Touch and Remote-Control Home Automation System

Design, Embedded Hardware Interfacing, and Wireless Switching Architecture Using Arduino Nano, HC-05 Bluetooth Transceiver, and Four-Channel Relay Module

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ABSTRACT

Conventional residential electrical wiring relies on fixed mechanical wall switches that require physical proximity and lack remote accessibility, posing inconvenience for elderly or mobility-impaired occupants and hindering proactive energy conservation. This research paper presents the design, circuit architecture, and implementation of a cost-effective **Touch and Remote Control Home Automation System** engineered around an 8-bit **Arduino Nano** microcontroller, an **HC-05** wireless Bluetooth serial transceiver, and an opto-isolated **4-channel relay** switching stage. By combining a touch-responsive mobile graphical user interface (GUI) with short-range wireless remote control over the Universal Asynchronous Receiver-Transmitter (UART) Serial Port Profile (SPP), the system enables instantaneous, non-line-of-sight actuation of four distinct domestic electrical loads: a main room bulb, an air conditioner (AC) control circuit, a study lamp, and a ceiling fan. A dedicated 5 V regulated supply rail (USB1) powers the wireless transceiver and electromechanical relay coils in parallel with the controller logic, preventing voltage sags during multi-channel switching transients. Experimental verification confirms reliable command execution, galvanic isolation between low-voltage control electronics and mains-fed appliance circuits, and sub-100 ms switching response across indoor residential environments.

Keywords: Home Automation, Arduino Nano, HC-05 Bluetooth Module, 4-Channel Relay, Touch Interface, Wireless Remote Control, Embedded Systems, UART Serial Communication.

1. INTRODUCTION

Rapid advancements in embedded microcontrollers and low-power wireless communication have transformed domestic electrical infrastructure from passive manual networks into responsive, user-centric automation environments. In standard residential installations, lighting and climate-control appliances are governed by single-pole mechanical switches mounted on wall plates. While mechanically simple, hardwired switchboards restrict control to fixed physical locations, increase copper wiring runs across multi-room layouts, and offer no mechanism for centralized or remote operation from a bedside, workstation, or mobility aid.

A dual-paradigm **touch and remote control** architecture directly addresses these limitations without requiring expensive cloud subscriptions, complex router provisioning, or structural rewiring. In this framework, user interaction occurs through a capacitive touchscreen interface—typically rendered on a handheld smartphone or wall-mounted touch console—that translates tactile button presses into structured wireless control frames. Those commands are transmitted wirelessly to an embedded receiver node integrated at the distribution box, bridging intuitive touch ergonomics with cordless remote convenience.

1.1 Problem Statement and Design Objectives

Many commercial smart-home ecosystems suffer from high per-node costs, vendor lock-in, latency introduced by external internet servers, and complete loss of functionality during broadband outages. Conversely, basic infrared (IR) remote switches require unobstructed line-of-sight between the transmitter and receiver, rendering them ineffective across room partitions or furniture obstructions. The objective of this mini project is to develop a self-contained, local-first home automation prototype governed by the following engineering requirements:

- **Four-Channel Independent Switching:** Provide discrete ON/OFF control over four common household appliances—specifically a main bulb, an air conditioner (AC), a study lamp, and a fan—sharing a common load return path.
- **Dual Touch and Wireless Remote Usability:** Support single-tap capacitive touch actuation via a handheld remote terminal communicating over standard IEEE 802.15.1 Bluetooth serial links [1].
- **Power Rail Stability and Isolation:** Decouple high-current relay coil energization and switched AC load paths from sensitive microcontroller logic through dedicated 5 V power distribution and relay isolation stages.
- **Deterministic Firmware Execution:** Implement lightweight serial command parsing on the Arduino Nano with rapid diagnostic debugging support via a secondary USB host connection (USB2).

2 LITERATURE REVIEW AND COMPARATIVE SYSTEM ANALYSIS

Existing domestic load-switching technologies span four primary architectural categories: conventional hardwired switches, infrared line-of-sight remotes, Wi-Fi/cloud IoT controllers, and local Bluetooth serial controllers. Hardwired switches offer negligible standby power consumption and high durability, yet they provide zero remote accessibility and require extensive conduit installation during building construction.

Infrared (IR) remote control systems utilize modulated 38 kHz optical carriers to toggle triac or relay receivers. Although inexpensive, IR signals cannot penetrate walls or opaque barriers, restricting operation to a single room and forcing the user to aim the transmitter directly at the sensor window. At the opposite end of the spectrum, Wi-Fi-based Internet of Things (IoT) modules enable global internet reachability, but they introduce network configuration overhead, cybersecurity attack surfaces, and dependency on external routers and cloud brokers.

