32 pins |
| **ADC Channels** | 8 channels |
| **Timers** | 3 timers |

**Mnemonic**

"32K Flash 2K SRAM 1K EEPROM 32 I/O 8 ADC 3 Timers"

**OR**

# Question 2(b) [4 marks]

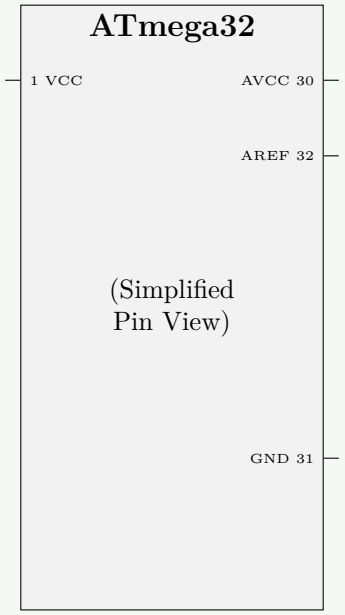
**Draw ATmega32 pin diagram and write function of Vcc, AVcc and Aref pin.**

**Solution**

**ATmega32 Pin Functions:**

**Table 9.** Pin Functions

| Pin | Function |
|---|---|
| **Vcc** | Main power supply (+5V) |
| **AVcc** | Analog power supply for ADC |
| **Aref** | ADC reference voltage |




- **Vcc**: Supplies power to digital circuits.
- **AVcc**: Separate supply for ADC to reduce noise.
- **Aref**: External reference for ADC conversion.

**Mnemonic**

"Vcc Digital AVcc Analog Aref Reference"

**OR**

## Question 2(c) [7 marks]

**Explain AVR status register in detail.**

**Solution**

**SREG (Status Register) Bits:**

**Table 10.** SREG Bits

| Bit | Name | Function |
|---|---|---|
| 7 | I | Global Interrupt Enable |
| 6 | T | Bit Copy Storage |
| 5 | H | Half Carry Flag |
| 4 | S | Sign Flag |
| 3 | V | Overflow Flag |
| 2 | N | Negative Flag |
| 1 | Z | Zero Flag |
| 0 | C | Carry Flag |

**Table 11.** SREG Layout

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

**Bit Details:**
- **I Flag**: Controls global interrupt enable/disable.
- **Arithmetic Flags**: C, Z, N, V, S, H updated after ALU operations.
- **T Flag**: Used by BLD and BST instructions for bit manipulation.

**Mnemonic**

"I Transfer Half Sign oVerflow Negative Zero Carry"

## Question 3(a) [3 marks]

**Explain RESET circuit for the AVR microcontroller.**

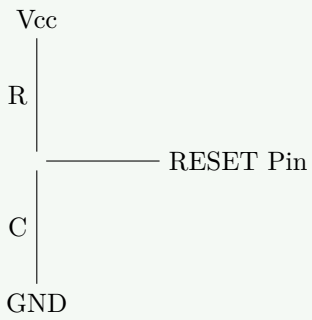
**Solution**

**Reset Sources:**

**Table 12.** Reset Sources

| Reset Source | Description |
|---|---|
| **Power-on Reset** | When power is applied |
| **External Reset** | Through RESET pin |
| **Brown-out Reset** | When voltage drops |
| **Watchdog Reset** | Watchdog timer overflow |

**Reset Circuit:**




- **Reset Duration**: Minimum 2 clock cycles.
- **Reset Vector**: Program starts from address 0x0000.

**Mnemonic**

"Power External Brown-out Watchdog"

## Question 3(b) [4 marks]

**List I/O registers associated with EEPROM. Write programming steps to write data on EEPROM.**

**Solution**

**EEPROM Registers:**

**Table 13.** EEPROM Registers

| Register | Function |
|---|---|
| **EEAR** | EEPROM Address Register |
| **EEDR** | EEPROM Data Register |
| **EECR** | EEPROM Control Register |

**Programming Steps:**

1. Wait for previous write to complete (check **EEWE** bit).
2. Set address in **EEAR** register.
3. Set data in **EEDR** register.
4. Set **EEMWE** bit in **EECR**.
5. Set **EEWE** bit within 4 clock cycles.

