CHAPTER 1

Chapter 1: Introduction

1.1 Motivation

With the growing demand for automation and comfort in the automotive industry, vehicles are rapidly evolving into intelligent systems that offer not only performance but also a high degree of personalization. One key area of innovation is seat control systems, which have traditionally been manual in most budget and mid-range vehicles. In luxury cars, however, electronically adjustable seats, ventilation, ambient lighting, and USB charging have become standard features that enhance passenger experience and comfort.

The motivation behind this project stems from the idea of bridging the gap between basic seat functionality and advanced smart features using affordable, modular, and easily implementable electronics. By designing a Seat Control Module that incorporates motorized seat adjustments, fan-based ventilation, RGB lighting, and charging ports—controlled through capacitive touch sensors and a microcontroller—we aim to bring smart car technology within reach of cost-sensitive applications.

Another key motivation is the desire to build practical embedded systems experience by integrating various hardware modules like motors, drivers, sensors, and power electronics into a unified control architecture. Working with the STM32 microcontroller platform enables us to explore real-time control, GPIO-based interaction, and system-level design, making the project an excellent blend of theoretical learning and hands-on engineering.

This project also opens the door to future scalability, such as memory-based seat positions, mobile app integration, or even voice control. By completing this module, we take a significant step toward designing more advanced and user-friendly smart car systems.

1.2 Background

In recent years, the automotive industry has witnessed a significant shift towards intelligent and user-centric vehicle systems. Features that were once limited to high-end luxury vehicles—such as motorized seat adjustment, seat ventilation, ambient lighting, and integrated charging—are gradually being incorporated into mainstream designs. This evolution is driven by the growing expectations of consumers for comfort, convenience, and personalization in their driving experience.

Traditionally, seat positioning in vehicles has been achieved using manual levers and mechanical linkages. While effective, these systems lack the precision, ease of use, and adaptability required in modern vehicle environments. As technology has advanced, the integration of electronic systems to control seating has enabled automated positioning, smoother adjustments, and memory-based configurations that enhance ergonomics and passenger satisfaction.

The development of embedded systems and affordable microcontrollers has made it possible to implement such features without significantly increasing manufacturing costs. With platforms like the STM32 series, complex control mechanisms can now be realized using compact and low-power components. Furthermore, the use of touch-based input and intuitive interfaces has improved the overall interaction between users and vehicle interiors.

The proposed seat control module builds on these advancements by creating a modular system that includes multi-directional motorized seat control, fan-based ventilation, RGB ambient lighting, and USB charging—all governed through a centralized microcontroller-based architecture. The design emphasizes low cost, ease of implementation, and modular expandability, making it suitable for a wide range of automotive and industrial seating applications.

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CHAPTER 2

Chapter 2: Literature Survey

2.1. Literature Survey Table

Table 2.1: Literature Survey Table

Sr. No.	Title of the Paper	Year	Publisher	Methodology
1	The dynamics of technological change in the automotive seat segment	2006	International Journal of Automotive Technology and Management	The study examines the technological evolution of automotive seats by analyzing patents and tracking innovations over time. It categorizes seat development into two generations, from passive mechanical structures to advanced mechatronic systems. The research focuses on functional changes, safety enhancements, and automation trends to understand how technological advancements have shaped modern automotive seating.
2	Research on Vibration Reduction Performance of Electromagnetic Active Seat Suspension Based on Sliding Mode Control	2022	Sensors	The study models an electromagnetic vibration damping system with electromagnets at both ends and an armature connected to the seat. It analyzes the system's behavior by considering control current, air gap flux, and electromagnetic force while assuming negligible magnetic flux leakage and resistance. The mathematical formulation is based on uniform magnetic potential drops and fixed electromagnet positioning.
3	Development of a Soft Robotics Module for Active Control of Sitting Comfort	2022	Micromachines	The soft robotic module is designed with pneumatic actuation and embedded sensors to change shape and stiffness. It consists of a 3D-printed base, a molded silicone bellow, and an Octaspring foam for structural support. The embedded sensor system includes a pressure sensor and an LED-based optical sensing mechanism to detect shape changes through light reflection, enabling precise motion tracking.
4	A K-Seat-Based PID Controller for Active Seat Suspension to Enhance Motion Comfort	2022	SAE International Journal of Connected and Automated Vehicles	The study investigates the ActiveK-seat, an advanced active suspension system based on the K-seat's negative stiffness elements, to mitigate motion sickness (MS) in autonomous vehicles (AVs). The ActiveK- seat is compared against passive, semi-active (EMD-based), and simple active seat models under real road conditions (Class C roughness) to evaluate comfort and MS reduction.
5	Design and Control of a Multi-Axis Servo Motion Chair System Based on a Microcontroller	2022	Energies	The motion chair system operates through a three-layer methodology: the monitor layer (host software in C# for trajectory planning and command generation), the control layer (MCU-based hardware for signal processing and communication via RS232/RS485), and the execution layer (servo motors and mechanical

				linkages for motion control). Real-time tracking is achieved through feedback from motor encoders.

2.2. Summary of Literature Survey:

The literature survey explores the evolution of automotive seating technology by analyzing patents and tracking innovations, categorizing developments into passive mechanical structures and advanced mechatronic systems. Studies focus on safety, automation, and functional enhancements, including an electromagnetic vibration damping system that models control current, air gap flux, and electromagnetic force for improved ride comfort. Research on soft robotic modules highlights pneumatic actuation with embedded sensors for adaptive shape and stiffness control. The ActiveK-seat, an advanced active suspension system integrating negative stiffness elements, is examined for mitigating motion sickness in autonomous vehicles under real road conditions. Additionally, a motion chair system is reviewed, utilizing a three-layer control methodology with real-time tracking via motor encoders for precise motion execution.