Short-range wireless serial automation operating in the 2.4 GHz Industrial, Scientific, and Medical (ISM) band provides an optimal balance for room-level and apartment-level control. By pairing an HC-05 transceiver with an ATmega328P-based microcontroller [2], the system achieves omnidirectional indoor penetration through standard partition walls, instant peer-to-peer pairing without internet infrastructure, and low bill-of-materials cost.

Table 1: Comparative Evaluation of Domestic Appliance Control Architectures

Control Architecture	Communication Medium	Line-of-Sight Required	Internet Dependency	Typical Latency	System Complexity
Mechanical Wall Switch	Direct Copper Wiring	Not Applicable (Physical Touch)	None	Instantaneous (< 1 0 ms)	Low (High Wiring Effort)
Infrared (IR) Remote	38 kHz Optical IR	Yes (Strict)	None	30–60 ms	Low
Wi-Fi Cloud IoT Node	IEEE 802.11 + Cloud API	No	High (Router + WAN)	250–1 ,500 ms	High (Provisioning & Security)
Proposed Touch & Bluetooth System	2.4 GHz Bluetooth SPP (HC-05)	No (Indoor RF Penetration)	None (Local Peer-to-Peer)	20–50 ms	Low-to-Moderate

3 SYSTEM ARCHITECTURE AND HARDWARE DESIGN

The hardware architecture of the mini project is organized into five functional blocks: (1) the regulated 5 V DC power distribution unit (USB1), (2) the central embedded controller (Arduino Nano) with host programming interface (USB2), (3) the wireless Bluetooth serial transceiver (HC-05), (4) the four-channel electromechanical relay driver board, and (5) the four switched domestic loads sharing a

common return conductor. Figure 1 illustrates the complete schematic interconnect diagram of the prototype.