**Mnemonic**

"Wait Address Data Master-Write Enable-Write"

## Question 3(c) [7 marks]

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

**Solution**

**TCCR0 (Timer/Counter0 Control Register):**

**Table 14.** TCCR0 Bits

| Bit | Name | Function |
|---|---|---|
| 7 | FOC0 | Force Output Compare |
| 6,3 | WGM01/00 | Waveform Generation Mode |
| 5,4 | COM01/00 | Compare Output Mode |
| 2,1,0 | CS02/01/00 | Clock Select |

**Table 15.** TCCR0 Layout

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

**Clock Select Options:**

- **000**: No clock (Timer stopped)
- **001**: clk/1 (No prescaling)
- **010**: clk/8, **011**: clk/64
- **100**: clk/256, **101**: clk/1024

**Mnemonic**

"Force Waveform Compare Clock Select"

**OR**

# Question 3(a) [3 marks]

**List registers associated with Timer 1.**

**Solution**

**Timer1 Registers:**

**Table 16.** Timer1 Registers

| Register | Function |
|---|---|
| **TCCR1A** | Timer1 Control Register A |
| **TCCR1B** | Timer1 Control Register B |
| **TCNT1H/L** | Timer1 Counter Register |
| **OCR1AH/L** | Output Compare Register A |
| **OCR1BH/L** | Output Compare Register B |
| **ICR1H/L** | Input Capture Register |

**Mnemonic**

"Control Counter Output-Compare Input-Capture"

**OR**

# Question 3(b) [4 marks]

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

**Solution**

**Program:**

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

void eeprom_write_byte_custom(uint16_t addr, uint8_t data)
{
    while(EECR & (1<<EEWE));  // Wait for previous write
    EEAR = addr;              // Set address
    EEDR = data;              // Set data
    EECR |= (1<<EEMWE);       // Master write enable
    EECR |= (1<<EEWE);        // Write enable
}

int main()
{
    eeprom_write_byte_custom(0x005F, 'G');
    return 0;
}
```

**Program Steps:**

- Check **EEWE** bit for completion.
- Load address `0x005F` into **EEAR**.
- Load 'G' (ASCII 71) into **EEDR**.
- Enable master write, then write enable.

**Mnemonic**

"Wait Address Data Master Write"

**OR**

## Question 3(c) [7 marks]

**Write a C program to toggle only the PORTB.4 bit continuously every 70 $\mu$s. Use Timer0, Normal mode, and 1:8 prescaler to create the delay. Assume XTAL = 8 MHz.**

**Solution**

**Calculation:**

- **Clock** = 8MHz/8 = 1MHz (1$\mu s$ period).
- For 70$\mu s$: **Count** = 70 cycles.
- **Initial value** = 256 − 70 = 186.

**Program:**

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

int main()
{
    DDRB |= (1<<4);           // Set PB4 as output
    TCCR0 = 0x02;             // Prescaler 1:8

    while(1)
    {
        TCNT0 = 186;          // Load initial value
        while(!(TIFR & (1<<TOV0))); // Wait for overflow
        TIFR |= (1<<TOV0);    // Clear flag
        PORTB ^= (1<<4);      // Toggle PB4
    }
    return 0;
}
```

**Mnemonic**

"Direction Control Count Wait Clear Toggle"

## Question 4(a) [3 marks]

**Write an AVR C program to monitor bit 5 of port C. If it is HIGH, send 55H to Port B; otherwise, send AAH to Port B.**

**Solution**

**Program:**

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

int main()
{
    DDRC &= ~(1<<5);          // PC5 as input
    DDRB = 0xFF;              // Port B as output