2.3 Gap Identified through Literature Survey:

The literature survey highlights significant advancements in automotive seating, yet several gaps remain. While modern seats integrate automation and mechatronics for enhanced comfort and adaptability, there is limited exploration of energy-efficient active suspension systems that balance performance with low power consumption. Existing studies on vibration suppression focus primarily on vehicle applications, overlooking potential extensions to diverse environments such as aerospace or medical transport. Additionally, while soft robotic modules demonstrate promising shape adaptation and stiffness modulation, their long-term durability and performance under varying environmental conditions require further investigation. Although the ActiveK-seat effectively reduces motion sickness, research on optimizing its response to different road conditions and passenger preferences remains insufficient. Furthermore, the development of digital control systems for adjustable-height chairs showcases robust motion control, but scalability and integration with intelligent user interfaces for personalized comfort adjustments need further exploration. These gaps suggest opportunities for refining existing technologies and broadening their applicability to diverse real-world scenarios.

2.4 Problem Statement

2.4.1. Aim

To develop an advanced multiple seat control system, integrating embedded electronics, sensor-based automation designed to enhance Passenger comfort, ensure precise adjustments, improve safety, optimize energy efficiency, and provide an intuitive user experience in modern automobile.

2.4.2 Objectives

1. Develop an Intelligent Seat Control System: Design and implement a system that provides automated seat adjustments for enhanced Passenger comfort and safety.
2. Integrate Key Circuits for Efficient Operation: Incorporate reverse polarity protection, wake-up circuits, fail-out circuits, ignition circuits, and GPIO circuits to ensure reliability and safety.
3. Enhance Ergonomic Seating and Comfort: Enable precise seat positioning, lumbar support, and temperature regulation to reduce fatigue and posture-related issues.
4. Ensure User-Friendly Operation: Develop an intuitive interface, supporting memory functions and controls via touch, voice, or mobile applications.
5. Improve Safety Features: Implement fail-safe mechanisms to prevent malfunctions and ensure secure adjustments while driving.

CHAPTER 3

Chapter 3: Methodology

3.1 Project Outline

The proposed project focuses on the development of a smart automotive seat control module aimed at enhancing user comfort, convenience, and functionality through an embedded system design. The system integrates several essential features including seat adjustment, ventilation, ambient lighting, and mobile device charging, all managed through a centralized microcontroller platform. The design follows a modular architecture where each functional block is developed independently yet orchestrated cohesively under one control unit. The seat adjustment mechanism is facilitated by three DC motors, which handle vertical displacement, horizontal movement, and reclination of the seat respectively. These motors are driven using the L298N dual H-Bridge driver module that allows bidirectional control. User inputs are captured through capacitive touch sensors (TTP223), which operate based on touch duration: holding a touch pad continues motor movement, and releasing it halts the motion, allowing users to adjust the seat precisely to their comfort level.

To further enhance comfort, a blower fan is incorporated into the system to provide ventilation to the seat. The fan speed is regulated using a hardware-based PWM speed controller, operated via a manual adjustment knob. This approach avoids the need for software-based control while still enabling real-time adjustment of airflow. For added safety, a high-side switch is integrated into the blower's power line to prevent current surges or overheating. Additionally, ambient lighting is provided by an RGB LED module that offers simple on-off functionality. This lighting system is also connected through a high-side switch for safe operation. The control of this lighting is managed through a single capacitive touch sensor, allowing the user to toggle the light with a tap.

A USB charging module is embedded into the seat control unit, offering mobile charging capability directly from the system. The USB module operates on a stable 5V supply and is protected by a diode-based safety circuit, which prevents over-voltage or reverse current situations, ensuring the safety of both the charger and connected devices. Power for the entire system is supplied through a 12V DC adapter. This 12V input is routed through LDO regulators that derive 5V and 3.3V outputs required for different components of the system. The motors operate on the full 12V, while the 5V line powers the USB charger, blower fan, and RGB module. The 3.3V line supplies the STM32F103C8T6 microcontroller and the touch sensors, maintaining system stability and protecting sensitive components.

At the core of the system lies the STM32F103C8T6 microcontroller, which is responsible for interpreting sensor inputs and managing the logic behind seat positioning, lighting, and safety control mechanisms. The embedded software is developed using STM32CubeIDE, leveraging HAL libraries for GPIO, PWM, and timer control. All control logic is written in modular C code, ensuring ease of future expansion and maintenance. The system is tested across various stages, including unit testing of each component, integration testing of combined functionalities, and validation of voltage and current parameters to ensure safety and reliability. Calibration of touch sensor sensitivity and performance checks under load conditions are also conducted. This comprehensive design results in a user-centric automotive seat module capable of providing comfort, functionality, and safety, while being adaptable to future enhancements or integrations with advanced vehicle systems.

3.2 Block Diagram

The Fig 1. provides a high-level overview of the system architecture for the smart automotive seat control module. It illustrates the interconnection between various hardware components including power supply, control units, actuators, and output modules. The central microcontroller coordinates all operations based on user inputs, enabling features such as seat adjustment, ventilation, ambient lighting, and mobile charging. This diagram serves as a visual representation of the functional flow and interaction among the key modules in the system.