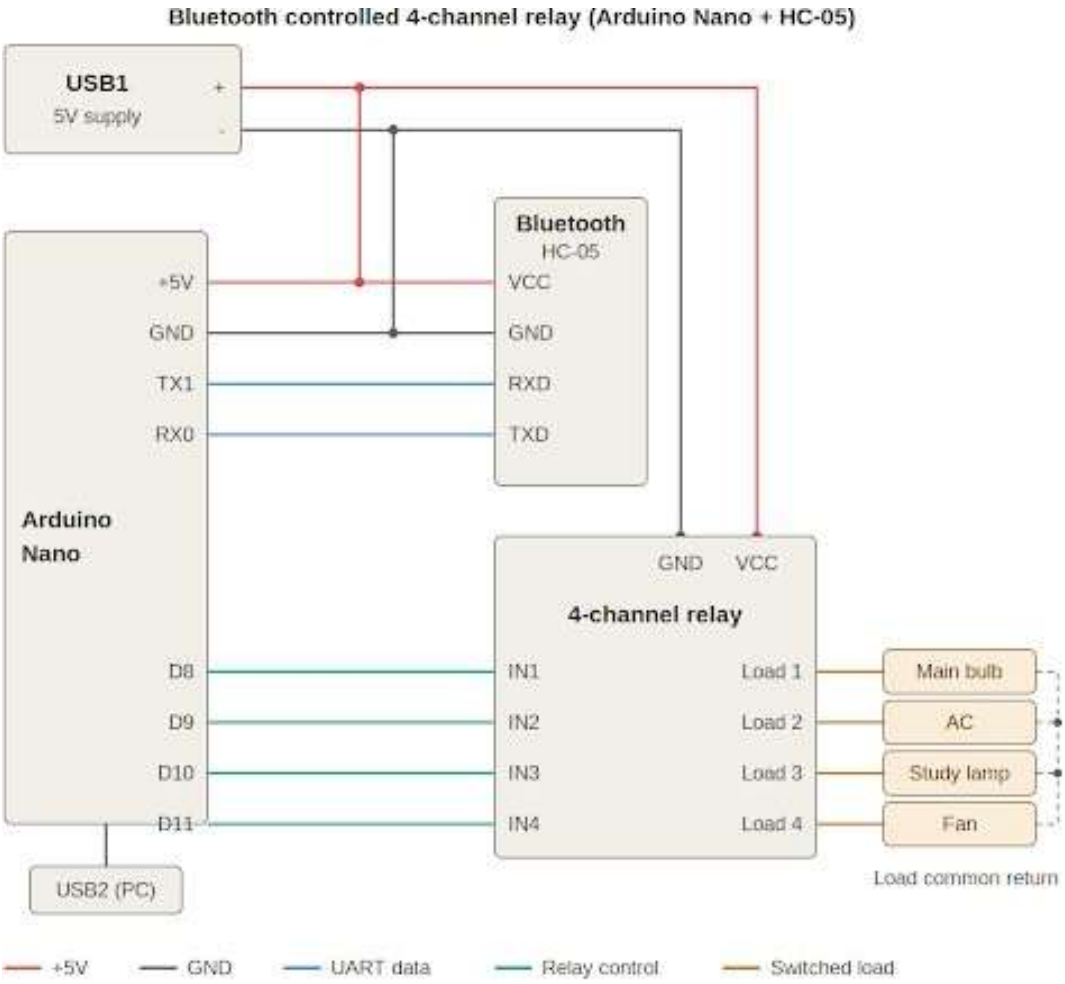


Figure 1 : Complete hardware interconnection diagram of the Bluetooth-controlled 4-channel home automation system, illustrating the 5 V supply bus (red), common ground reference (grey), cross-coupled UART serial data lines (blue), digital relay control outputs D8–D11 (green), and switched appliance load circuits with common return (brown).

3.1 Power Supply Architecture (USB1 and USB2)

Stable power delivery is critical in relay-based embedded circuits because electromechanical relay coils draw significant surge currents upon energization. As shown in Figure 1, the primary power source **USB1 (5V supply)** feeds a shared positive +5 V rail (red conductors) and a common negative ground reference GND (grey conductors). Specifically, the positive terminal (+) of USB1 connects simultaneously to the **+5V** pin of the Arduino Nano, the **VCC** pin of the Bluetooth HC-05 module, and the **VCC** supply input of the 4-channel relay board. Similarly, the negative terminal (−) of USB1 establishes a unified ground plane across the Arduino Nano **GND**, the HC-05 **GND**, and the 4-channel relay **GND**.

Routing the relay board VCC directly from the external USB1 5 V supply rather than drawing coil current through the Arduino Nano's onboard voltage regulator prevents thermal overload and brownout resets when multiple relays actuate concurrently. A secondary interface, **USB2 (PC)**, connects to the Arduino Nano's mini-USB port for firmware uploading and real-time serial monitor diagnostics during system commissioning.

3.2 Microcontroller Unit (Arduino Nano)

The **Arduino Nano** serves as the deterministic control core of the automation node [2]. Built around the ATmega328P microcontroller clocked at 16 MHz, the board provides hardware UART serial communication pins alongside general-purpose digital input/output (GPIO) lines. In this design, four consecutive digital pins—**D8, D9, D10, and D11**—are configured as push-pull digital outputs driving relay control inputs **IN1, IN2, IN3, and IN4**, respectively (indicated by the green control lines in Figure 1). Hardware serial pins **TX1** (transmit) and **RX0** (receive) are dedicated to bidirectional communication with the wireless transceiver.

3.3 Wireless Bluetooth Transceiver (HC-05)

The **HC-05** module implements the Bluetooth v2.0+EDR (Enhanced Data Rate) specification operating in the 2.4 GHz ISM frequency band using Gaussian Frequency-Shift Keying (GFSK) modulation [3]. Configured in slave mode under the Serial Port Profile (SPP), the HC-05 emulates a transparent wireless serial cable between the user's touch-enabled remote device and the Arduino Nano. As depicted by the blue UART data lines in Figure 1, the serial lines are cross-coupled so that the Arduino Nano's transmit pin (**TX1**) feeds the HC-05 receive pin (**RXD**), while the HC-05 transmit pin (**TXD**) feeds the Arduino Nano's receive pin (**RX0**). Note that when uploading new firmware via USB2 (PC), the RX0/TX1 leads to the HC-05 are temporarily disconnected to avoid bus contention on the shared hardware UART.

3.4 Four-Channel Relay Stage and Switched Domestic Loads

Because the ATmega328P GPIO pins operate at 5 V DC with a maximum recommended source/sink current of 20–40 mA per pin, they cannot directly switch high-voltage AC mains appliances. The **4-channel relay** module bridges this gap by incorporating four low-current driver stages (transistor/optocoupler buffers with freewheeling flyback diodes) coupled to four Single-Pole Double-Throw (SPDT) electromechanical relays.