    while(1)
```

```
    {
        if(PINC & (1<<5))      // Check PC5
            PORTB = 0x55;      // Send 55H if HIGH
        else
            PORTB = 0xAA;      // Send AAH if LOW
    }
    return 0;
}
```

**Program Logic:**

- Configure PC5 as input, Port B as output.
- Continuously check PC5 status using bitwise AND.
- Output `0x55` or `0xAA` based on input.

**Mnemonic**

"Direction Check Output"

## Question 4(b) [4 marks]

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

**Solution**

**LM35 Interface:**

**Figure 3.** LM35 Connection

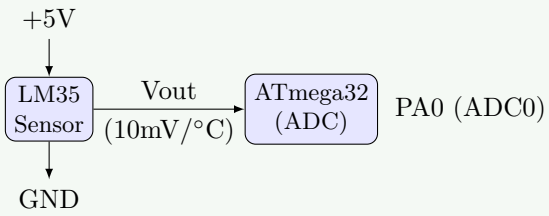



**Table 17.** Connection Details

| LM35 Pin | ATmega32 Pin | Function |
|---|---|---|
| Vcc | +5V | Power supply |
| Output | PA0 (ADC0) | Analog voltage |
| GND | GND | Ground |

**Specifications:**

- **Temperature Conversion**: 10mV/°C output.
- **ADC Resolution**: 10-bit (0-1023).
- **Voltage Range**: 0V to 5V (0°C to 500°C).

**Mnemonic**

"Power Output Ground Temperature"

## Question 4(c) [7 marks]

**Draw and explain interfacing of MAX7221 with ATmega32.**

**Solution**

**MAX7221 Interface:**

**Figure 4.** MAX7221 Connection

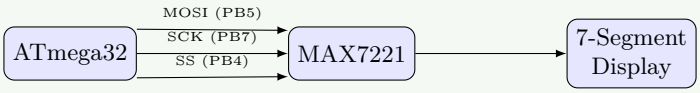



**Table 18.** Pin Connections

| MAX7221 Pin | ATmega32 Pin | Function |
|---|---|---|
| DIN | MOSI (PB5) | Serial data input |
| CLK | SCK (PB7) | Serial clock |
| LOAD | SS (PB4) | Chip select |

**Features:**

- **SPI Interface**: Serial communication protocol.
- **8-Digit Display**: Controls up to 8 common-cathode seven-segment displays.
- **Built-in Decoder**: BCD to seven-segment conversion.
- **Brightness Control**: 16 intensity levels via register.

**Programming Steps:**

1. Initialize SPI in master mode.
2. Send address and data bytes.
3. Pulse LOAD signal to latch data.

**Mnemonic**

"Serial Clock Load Display"

**OR**

## Question 4(a) [3 marks]

**Write an AVR C program to get a byte of data from Port B, and then send it to Port C.**

**Solution**

**Program:**

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

int main()
{
    DDRB = 0x00;              // Port B as input
    DDRC = 0xFF;              // Port C as output

    unsigned char data;

    while(1)
    {
        data = PINB;          // Read from Port B
        PORTC = data;         // Send to Port C
    }
    return 0;
}
```

**Program Function:**

- Configure Port B as input, Port C as output.
- Continuously read from **PINB** and write to **PORTC**.

**Mnemonic**

"Input Output Read Write"

**OR**

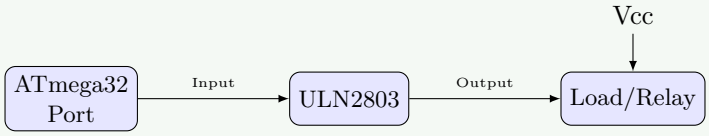
## Question 4(b) [4 marks]

**Draw and explain interfacing of ULN2803 with ATmega32.**

**Solution**

**ULN2803 Interface:**

**Figure 5.** ULN2803 Connection




**ULN2803 Features:**
- **8 Darlington Arrays**: High current switching.
- **Input Current**: 500$\mu$A typical.
- **Output Current**: 500mA per channel.
- **Built-in Flyback Diodes**: Inductive load protection.

**Operation**:
- **Application**: Drive relays, motors, solenoids.
- **Active Low Output**: Output goes low (sinks current) when input is high.

**Mnemonic**

"Darlington Current Protection Drive"

**OR**

## Question 4(c) [7 marks]

**Discuss registers used to program SPI in the AVR.**

**Solution**

**SPI Registers:**

**Table 19.** SPI Register Summary

| Register | Bits | Function |
|---|---|---|
| **SPCR** | SPE, DORD, MSTR, CPOL | SPI Control Register |
| **SPSR** | SPIF, WCOL, SPI2X | SPI Status Register |
| **SPDR** | - | SPI Data Register |

**SPCR Register Bits:**

- **SPE**: SPI Enable.
- **DORD**: Data Order (MSB/LSB first).
- **MSTR**: Master/Slave Select.
- **CPOL**: Clock Polarity.
- **CPHA**: Clock Phase.

**SPSR Register Bits:**

- **SPIF**: SPI Interrupt Flag.
- **WCOL**: Write Collision Flag.
- **SPI2X**: Double Speed Mode.