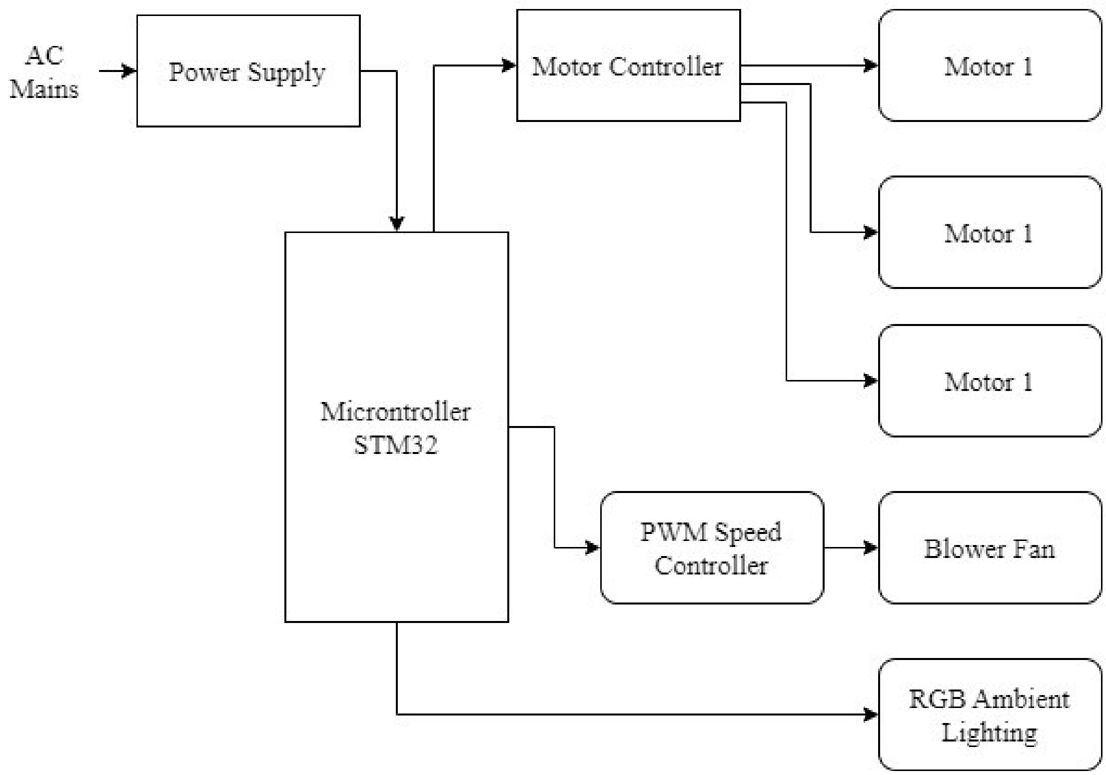

Fig 3.1. Block diagram for automatic seat control mechanism

3.2.1. AC Mains: The AC Mains block represents the primary power input source to the entire system. It supplies standard high-voltage alternating current (typically 220V or 110V depending on region) which is essential to run the system. This block is crucial because without this raw electrical energy, none of the other components can be powered. It forms the initial stage of the power delivery chain. However, since most of the electronic and electromechanical components used in this system operate on low-voltage DC, the AC power must be converted into appropriate DC levels by the next block — the power supply unit.

3.2.2. Power Supply: The Power Supply unit is responsible for converting the incoming high-voltage AC into regulated DC voltages that match the requirements of individual subsystems. It typically outputs 12V, 5V, and 3.3V using internal regulators and LDOs (Low Dropout Regulators). This block is critical as it ensures safe and reliable operation of the system components.

• The 12V line is used to power the high-load devices like DC motors.
• The 5V output supplies power to modules like the blower fan, USB charger, PWM speed

controller, and RGB ambient light.
• The 3.3V output is dedicated to powering the STM32 microcontroller, which operates at low logic levels.
This segmentation helps in power management and protects sensitive components from damage due to overvoltage or fluctuations.

3.2.3. Microcontroller (STM32): The STM32F401CCU6 microcontroller acts as the brain of the system. It plays a central and highly critical role, as it handles all logic processing, decision making, and control functions. The microcontroller receives user input from capacitive touch sensors and generates the appropriate control signals for outputs like motors, fan speed controller, and RGB lighting. It uses GPIO (General Purpose Input/Output) pins to send digital HIGH/LOW signals, and PWM (Pulse Width Modulation) signals for variable control (such as fan speed).
In addition, the STM32 interfaces with power regulators to draw stable 3.3V power, ensuring reliable execution of the firmware. Programming is done using STM32CubeIDE, where interrupt routines, logic conditions, and timing delays are coded to manage the entire seat control system. The microcontroller ensures synchronized operation of all hardware elements based on real-time user interactions.

3.2.4. Motor Controller: The Motor Controller block, implemented using an L298N dual H-bridge driver module, serves as the intermediary between the microcontroller and the DC motors. It is a crucial component because it translates the low-current logic-level signals from the STM32 into high-current control signals capable of driving the motors. It allows for bidirectional control of each motor, meaning the motors can move both forward and reverse. This capability is essential for precise seat movement such as reclining or lifting. The controller also ensures safe operation by isolating the microcontroller from the back EMF (electromotive force) that motors often generate. This block receives logic inputs from the STM32 and outputs the corresponding motor control signals with sufficient power and voltage level.

3.2.5. DC Motors: Three separate DC motors are used, each responsible for a unique movement of the vehicle seat: vertical lift/drop, forward/backward horizontal slide, and reclining motion of the backrest. These motors provide the mechanical force required to physically move the seat into the desired position. The importance of these motors lies in their ability to provide flexible, adjustable comfort for users in real-time.
Each motor is driven by the motor controller and responds to directional commands based on how long the user touches the corresponding sensor. The longer the sensor is held, the longer the motor continues to move, giving users fine-grained control over the seat's orientation. These motors are robust and chosen to handle the mechanical load and friction typically present in automotive seating systems.

3.2.6. PWM Speed Controller: The PWM (Pulse Width Modulation) Speed Controller is responsible for varying the speed of the blower fan based on user preferences. This block receives PWM signals from the STM32 microcontroller. The importance of this block lies in its ability to modulate power delivery by rapidly switching the signal ON and OFF at varying intervals (duty cycles).
This method allows the blower to run at different speeds while consuming less power and generating less heat compared to traditional resistive speed controls. The PWM controller thus enhances energy efficiency and comfort by giving users control over the intensity of seat ventilation.

3.2.7. Blower Fan: The blower fan provides ventilation to the seat, which is especially useful in hot climates or after prolonged sitting. It pulls air from behind the seat and circulates it around the user, maintaining a comfortable temperature. The blower is directly controlled by the PWM speed controller, which means the fan speed can be increased or decreased smoothly based on PWM signal strength.
Its importance lies in improving thermal comfort for the user and preventing sweating or discomfort during long drives. The fan is powered by 5V DC and mounted discreetly in the seat structure. It is an add-on feature that greatly enhances user experience.