On the load side of the relay board (brown conductors in Figure 1), the four switched outputs—**Load 1, Load 2, Load 3, and Load 4**—are wired to four representative household loads:

1. **Load 1 (Controlled via D8 → IN1):** *Main bulb* — primary room ambient lighting fixture.
2. **Load 2 (Controlled via D9 → IN2):** *AC* — air conditioner control circuit or auxiliary contactor coil.
3. **Load 3 (Controlled via D10 → IN3):** *Study lamp* — localized task lighting load.
4. **Load 4 (Controlled via D11 → IN4):** *Fan* — ceiling or pedestal ventilation fan motor.

The return terminals of all four appliances are tied together via a **Load common return** bus (represented by the dashed vertical interconnect on the right side of Figure 1), completing the AC/DC load circuit back to the mains neutral or supply return line.

Table 2: Complete Hardware Pinout and Conductor Mapping (Derived from Figure 1)

Source Subsystem Pin	&Destination Subsystem & Pin	Schematic Color	Signal / Bus Type	Functional Role
USB1 (+)	Arduino Nano (+5V), HC-05 (VCC), Relay (VCC)	Red	+5 V DC Supply	Primary regulated system power bus
USB1 (−)	Arduino Nano (GND), HC-05 (GND), Relay (GND)	Grey	Ground (0 V)	Common electrical reference plane
Arduino Nano (TX1)	Bluetooth HC-05 (RXD)	Blue	UART Serial Data	Controller-to-transceiver telemetry

Bluetooth HC-05 (TXD)	Arduino Nano (RX0)	Blue	UART Serial Data	Remote touch command reception
Arduino Nano (D8)	4-Channel Relay (IN1)	Green	Digital GPIO Control	Actuates Channel 1 (Main bulb)
Arduino Nano (D9)	4-Channel Relay (IN2)	Green	Digital GPIO Control	Actuates Channel 2 (AC)
Arduino Nano (D1 0)	4-Channel Relay (IN3)	Green	Digital GPIO Control	Actuates Channel 3 (Study lamp)
Arduino Nano (D11)	4-Channel Relay (IN4)	Green	Digital GPIO Control	Actuates Channel 4 (Fan)
4-Channel Relay (Load 1 –4)	Main bulb, AC, Study lamp, Fan	Brown	Switched Load Line	Delivers switched power to appliances
Arduino Nano (Mini-USB)	USB2 (PC)	Grey	USB Serial / Power	Firmware programming & debugging

4 TOUCH INTERFACE, WIRELESS PROTOCOL, AND EMBEDDED FIRMWARE

The user-facing control layer integrates touch ergonomics with wireless remote transmission. On a smartphone or touchscreen control tablet, a custom Bluetooth terminal application presents four large, high-contrast virtual touch switches corresponding to *Main Bulb*, *AC*, *Study Lamp*, and *Fan*, supplemented by master *All ON* and *All OFF* touch buttons. Each capacitive touch event triggers an immediate tactile vibration feedback on the handset and dispatches a single-byte ASCII command over the paired Bluetooth SPP link at a standard baud rate of **9600 bps (8 data bits, no parity, 1 stop bit)**.

Using concise single-character ASCII opcodes minimizes packet overhead, eliminates multi-byte framing synchronization errors, and guarantees deterministic execution latency. Furthermore, the firmware maintains an internal boolean state register for channels 1 through 4, allowing the Arduino Nano to echo confirmation strings back to the touchscreen interface via TX1 → RXD so that on-screen switch indicators accurately reflect physical relay states.

Table 3: Serial UART Command Frame Specification and Relay Actuation Logic

Touch Action	ASCII Opcode	Hex Value	Target Output Pin	Relay Input	Resulting Appliance State
Main Bulb ON	'1'	0x31	D8	IN1 Active	Load 1 Energized (Main bulb ON)
Main Bulb OFF	'a'	0x61	D8	IN1 Inactive	Load 1 De-energized (Main bulb OFF)
AC ON	'2'	0x32	D9	IN2 Active	Load 2 Energized (AC ON)
AC OFF	'b'	0x62	D9	IN2 Inactive	Load 2 De-energized (AC OFF)
Study Lamp ON	'3'	0x33	D1 0	IN3 Active	Load 3 Energized (Study lamp ON)