**Programming Sequence:**

1. Configure SPI pins as input/output.
2. Set SPCR register for desired mode.
3. Write data to SPDR.
4. Wait for SPIF flag.
5. Read received data from SPDR.

**Mnemonic**

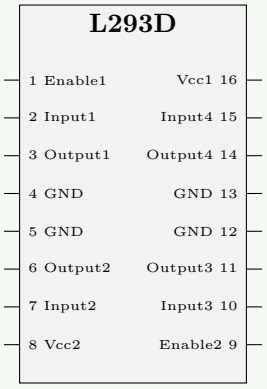
"Control Status Data Enable Order Master"

## Question 5(a) [3 marks]

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

**Solution**

**L293D Pinout:**




**Pin Functions:**

- **1A, 2A**: Input signals for Motor 1.
- **1Y, 2Y**: Output to Motor 1.
- **1EN, 2EN**: Enable pins for motors.
- **Vcc1**: Logic supply (+5V).
- **Vcc2**: Motor supply (+12V).

**Mnemonic**

"Input Output Enable Logic Motor Supply"

## Question 5(b) [4 marks]

**Draw and explain ADMUX register.**

**Solution**

**ADMUX (ADC Multiplexer Selection Register):**

**Table 20.** ADMUX Register

| Bit | Name | Function |
|---|---|---|
| 7,6 | REFS1/0 | Reference Selection |
| 5 | ADLAR | ADC Left Adjust Result |
| 4-0 | MUX4-0 | Analog Channel Selection |

**Table 21.** ADMUX Bits

| REFS1 | REFS0 | ADLAR | MUX4 | MUX3 | MUX2 | MUX1 | MUX0 |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

**Reference Selection (REFS1:0):**
- **00**: AREF pin.
- **01**: AVcc with external capacitor.
- **11**: Internal 2.56V reference.

**Channel Selection**: MUX bits select ADC0-ADC7 channels.

**Mnemonic**

"Reference Adjust Multiplexer Channel"

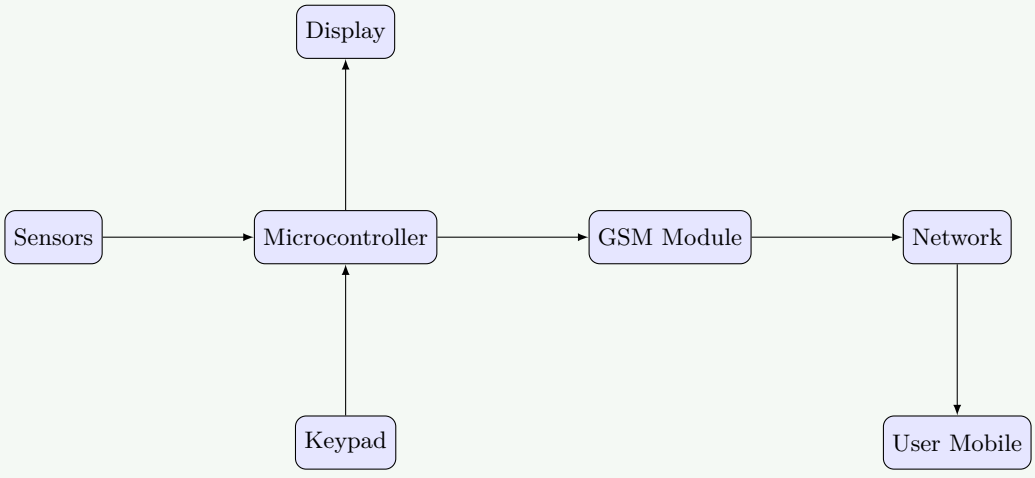
## Question 5(c) [7 marks]

**Explain GSM based security system.**

**Solution**

**GSM Security System:**

**Figure 6.** GSM Security Block Diagram




**System Components:**
- **Sensors**: PIR (motion), Door (entry) detection.
- **GSM Module**: SMS/Call communication.
- **Microcontroller**: System control and processing.
- **Keypad/Display**: User interface for status and control.

**Working Principle:**
1. Sensors detect intrusion.
2. Microcontroller processes signal.
3. GSM module sends SMS alert ("Intruder Detected").
4. User receives notification and can respond remotely.