3.2.8. RGB Ambient Lighting: This block represents the RGB LED module used for aesthetic and functional ambient lighting. The light is placed around the seat or interior trim and is designed to provide soft, color-tinted lighting that improves the atmosphere inside the vehicle cabin.
This module is toggled ON or OFF using capacitive touch input. In its current design, it does not support color switching or dimming, but those features could be added in the future with minimal hardware changes. The lighting is powered by a 5V source and controlled through a digital output pin from the STM32. The importance of this block lies in enhancing the visual appeal and visibility of the seating area during night-time or low-light conditions.

CHAPTER 4

Chapter 4: Design & Implementation of Proposed System

4.1 Circuit Diagram

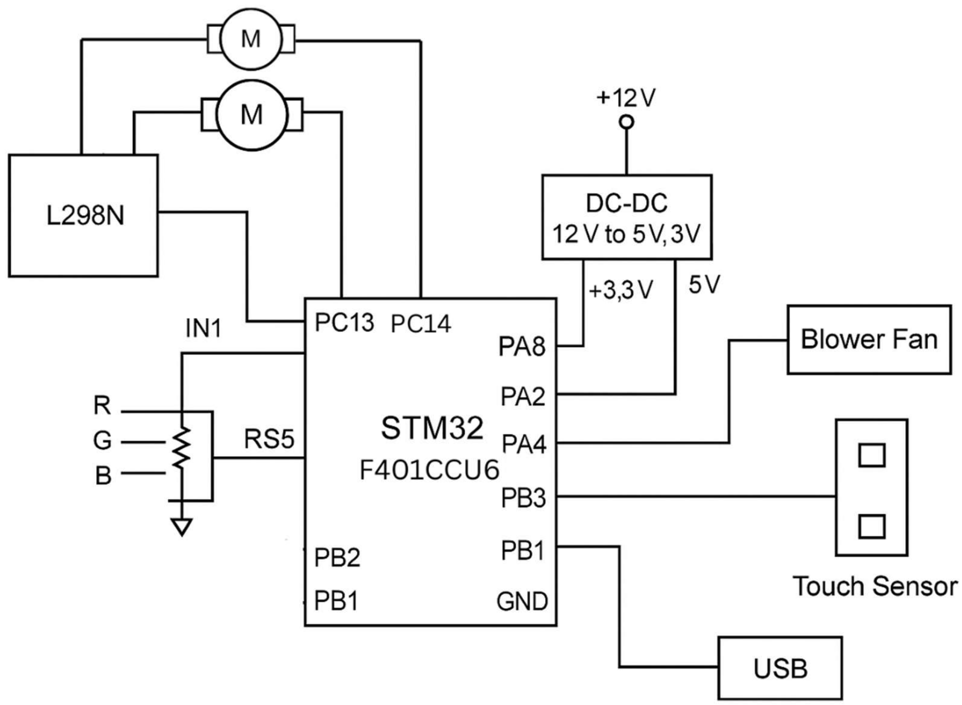

Figure 4.1 : Circuit Diagram

4.2 Hardware specification:

Table 4.1 Hardware Specification

Sr.No.	Hardware/Component
1	DC-DC 12V LDO
2	L298N Motor Driver
3	DC Motor 12V
4	Blower Fan
5	RGB Led
6	Touch Sensor TTP223

4.3 Design Consideration:

To build the water quality monitoring system, two physical units are deployed—one at the inlet and the other at the outlet of the purification tank—to enable real-time, comparative monitoring of water parameters. Each unit consists of multiple water quality sensors connected to a ESP32 microcontroller, which transmits live data to the ThingSpeak cloud platform. The system uses threshold-based logic to detect quality violations and trigger alerts on Blynk application, while historical data enables deeper analysis of purification effectiveness and system performance.

1. **Sensor Selection & Placement:** pH, TDS, turbidity, electrical conductivity, and residual chlorine sensors are strategically placed in both inlet and outlet units to measure water quality before and after purification. The placement ensures accurate detection of variations in water treatment performance.
2. **Data Collection and Integration:** Each NodeMCU gathers real-time data from its respective sensors and sends it to the ThingSpeak cloud using Wi-Fi. The data flow is continuous, enabling immediate analysis and visualization of water quality metrics across both stages.
3. **Threshold-Based Alerts:** Threshold values for each parameter are determined based on water purification standards. If outlet readings exceed these thresholds, the system triggers a buzzer and sends alerts to the operator's mobile via cloud integration, ensuring timely corrective actions.
4. **Comparative Analysis and Visualization:** The collected data from both units is plotted in real-time on the cloud. This allows for comparative analysis between inlet and outlet water quality, helping assess the efficiency of the purification process and identify issues over time.
5. **Real-Time Updates:** As sensor data is streamed in real-time, the system reflects the current condition of water at both stages, the in-situ Display as well as on Blynk Mobile Application. This enables on-the-fly monitoring, instant detection of parameter shifts, and timely alerts for anomalies.

CHAPTER 5

Chapter 5: Software Implementation

5.1 Software Required

STM32CubeIDE:

STM32CubeIDE is the primary software development platform used for programming the STM32F103C8T6 microcontroller. It offers a complete development environment that includes code writing, compiling, debugging, and device configuration tools. The IDE provides access to STM32's HAL (Hardware Abstraction Layer) libraries, which simplify peripheral configuration such as PWM generation, GPIO handling, and sensor interfacing. It also includes an integrated debugger that allows step-by-step execution and real-time monitoring of program variables, which is essential for ensuring proper logic flow and functionality across all modules in the seat control system.

Proteus:

Proteus is used for simulating the entire embedded system design in a virtual environment before the physical implementation begins. It allows real-time simulation of microcontrollers along with connected peripherals such as DC motors, sensors, LEDs, and power supply modules. In this project, Proteus plays a key role in verifying the logic of the microcontroller code, testing signal responses, and observing the behavior of motor control and touch-based interactions. It helps detect errors and refine circuit logic without risking damage to hardware components, thus reducing prototyping costs and time.