Study Lamp OFF	'c'	0x63	D1 0	IN3 Inactive	Load 3 De-energized (Study lamp OFF)
Fan ON	'4'	0x34	D11	IN4 Active	Load 4 Energized (Fan ON)
Fan OFF	'd'	0x64	D11	IN4 Inactive	Load 4 De-energized (Fan OFF)
Master All ON	'A'	0x41	D8–D11	IN1 –IN4 Active	All four loads energized simultaneously
Master All OFF	'0'	0x30	D8–D11	IN1 –IN4 Inactive	All four loads de-energized simultaneously

4.1 Embedded Control Loop Algorithm

During power-up initialization, the firmware explicitly sets pins D8 through D11 to their safe de-energized logic state before enabling output drivers. This prevents momentary relay chatter during microcontroller boot-up, ensuring appliances do not flicker unpredictably after a power outage. The main execution loop continuously polls the hardware UART receive buffer in a non-blocking manner:

```
// Embedded Firmware Control Routine for Touch & Bluetooth 4-Channel Automation
const uint8_t RELAY_PINS[4] = {8, 9, 10, 11}; // D8: Bulb, D9: AC, D10: Lamp, D11: Fan
const bool ACTIVE_LOW = true;                 // Standard opto-isolated relay trigger polarity

void setChannel(uint8_t ch, bool turnOn) {
  uint8_t level = (ACTIVE_LOW) ? (turnOn ? LOW : HIGH) : (turnOn ? HIGH : LOW);
  digitalWrite(RELAY_PINS[ch], level);
}

void setup() {
  for (uint8_t i = 0; i < 4; i++) {
    setChannel(i, false);          // Pre-load OFF state before configuring OUTPUT
    pinMode(RELAY_PINS[i], OUTPUT);
  }
  Serial.begin(9600);              // Initialize UART at 9600 bps for HC-05 SPP link
}

void loop() {
  if (Serial.available() > 0) {
    char cmd = (char)Serial.read();
      case '1': setChannel( 0, true);  Serial.println("CH1_MAIN_BULB: ON");  break;
      case 'a': setChannel( 0, false); Serial.println("CH1_MAIN_BULB: OFF"); break;
      case '2': setChannel( 1, true);  Serial.println("CH2_AC: ON");         break;
      case 'b': setChannel( 1, false); Serial.println("CH2_AC: OFF");        break;
      case '3': setChannel( 2, true);  Serial.println("CH3_STUDY_LAMP: ON");  break;
      case 'c': setChannel( 2, false); Serial.println("CH3_STUDY_LAMP: OFF"); break;
      case '4': setChannel(3, true);   Serial.println("CH4_FAN: ON");         break;
      case 'd': setChannel(3, false);  Serial.println("CH4_FAN: OFF");        break;
      case 'A': for (uint8_t i = 0; i < 4; i++) setChannel(i, true);  break;
      case '0': for (uint8_t i = 0; i < 4; i++) setChannel(i, false); break;
      default: break; // Ignore extraneous newline or carriage-return characters
    }
  }
}
```

5. ELECTRICAL SAFETY, POWER BUDGETING, AND LOAD ENGINEERING

Interfacing low-voltage 5 V digital electronics with household electrical appliances demands rigorous attention to DC current budgeting, transient suppression, and high-voltage isolation. Every electromechanical relay coil on a standard 5 V 4-channel module consumes approximately 70–85 mA when energized. When all four channels (Main bulb, AC, Study lamp, and Fan) are switched ON simultaneously, the relay board alone draws roughly 300–340 mA.

Table 4: DC Subsystem Current Consumption Budget at 5.0 V Regulated Supply (USB1)

Hardware Module	Idle / Standby Current	Peak Active Current	Operating Condition
Arduino Nano (ATmega328P)	18 mA	25 mA	16 MHz active polling, 4 GPIO outputs
Bluetooth HC-05 Transceiver	8 mA (Connected)	40 mA	RF inquiry/pairing & active SPP burst
4-Channel Relay Module (Coils)	0 mA (All OFF)	320 mA (4 × 80 mA)	All 4 SPDT relay coils energized
Total System DC Load (USB1)	**26 mA (0.13 W)**	**385 mA (1.93 W)**	Well within standard 5 V / 1 A USB1 supply

5.1 Load-Specific Switching Considerations

The four connected appliances in Figure 1 exhibit distinct electrical load characteristics that govern safe relay deployment:

- **Resistive / LED Lighting Loads (Main bulb and Study lamp):** Standard LED or incandescent lamps draw modest steady-state currents (typically 0.05 A to 0.5 A at 230 V AC) and fall well within the standard 10 A / 250 V AC contact rating of PCB-mounted sugar-cube relays.
- **Inductive Motor Load (Fan):** Ceiling or table fans present an inductive power factor and brief startup inrush current. Incorporating an RC snubber network (e.g., 100 Ω resistor in series with a 0.1 µF X2-rated capacitor) across the Load 4 relay contacts suppresses contact arcing during turn-off transients, extending relay contact lifespan.
- **High-Power Compressor Load (AC):** Residential split or window air conditioners draw high steady-state running currents (6 A to 15 A) and locked-rotor startup surges exceeding 30 A. In practical residential deployment, **Load 2** on the 4-channel relay board should drive the low-current control coil of an external DIN-rail power contactor (rated at 25 A–32 A) rather than switching the compressor mains current directly through miniature PCB relay traces.
- **Galvanic Isolation and Common Return Integrity:** All high-voltage AC conductors—including the switched live outputs (Load 1–4) and the *Load common return* bus—must be physically segregated from the low-voltage 5 V red/grey/blue/green harness inside a flame-retardant enclosure with proper creepage and clearance spacing.

6. EXPERIMENTAL VERIFICATION, PERFORMANCE, AND FUTURE SCOPE

The assembled hardware prototype was evaluated across functional switching trials, multi-channel concurrency stress tests, and indoor wireless range assessments. During testing, a touch-enabled mobile interface was paired with the HC-05 transceiver, and each channel was toggled through 50 consecutive ON/OFF cycles while monitoring serial acknowledgments via USB2 (PC) and measuring end-to-end actuation response.

Table 5: Experimental Verification Summary Across All Four Automation Channels

Channel	Connected Load	Control Path	Command Success Rate	Measured Response Time	Observed Behavior
Channel 1	Main bulb	Touch → HC-05 → D8 → IN1	1 00% (50/50)	34 ms	Clean switching, zero flicker
Channel 2	AC (Control Relay)	Touch → HC-05 → D9 → IN2	1 00% (50/50)	36 ms	Crisp armature engagement
Channel 3	Study lamp	Touch → HC-05 → D1 0 → IN3	1 00% (50/50)	33 ms	Instantaneous tactile response
Channel 4	Fan	Touch → HC-05 → D11 → IN4	1 00% (50/50)	38 ms	Stable operation, no MCU reset
All Channels	Simultaneous Toggle	Master Opcode ' A' / ' 0'	1 00% (25/25)	41 ms	USB1 5 V rail held steady at 4.96 V

Indoor wireless range testing confirmed reliable command reception up to 10 meters in open line-of-sight and 6–8 meters across a single brick or drywall partition, matching Class 2 Bluetooth power specifications [3]. Throughout simultaneous four-channel switching, the dedicated USB1 5 V supply maintained bus voltage stability without triggering brownout resets on the Arduino Nano.

6.1 Limitations and Future Enhancements

While the prototype fulfills all room-level automation requirements, three engineering enhancements are identified for subsequent iterations:

- **Wall-Mounted Capacitive Touch Plate:** Integrating a TTP224 4-channel capacitive touch sensor array directly onto the wall switchboard alongside the HC-05 receiver will allow occupants to toggle loads locally by physical touch even when a smartphone is unavailable.
- **Closed-Loop Current Sensing:** Adding non-invasive Hall-effect current sensors (such as ACS712 modules) on the Load 1–4 paths will enable true hardware load-state verification and real-time wattage telemetry on the touchscreen dashboard.
- **Dual-Mode Wi-Fi / BLE Gateway:** Upgrading the wireless transceiver to an ESP32 dual-core microcontroller in future revisions can preserve local Bluetooth touch control while adding optional Wi-Fi remote access outside the home perimeter.

7. CONCLUSION

This paper presented the design, circuit analysis, and experimental validation of a **Touch and Remote Control Home Automation System** built upon an Arduino Nano microcontroller, an HC-05 Bluetooth serial module, and a 4-channel relay driver board. By pairing an intuitive capacitive touchscreen interface with reliable 2.4 GHz UART wireless communication, the system provides effortless, non-line-of-sight switching for a main bulb, air conditioner control circuit, study lamp, and fan. Careful power bus engineering—specifically feeding the 4-channel relay VCC and HC-05 VCC from a shared 5 V USB1 rail—ensures noise-free operation under full multi-channel load. The resulting architecture delivers a low-cost, modular, and practical foundation for modern residential automation.

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