**Features:** Remote monitoring, multiple sensors, automatic alerts.

**Mnemonic**

"Sensors Process Communicate Alert Control"

**OR**

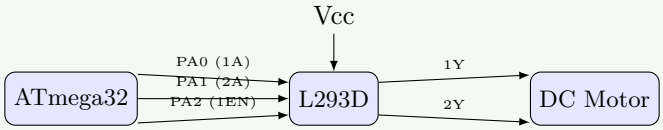
## Question 5(a) [3 marks]

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

**Solution**

**DC Motor Interface:**

**Figure 7.** L293D DC Motor Interface




**Connection Details:**
- **PA0** to Input 1A.
- **PA1** to Input 2A.
- **PA2** to Enable 1EN.

**Control Logic:**
- **Clockwise**: PA0=1, PA1=0.
- **Counter-Clockwise**: PA0=0, PA1=1.
- **Stop**: PA2=0.

**Mnemonic**

"Direction Enable Control Stop"

**OR**

## Question 5(b) [4 marks]

**Draw and explain ADCSRA register.**

**Solution**

**ADCSRA (ADC Control and Status Register A):**

**Table 22.** ADCSRA Register

| Bit | Name | Function |
|---|---|---|
| 7 | ADEN | ADC Enable |
| 6 | ADSC | ADC Start Conversion |
| 5 | ADATE | ADC Auto Trigger Enable |
| 4 | ADIF | ADC Interrupt Flag |
| 3 | ADIE | ADC Interrupt Enable |
| 2-0 | ADPS2-0 | ADC Prescaler Select |

**Table 23.** ADCSRA Layout

| ADEN | ADSC | ADATE | ADIF | ADIE | ADPS2 | ADPS1 | ADPS0 |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

**Prescaler Selection:**
- **000, 001**: Division factor 2.
- **010**: Division factor 4.
- **011**: Division factor 8.

**ADC Operation:**
1. Set **ADEN** to enable ADC.
2. Set **ADSC** to start conversion.
3. Wait for **ADIF** flag.
4. Read result from **ADCH:ADCL**.

**Mnemonic**

"Enable Start Auto Interrupt Prescaler"

**OR**

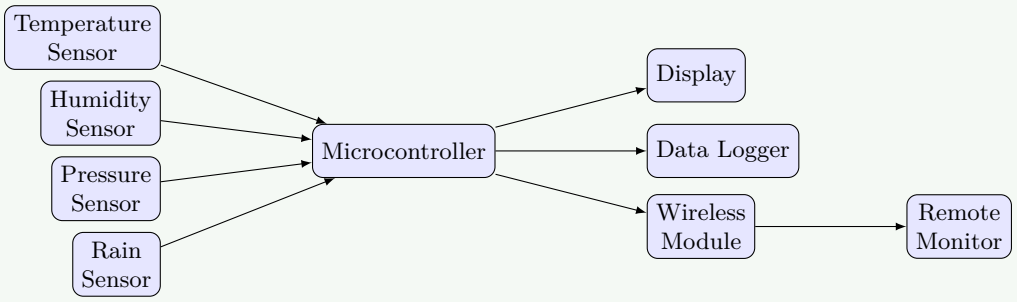
## Question 5(c) [7 marks]

**Explain Weather monitoring system.**

**Solution**

**Weather Monitoring System:**

**Figure 8.** Weather Monitoring Block Diagram




**System Components:**

**Table 24.** Sensor Components

| Sensor | Parameter | Interface |
|---|---|---|
| **LM35** | Temperature | Analog (ADC) |
| **DHT11** | Humidity | Digital |
| **BMP180** | Pressure | I2C |
| **Rain Sensor** | Precipitation | Digital |

**Features:**

- **Multi-parameter Monitoring**: Temperature, humidity, pressure, rainfall.
- **Data Logging**: Store readings in EEPROM/SD card.
- **Real-time Display**: LCD shows current readings.
- **Wireless Communication**: WiFi/GSM for remote monitoring.
- **Alert System**: Threshold-based warnings.

**Applications:**

- Agricultural monitoring
- Weather forecasting
- Environmental research
- Smart home automation

**System Benefits:**

- **Automated Data Collection**: Continuous monitoring.
- **Remote Access**: View data from anywhere.
- **Historical Analysis**: Trend identification.
- **Early Warning**: Extreme weather alerts.

**Mnemonic**

"Temperature Humidity Pressure Rain Display Log Wireless"