Altium Designer:

Altium Designer is employed to create the schematic and printed circuit board (PCB) layout of the complete system. It provides advanced tools for designing multilayer PCBs, accurate component placement, and routing optimization. In this project, Altium is used to design the circuit layout that integrates the STM32 microcontroller, motor driver (L298N), power supply lines, touch sensors, and all output modules like RGB lighting and blower fans. The software helps ensure electrical integrity, space-efficient design, and manufacturability. It also generates Gerber files and documentation required for professional PCB fabrication.

5.2 Software specification

STM32CubeIDE Version: STM32CubeIDE v1.12.1 or later
System Requirement: Windows 10 (64-bit) or Linux Ubuntu 18.04 and above, minimum 4GB RAM
Required Tools: Integrated STM32CubeMX, ARM GCC Compiler
Purpose: Used for embedded C code development, peripheral configuration, firmware debugging, and programming the STM32F103C8T6 microcontroller
License: Freeware provided by STMicroelectronics

Proteus Version: Proteus Design Suite 8.12 or higher.
System Requirement: Windows 7/8/10 (64-bit), minimum 4GB RAM, DirectX-compatible graphics.
Required Modules: ISIS for circuit design, VSM for virtual microcontroller simulation.
Purpose: Used for simulating the embedded system design, including motors, sensors, and microcontroller behavior.
License: Commercial (available with Student or Professional license).

Altium Designer
Version: Altium Designer 20 or later
System Requirement: Windows 10 (64-bit), Intel i5 processor or better, 8GB RAM minimum
Required Libraries: Standard component libraries, schematic and PCB layout templates
Purpose: Used for designing PCB schematics, multilayer PCB layout routing, and generation of manufacturing-ready Gerber files
License: Commercial (requires active subscription license)

5.3 Implementation

The software implementation of the Smart Automotive Seat Control Module is designed to manage the operation of several core components, including the microcontroller (STM32F103C8T6), motor controller, PWM speed control for the blower fan, DC motors, and RGB ambient lighting. The software ensures smooth interaction between user input, hardware control, and feedback to deliver an optimal user experience.

5.3.1 Microcontroller (STM32) Setup

The STM32F103C8T6 microcontroller is the heart of the system, and its setup includes configuring the necessary peripherals and system functions:

1. Clock Configuration: The system clock is set up to provide a stable timing reference necessary for controlling the motors, fan, and lighting system.
2. GPIO Configuration: General Purpose Input/Output (GPIO) pins are initialized for controlling the DC motors, PWM signals for the blower fan, and the RGB LED for ambient lighting.
3. PWM Setup: The microcontroller is configured to generate PWM signals used to control the speed of the blower fan and manage the RGB lighting intensity.
4. Timer Configuration: Timers are set up to manage the timing of PWM signals and motor operation, ensuring accurate and smooth control.

5.3.2 Motor Controller Operation

The L298N motor controller is used to control the DC motors responsible for adjusting the seat's position. The STM32 communicates with the motor controller to execute seat movements based on user input:

1. Direction Control: The software manages the direction of the motors by sending control signals to the motor controller. This allows for precise movement of the seat in various directions (vertical lift, horizontal slide, and reclining).
2. Speed Control: PWM signals generated by the microcontroller adjust the speed of the motors, ensuring smooth seat adjustments. The longer the user touches the corresponding sensor, the longer the motor continues to move, allowing fine-grained control over the seat position.
3. Motor Operation Duration: The software ensures that the motors only run for as long as the user holds the touch sensor. Once the user releases the sensor, the motor stops, providing precise control over the seat's movement.

5.3.3 PWM Speed Control for Blower Fan

The PWM speed controller modulates the speed of the blower fan based on user input. The microcontroller generates PWM signals that control the fan's operation:

1. Fan Speed Adjustment: The user can adjust the fan's speed through the touch sensor. The microcontroller changes the duty cycle of the PWM signal to increase or decrease the fan speed accordingly.

2. Smooth Fan Operation: The software ensures that changes in fan speed are smooth, avoiding abrupt transitions that could be uncomfortable for the user.
3. Energy Efficiency: By using PWM, the fan runs more efficiently, consuming less power while still providing the desired level of ventilation.

5.3.4 RGB Ambient Lighting Control

The RGB ambient lighting is controlled by the microcontroller through a GPIO pin, toggling the light on or off based on user input:

1. On/Off Control: The user can turn the RGB ambient lighting on or off by touching the corresponding sensor. A single touch toggles the light's state.
2. Basic Lighting Functionality: In this implementation, the ambient lighting only supports on/off control. However, future software updates could enable color changes or dimming functionality with minimal hardware changes.
3. Lighting Management: The microcontroller uses a simple digital output to control the RGB LED, ensuring that the lighting is activated when required for aesthetic purposes or visibility.

5.3.5 System Error Handling

The software includes basic error handling to ensure the system operates safely:

1. Motor Safety Monitoring: The software monitors motor operation to detect potential issues, such as excessive current draw, and ensures motors stop if abnormal behavior is detected.
2. PWM Duty Cycle Limits: The PWM signals are bounded within safe limits, preventing damage to the blower fan and ambient lighting components.
3. Touch Sensor Handling: The system ensures that erroneous or multiple touch events do not cause unintended behavior by implementing debouncing mechanisms.

5.3.6 Debugging and Testing

To ensure the software runs smoothly, STM32CubeIDE's debugging tools are utilized during the development phase:

1. Breakpoints and Monitoring: Breakpoints are set at key parts of the code to monitor motor control, fan speed adjustments, and lighting control.
2. Serial Debugging: Debug messages are output over the serial connection to help trace errors or check system status during testing.

CHAPTER 6

Chapter 6: Testing & Troubleshooting

6.1 Testing:

The testing phase was carried out after the full assembly and integration of all hardware components on a single module. The process involved validating each function independently, followed by system-level testing to ensure cohesive performance of the seat control module. The STM32F103C8T6 microcontroller served as the core controller for managing all peripherals. Testing was conducted under a stable 12V DC power source with regulated 5V and 3.3V outputs derived via a buck convert.

