# Smart Home

## 1. Project Overview

### 1.1. Introduction

The Smart Room Automation System (SRAS) is an embedded solution designed to centrally manage and automate household appliances across multiple rooms. It utilizes a two-microcontroller architecture (Master/Slave) connected via Serial Peripheral Interface (SPI) to ensure modularity, scalability, and robust control over various devices and environmental factors.

### 1.2. Goals

- Enable centralized ON/OFF control for lights, fans, and TV across four rooms.
- Implement secure access control via **Admin** and **Guest** modes (Keypad login).
- Automate central air conditioning based on real-time temperature monitoring (LM35 sensor).
- Provide persistence by saving and restoring device states using EEPROM memory upon power cycle.
- Control the main home door (Servo Motor) via authenticated commands.

### 1.3. Scope ofi Delivery

This document details the hardware mapping, communication protocol, and software logic required for the Master (User Interface & Logic) and Slave (Actuator Control) ATMEGA32 microcontrollers.

## 2. System Architecture

The system is partitioned into two main units: the **Master Control Unit (MCU)**, which handles all user interaction and central logic, and the **Slave Control Unit (SCU)**, which interfaces directly with the controlled devices (actuators).

### 2.1. System Block Diagram

The following diagram illustrates the interconnection of major system components.

| Component | Connected to | Function |
|---|---|---|
| **ATMEGA32 (Master)** | Keypad, LCD, SPI (SCK, MOSI, SS) | User input, central logic, command dispatch. |
| **ATMEGA32 (Slave)** | SPI (SCK, MISO, SS), Room Modules, TV, Door, AC Relay | Actuator control and status reporting. |
| **4x4 Keypad** | Master MCU | User input, command entry, login credentials. |
| **LM044L LCD** | Master MCU | Status display, temperature, device feedback, login prompts. |
| **LM35 Sensor** | Master MCU (ADC) | Reads ambient temperature for AC control. |
| **EEPROM** | Master/Slave (Internal) | Device state persistence. |
| **Actuators (LEDs/Motors)** | Slave MCU (via L293D/Relays) | Controlled devices (Lights, Fans, TV, Door). |

## 2.2. Master/Slave Roles

| Role | Responsibility | Interfacing Highlights |
|---|---|---|
| **Master MCU (Logic/UI)** | Processes Keypad input, manages login state (Admin/Guest), reads temperature (LM35/ADC), formats control commands, and transmits data via SPI. | Keypad, LCD, LM35 (ADC), SPI Master |
| **Slave MCU (Actuator/IO)** | Receives SPI commands, controls all output devices (Lights, Fans via L293D, TV, Door Servo), and reports back status (if needed). | SPI Slave, Room Modules (L293D), Servo Motor, AC Relay |

# 3. Hardware Implementation and Pin Assignment

## 3.1. SPI Communication Protocol

The two ATMEGA32 microcontrollers are hard-wired in an SPI configuration.

| Signal | Master Pin | Slave Pin | Description |
|---|---|---|---|
| **MOSI** (Master Out, Slave In) | PORTB.5 | PORTB.5 | Data line (Master -> Slave) |
| **MISO** (Master In, Slave Out) | PORTB.6 | PORTB.6 | Data line (Slave -> Master) - Primarily used for status ACK |
| **SCK** (Serial Clock) | PORTB.7 | PORTB.7 | Clock signal generated by Master |
| **SS** (Slave Select) | PORTB.4 | PORTB.4 | Active Low signal to enable Slave |

## 3.2. Master MCU Pinout (Summary)

| Peripheral | Port/Pin | Purpose |
|---|---|---|
| **Keypad** | PORTA (4 Rows, 4 Cols) | Input for commands and login. |
| **LCD (LM044L)** | PORTC (Data), PORTB.0, B.1, B.2 (RS, RW, E) | Display system status. |
| **LM35 Sensor** | **PORTA.0 (ADC0)** | Analog input for temperature reading. |
| **SPI Interface** | PORTB.4, B.5, B.6, B.7 | Communication with Slave MCU. |
| **Mode LEDs** | PORTD.0 (Admin), PORTD.1 (Guest) | Visual indication of active access mode. |