6.1.1 Motor Control Validation: Each of the three DC motors, connected via the L298N motor driver, was tested for its respective function—vertical seat adjustment, horizontal adjustment, and backrest reclination. The motors were operated using dedicated GPIO pins for direction control and PWM pins for speed modulation.

Procedure:

1. The touch sensor input was used to activate the respective motor.
2. Holding the sensor continuously allowed the motor to operate until released.
3. Directional changes were validated by alternating the logic levels of the control pins.

Result:

1. Each motor responded correctly to the touch input.
2. Directional control and continuous operation were functional as intended.

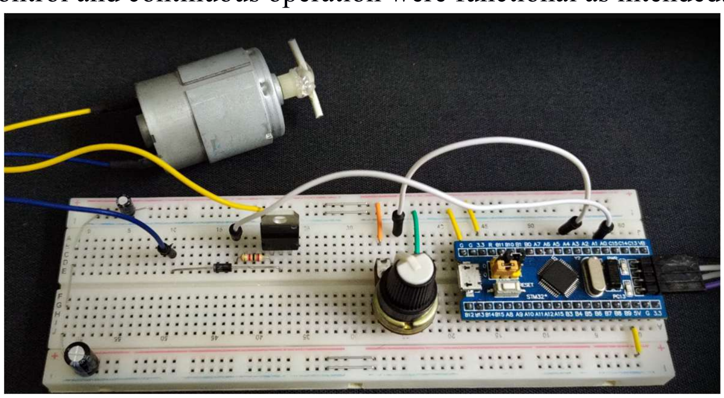

Figure 6.1 Motor Integration

6.1.2 Fan and PWM Speed Control

The blower fan was connected via a high-speed switching MOSFET circuit, driven by a PWM signal from STM32. A PWM controller knob was used to manually vary the duty cycle and hence the fan speed.

Procedure:

1. The PWM signal was initialized and varied using the controller knob.
2. The voltage across the fan was monitored using a multimeter to confirm PWM modulation.

3. Fan speed was observed to correlate with duty cycle variation.

Result:

1. Smooth fan speed variation was achieved.
2. The system successfully handled dynamic PWM values without instability.

6.1.3 RGB LED Operation

Ambient lighting was tested using an RGB LED connected through a high-side switch. The LED was toggled using touch input.

Procedure:

1. A single tap on the touch sensor controlled the on/off state.
2. Each channel (Red, Green, Blue) was separately tested by activating the corresponding GPIO pin.

Result:

1. The RGB LED responded correctly to touch activation.
2. Brightness levels were within expected range, and no flickering occurred.

6.1.4 USB Charging and Diode Protection

The USB charging module was tested under load with a mobile phone and a USB current monitor.

Procedure:

1. A mobile device was connected to the USB output.
2. Voltage levels were monitored to verify the diode protection circuit.

Result:

1. Stable 5V output was observed at the USB port.
2. Diode protection prevented any over-voltage conditions.

6.1.5 Integration Test

A full system integration test was conducted using the complete hardware setup. All features were activated sequentially and in combination.

Procedure:

1. Power was supplied to the entire module.
2. Each function was triggered using touch input.
3. Multimeter and logic analyzer tools were used for voltage and signal integrity monitoring.

Result:

1. The complete module functioned as intended.
2. No hardware conflicts, power failures, or signal issues were observed.
3. User experience was smooth, with responsive control and consistent operation.

6.2 Testing strategies & Test Procedures:

In order to ensure the reliability and robustness of the seat control module, a comprehensive testing strategy was adopted. The approach included unit-level verification, integration-level testing, and functional validation under real operating conditions. The testing strategies were devised to detect electrical faults, confirm firmware accuracy, and validate the complete system response under user interaction.

6.2.1 Testing Strategies

The testing strategy encompassed the following key phases:

- **Unit Testing:** Each component, including the DC motors, blower fan, RGB LED, USB charging module, and touch sensor, was tested independently using direct pin control from the STM32 microcontroller. This helped isolate hardware issues before integration.
- **Integration Testing:** After individual validation, subsystems were connected together. The STM32 firmware was used to simultaneously manage multiple peripherals. This phase helped detect any pin conflicts, power limitations, or timing issues between modules.
- **Black Box Testing:** The entire module was treated as a black box where inputs (touches, PWM knob rotations) were provided, and outputs (motor motion, fan speed, LED status, USB voltage) were observed. This helped assess the module's response from a user perspective.
- **Stress Testing:** Prolonged operation was simulated by running all peripherals for extended durations under nominal voltage. Load was applied to the USB port via mobile charging, and fans/motors were run continuously to test thermal and power stability.
- **Boundary Testing:** Edge-case scenarios such as maximum PWM duty cycles, back-to-back motor activation, and full current draw on the USB port were tested to ensure safe behaviour under extreme conditions.

6.2.2 Test Procedures

The testing procedures were performed in the following sequential steps:

1. Power Supply Validation
   - Confirmed stable output voltages (12V, 5V, 3.3V) using a multimeter.
   - Checked for voltage drops during load using fan and motor operation.
2. GPIO and PWM Pin Configuration
   - Verified the correct initialization of GPIO and PWM pins in STM32CubeIDE.
   - Tested pin functionality using LED blink and PWM output measurements via an oscilloscope.
3. Motor Operation Test
   - Connected one DC motor at a time to L298N.
   - Verified bidirectional rotation by toggling direction pins.
   - Used PWM pins to vary speed and observe changes in motor RPM.
4. Fan PWM Control Test
   - Connected fan to MOSFET/PWM controller setup.

- Monitored duty cycle variation via logic analyzer.
- Measured fan speed response and checked for audible instability.

5. RGB LED Behavior
    - Sent high/low signals to LED channels (R, G, B) and confirmed color combinations.
    - Verified the touch control logic toggled the ambient light as expected.
6. USB Charging Functionality
    - Measured 5V output voltage on USB terminals with a multimeter.
    - Tested mobile charging and ensured the diode protection prevented voltage spikes.
7. Touch Sensor Responsiveness
    - Touched and held the sensor to control motor motion.
    - Performed single taps to toggle LED and fan states.
    - Verified debounce logic and input reliability over multiple attempts.
8. System-Level Test
    - Connected all modules to STM32 and activated each subsystem.
    - Verified simultaneous operation without system lag or power instability.
    - Used a single hardware photo to correlate component positions during testing.

6.3 Results & Analysis:

Following systematic testing of each subsystem and the complete seat control module, the results demonstrated consistent performance aligned with the intended functionality. Each component responded accurately to user interaction, and the system operated reliably under various operating conditions. The following section presents a detailed summary and analysis of the outcomes.

Table 6.1: Results and Outcome

Functionality	Expected Behavior	Observed Outcome	Status
Vertical/Horizontal/Recline	Motor rotates in both directions based on touch input	Smooth bidirectional movement achieved	☑ Functional
Fan Speed Control (PWM)	Speed varies with PWM duty cycle	Speed accurately changed with PWM knob	☑ Functional
RGB Ambient Lighting	Toggle ON/OFF via touch input	Responsive control; stable illumination	☑ Functional
Touch Sensor Inputs	Reliable detection for ON/OFF or Hold-Down actions	All inputs detected correctly; no false triggers	☑ Functional

6.3.2 Performance Analysis

- **Motor Performance:** All three motors operated smoothly with precise directional control. No thermal issues or power brownouts were observed even under sustained operation. The L298N motor driver handled the current without fault.

- **Fan and Ventilation Control:** The 2-pin blower fan, driven via PWM through a transistor-based switching circuit, successfully demonstrated speed variation. The circuit handled rapid changes in duty cycle without voltage dips, indicating effective power modulation.
- **Lighting and Aesthetics:** The RGB LED provided a simple ambient light effect. Although the current setup supports ON/OFF functionality, future implementations could integrate colour control for richer user customization.
- **Power Distribution and Stability:** Voltage levels across all components remained within acceptable ranges during simultaneous operation. The DC-DC converter efficiently provided regulated 5V and 3.3V, and the power design was sufficient to prevent resets or fluctuations in the STM32 microcontroller.
- **User Interaction:** The TTP223 touch sensors demonstrated reliable responsiveness with minimal debounce requirements. The system correctly distinguished between short taps and prolonged presses, allowing intuitive user control.

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CHAPTER 7

Chapter 7: Advantages & Applications

7.1 Advantages

1. **Provides precise and automated control of seat positions for enhanced user comfort:** The system enables seamless seat adjustments, such as vertical lift, horizontal movement, and reclining, all controlled electronically for superior comfort and convenience.
2. **Utilizes reliable communication protocols (CAN FD, LIN FD) for robust in-vehicle networking:** The system employs high-speed communication protocols to ensure reliable and efficient data transfer between control units, ensuring the system operates smoothly even in the demanding automotive environment.
3. **Incorporates multiple safety features such as reverse polarity, failout, and short-circuit protection:** These safety mechanisms safeguard against potential electrical issues like reversed connections, component failures, and short circuits, ensuring the system's reliability and longevity.
4. **Offers real-time motor control with sensor feedback for accurate motion handling:** Sensor feedback allows for real-time monitoring and control of motor movements, providing precise adjustments for seat positioning according to user preferences.
5. **Modular hardware design allows easy integration and customization for different vehicle models:** The modular design facilitates easy adaptation to various vehicles, enabling quick integration and customization to meet different automotive configurations and user needs.
6. **Reduces driver distraction by enabling quick seat adjustment through electronic control:** The system allows for quick, easy seat adjustments with minimal effort, helping reduce distractions for the driver and enhancing safety.
7. **Increases system reliability with automotive-grade components and diagnostics support:** The use of high-quality automotive-grade components ensures durability, while built-in diagnostics support continuous monitoring and early fault detection for enhanced system reliability.
8. **Supports efficient power management and thermal protection to ensure long-term performance:** The system incorporates power management strategies and thermal protection mechanisms to optimize energy consumption and prevent overheating, ensuring long-term durability.
9. **Allows for firmware updates and configuration storage through EEPROM:** Firmware can be updated remotely, and user preferences can be stored, providing flexibility and allowing for future upgrades or configuration changes without hardware modifications.
10. **Simulation and testing environments help in early fault detection and design optimization:** Pre-deployment simulation and testing identify potential issues and optimize the design, ensuring the system functions correctly under real-world conditions before physical deployment.

7.2 Applications:

1. **Automotive seat adjustment systems in passenger vehicles:** The system provides precise control for adjusting seat positions, enhancing comfort and ergonomics in passenger vehicles by offering easy, electronic seat adjustments for both the driver and passengers.
2. **Smart seating modules in electric and autonomous vehicles:** In electric and autonomous vehicles, the system allows for dynamic seat adjustments, enhancing comfort and flexibility. This is particularly important in autonomous vehicles, where passengers may need to adjust their seat positions for leisure or work during travel.

3. **Luxury car models with memory-based seat positioning features:** The system's memory feature enables luxury vehicles to store multiple seat positions, allowing passengers to quickly return to their preferred settings. This enhances the overall comfort and personalization for high-end car models.
4. **Driver-assist systems that automatically adjust seat based on user profile:** The system can integrate with driver-assist technologies to automatically adjust seat positions based on user profiles, ensuring optimal comfort and support for each driver every time they use the vehicle.
5. **Integration with in-vehicle infotainment and comfort systems** The seat control module can be seamlessly integrated with in-vehicle infotainment systems, enabling the synchronization of seat adjustments with entertainment or climate control settings for a more personalized user experience.
6. **Commercial vehicles requiring adjustable seating for long-distance travel** In commercial vehicles like trucks and buses, the system provides adjustable seats designed for long-duration comfort, reducing fatigue for drivers and passengers in long-distance travel scenarios.
7. **Research and development of next-gen intelligent seating platforms** The system supports the research and development of future seating technologies, contributing to the creation of more adaptive and intelligent seat control solutions that incorporate advanced sensors, AI, and real-time user data to improve comfort.
8. **Rehabilitation and mobility-assistive vehicles with personalized seat control** The system is essential for rehabilitation and mobility-assistive vehicles, offering personalized seat adjustments to meet the needs of individuals with mobility challenges, providing them with comfort and ease of movement.