### 3.3. Slave MCU Pinout (Summary)

| Peripheral | Port/Pin | Purpose |
|---|---|---|
| **Room 1 Light** | PORTD.0 | Output (Controlled by SPI Command) |
| **Room 1 Fan (L293D)** | PORTC.0 (IN1), PORTC.1 (IN2), PORTC.2 (Enable/PWM) | Motor control (Speed/ON/OFF) |
| **Room 2 Light** | PORTD.1 | Output (Controlled by SPI Command) |
| **Room 2 Fan (L293D)** | PORTC.3 (IN1), PORTC.4 (IN2), PORTC.5 (Enable/PWM) | Motor control (Speed/ON/OFF) |
| **TV Control (LED)** | PORTD.2 | TV ON/OFF status. |
| **AC System Relay** | PORTD.3 | Central AC ON/OFF control. |
| **Home Door (Servo)** | PORTB.3 (OC0 - PWM) | Door position control (0° Closed, 90° Open). |
| **SPI Interface** | PORTB.4, B.5, B.6, B.7 | Communication with Master MCU. |

# 4. Software Design and Communication Protocol

## 4.1. Core State Machine (Master MCU)

The Master MCU operates primarily on a state machine:

1. **STARTUP:** Initialize peripherals (LCD, Keypad, SPI, ADC, EEPROM). Load initial states from EEPROM. Display Welcome Message.
2. **LOGIN_MODE:** Prompt user for credentials. Accept 4-digit PIN.
3. **VALIDATION:** Check PIN against stored Admin/Guest PINs.
4. **ADMIN_MODE / GUEST_MODE:** Main operation loop. Process keypad input, execute local logic (LM35 check), and dispatch SPI commands.
5. **LOGOUT:** Return to LOGIN_MODE.

## 4.2. EEPROM Persistence Logic

- **Storage Location:** A dedicated block of addresses in the internal EEPROM is reserved to store the operational state (ON/OFF status) of all controlled devices (Lights, Fans, TV, AC).
- **Write Logic (Master/Slave):** When a device state changes (e.g., Light ON), the responsible MCU (Master for AC setpoint, Slave for light/fan status) *immediately* writes the new state (e.g., 0x01 for ON, 0x00 for OFF) to the corresponding EEPROM address.
- **Read Logic (Startup):** During the **STARTUP** phase, both MCUs read their respective EEPROM addresses to restore the last known device states and set the output ports accordingly.

## 4.3. SPI Communication Protocol (Crucial)

To ensure reliable control, a fixed 1-byte command protocol is defined for Master-to-Slave communication.

**Command Byte Format (8 bits):** [D7] [D6] [D5] [D4] [D3] [D2] [D1] [D0]

| Bit(s) | Function / Field | Value/Description |
|---|---|---|
| **D7, D6** | **Device Select (DS)** | 00: Lights |
| | | 01: Fans (Speed/Toggle) |
| | | 10: Global Devices (TV/Door/AC) |
| | | 11: Reserved for future use |
| **D5, D4** | **Room Select (RS)** | 00: Room 1 |
| | | 01: Room 2 |
| | | 10: Room 3 |
| | | 11: Room 4 |
| **D3** | **Action Type (AT)** | 0: ON/OFF Toggle |
| | | 1: Speed/Position Sefling (D0-D2 define the level) |
| **D2, D1, D0** | **Action Data (AD)** | **If AT=0 (Toggle):** 001 = ON, 000 = OFF. |

| | | |
|---|---|---|
| | | **If AT=1 (Set Level):** 000 to 111 (8 levels/positions, e.g., Fan Speed 1-8 or Door 0°-90°). |

**Example Commands:**

1. **Turn Room 2 Light ON:**
   - DS (00=Light), RS (01=Room 2), AT (0=Toggle), AD (001=ON)
   - **Command Byte:** 00 01 0 001 (Binary: 00010001, Hex: 0x11)
2. **Set Room 3 Fan to Medium Speed (Level 4):**
   - DS (01=Fan), RS (10=Room 3), AT (1=Set Level), AD (100=Level 4)
   - **Command Byte:** 01 10 1 100 (Binary: 01101100, Hex: 0x6C)
3. **Unlock Home Door (Set Position to 90° - Max Level 7):**
   - DS (10=Global), RS (00=Door/AC (use Room 1 slot as default/dummy)), AT (1=Set Level), AD (111=Max Pos)
   - **Command Byte:** 10 00 1 111 (Binary: 10001111, Hex: 0x8F)

# 5. Subsystem Details

## 5.1. Central Air Conditioning (AC) Control

The AC system is controlled by the **Master MCU** based on the LM35 sensor reading and a user-defined setpoint (stored in EEPROM).

- **Sensor Reading:** LM35 is connected to ADC0. The Master converts the 10-bit ADC value to degrees Celsius.$$T \text{ (in }^\circ\text{C)} = \frac{\text{ADC Reading}}{1024} \times \frac{V_{\text{REF}}}{\text{Sensitivity}}$$
  *(Assuming* $V_{\text{REF}} = 5V$ *and LM35 sensitivity* $= 10mV/^\circ\text{C}$*)*
- **Logic:** The Master periodically checks the temperature.
  - If $T > T_{\text{Setpoint}} + \text{Hysteresis}$, the Master sends the AC_ON command (0x81) via SPI.
  - If $T < T_{\text{Setpoint}} - \text{Hysteresis}$, the Master sends the AC_OFF command (0x80) via SPI.

## 5.2. Access Control (Admin/Guest Modes)

| Feature | Admin Mode | Guest Mode |
|---|---|---|
| **Lights/Fans** | Full Control (Toggle, Speed) | Limited Control (Toggle only, no speed change) |
| **TV** | Full ON/OFF Control | Read-Only Status |

| | | |
|---|---|---|
| **Home Door** | Open/Close (Requires PIN entry confirmation) | No Access |
| **AC Setpoint** | Adjust Setpoint and Enable/Disable Auto Mode | Read-Only Setpoint |
| **System Configuration** | Change Admin/Guest PINs | No Access |

### 5.3. Home Door (Servo Motor)

The door is controlled by a servo motor connected to the Slave MCU, utilizing a PWM signal generated via Timer/Counter 0 (or similar).

- **Positions:**
  - Closed: 0° (PWM value corresponding to 1ms pulse width)
  - Open: 90° (PWM value corresponding to 1.5ms pulse width - *this value will be mapped to the AD=111 level in the protocol*).
- **Security:** The door operation command is only accepted if the system is in **Admin Mode** and often requires a secondary confirmation/PIN entry at the Keypad.

## 6. System Restoration and Testing

### 6.1. Restoration Procedure

1. Power-up MCUs.
2. Both Master and Slave MCUs execute initial EEPROM read.
3. The Slave MCU sets its output ports (Lights, Fans, TV, AC Relay) according to the values retrieved from EEPROM.
4. The Master MCU displays the restored status on the LCD and initiates the **LOGIN_MODE**.

### 6.2. Testing & Validation Checklist

| Test Case | Description | Expected Result | Pass/Fail |
|---|---|---|---|
| **TC-01** | Full Power Cycle (Remove/Reapply Power) | All device states (Lights, Fans, TV) are restored to their last known state on the Slave MCU. | |
| **TC-02** | Admin Login | System enters ADMIN_MODE, Admin LED | |

| | | | |
|---|---|---|---|
| | | illuminates, full control is enabled. | |
| **TC-03** | Guest Login | System enters GUEST_MODE, Guest LED illuminates, Fan Speed control is restricted. | |
| **TC-04** | Temperature Control Check | If LM35 reading is $>$ Setpoint, AC turns ON (Slave receives 0x81). If reading is $<$ Setpoint, AC turns OFF (Slave receives 0x80). | |
| **TC-05** | SPI Integrity (Room 4 Light ON) | Master sends 0x31. Slave toggles PORTD.3 (Room 4 Light) ON and updates internal EEPROM. | |
| **TC-06** | Door Control Check (Admin) | Master sends 0x8F. Slave executes Servo PWM for 90° (Open). | |

# 7. Configuration Details

| **Parameter** | **Value** | **Location/Storage** |
|---|---|---|
| **Admin PIN** | 1234 (Default) | EEPROM Address 0x00 - 0x03 (Master) |
| **Guest PIN** | 0000 (Default) | EEPROM Address 0x04 - 0x07 (Master) |

| | | |
|---|---|---|
| **AC Setpoint** | 24°C (Default) | EEPROM Address 0x08 (Master) |
| **AC Hysteresis** | 1°C | Master MCU Code (Macro) |
| **System Clock** | 8 MHz (Default Internal RC) | ATMEGA32 Fuses |

# 8. Code Snippets (Reference)

The following C code snippets illustrate key functional components within the Master and Slave firmware.

## 8.1. Master MCU: ADC Conversion for LM35 (Section 5.1)

This function reads the 10-bit ADC value from the LM35 sensor (connected to ADC0) and converts it into temperature in degrees Celsius.