CHAPTER 8

Chapter 8: Conclusion & Future scope

8.1 Conclusion:

The Smart Automotive Seat Control Module represents a significant advancement in automotive comfort and user convenience, integrating innovative features such as automated seat adjustments, personalized settings, and enhanced comfort controls. By incorporating essential functionalities like precise motor control, dynamic seat positioning, ventilation, ambient lighting, and mobile charging, the system greatly improves the overall user experience, making long drives more comfortable and convenient.

Utilizing modern communication protocols and advanced microcontroller systems, the project ensures seamless operation and reliability, while also considering safety features like reverse polarity and short-circuit protection to guarantee longevity and smooth performance. The integration of capacitive touch sensors, PWM controllers, and feedback mechanisms enhances the interactive nature of the system, allowing for real-time adjustments based on user input.

Moreover, the modular design of the system allows for easy adaptation to various vehicle types, from passenger cars to commercial vehicles, and offers potential for future enhancements, such as wireless connectivity or integration with advanced driver-assist systems. This project not only aligns with current trends in automotive technology but also sets the stage for future innovations in intelligent and adaptive seating platforms.

In conclusion, the Smart Automotive Seat Control Module serves as a pivotal step forward in transforming automotive interiors, providing comfort, functionality, and personalization, while ensuring safety and efficiency across diverse vehicle models. It exemplifies the convergence of electronics, design, and user-centered innovation, marking a key milestone in the development of modern automotive technologies.

8.2 Future scope:

Smart Automotive Seat Control Module offers significant potential for enhancing the user experience and adapting to evolving automotive technologies. By integrating wireless connectivity, the system could enable remote seat adjustments via mobile apps, providing convenience and seamless integration with other smart home devices. Furthermore, it could be linked with advanced driver-assistance systems (ADAS) to automatically adjust seats based on driver preferences and safety requirements, offering personalized comfort. The incorporation of voice command capabilities and AI-based adaptive seat adjustments could further reduce distractions and tailor the system to individual user needs. Additionally, future developments could focus on more advanced lighting, ventilation, and health-monitoring features, offering customizable environments based on real-time user data. As electric vehicles become more widespread, the system will need to focus on energy efficiency and sustainability, potentially integrating low-power components and energy-harvesting techniques. Safety features could also be enhanced with sensors to detect improper seat adjustments or obstacles, ensuring a secure experience. Ultimately, the system could expand beyond passenger vehicles to include commercial and autonomous vehicles, enhancing comfort and usability across a variety of transportation sectors. As the technology progresses, the Smart Automotive Seat Control Module has the potential to become a key element in the future of automotive comfort, safety, and personalization.

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Appendix A : Data sheets

Datasheet STM32F401CCU6:

STM32F401xB STM32F401xC

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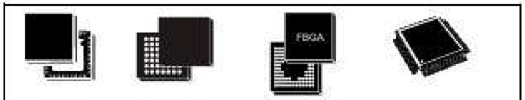
Arm® Cortex®-M4 32-bit MCU+FPU, 105 DMIPS, 256KB Flash / 64KB RAM, 11 TIMs, 1 ADC, 11 comm. interfaces

Datasheet - production data

Features

- Dynamic efficiency line with BAM (batch acquisition mode)
  - 1.7 V to 3.6 V power supply
  - -40 °C to 85/105/125 °C temperature range
- Core: Arm® 32-bit Cortex®-M4 CPU with FPU, Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait state execution from Flash memory, frequency up to 84 MHz, memory protection unit, 105 DMIPS/ 1.25 DMIPS/MHz (Dhrystone 2.1), and DSP instructions
- Memories
  - Up to 256 Kbytes of Flash memory
  - 512 bytes of OTP memory
  - Up to 64 Kbytes of SRAM
- Clock, reset and supply management
  - 1.7 V to 3.6 V application supply and I/Os
  - POR, PDR, PVD and BOR
  - 4-to-26 MHz crystal oscillator
  - Internal 16 MHz factory-trimmed RC
  - 32 kHz oscillator for RTC with calibration
  - Internal 32 kHz RC with calibration
- Power consumption
  - Run: 128 µA/MHz (peripheral off)
  - Stop (Flash in Stop mode, fast wakeup time): 42 µA typ @ 25 °C; 65 µA max @25 °C
  - Stop (Flash in Deep power down mode, slow wakeup time): down to 10 µA typ@ 25 °C; 28 µA max @25 °C
  - Standby: 2.4 µA @25 °C / 1.7 V without RTC; 12 µA @85 °C @1.7 V
  - V_{BAT} supply for RTC: 1 µA @25 °C
- 1×12-bit, 2.4 MSPS A/D converter: up to 16 channels
- General-purpose DMA: 16-stream DMA controllers with FIFOs and burst support
- Up to 11 timers: up to six 16-bit, two 32-bit timers up to 84 MHz, each with up to 4 IC/OC/PWM or pulse counter and quadrature (incremental) encoder input, two watchdog timers (independent and window) and a SysTick timer



- Debug mode
  - Serial wire debug (SWD) & JTAG interfaces
  - Cortex®-M4 Embedded Trace Macrocell™
- Up to 81 I/O ports with interrupt capability
  - All IO ports 5 V tolerant
  - Up to 78 fast I/Os up to 42 MHz
- Up to 11 communication interfaces
  - Up to 3 × I²C interfaces (1Mbit/s, SMBus/PMBus)
  - Up to 3 USARTs (2 x 10.5 Mbit/s, 1 x 5.25 Mbit/s), ISO 7816 interface, LIN, IrDA, modem control)
  - Up to 4 SPIs (up to 42 Mbits/s at f_{CPU} = 84 MHz), SPI2 and SPI3 with muxed full-duplex I²S to achieve audio class accuracy via internal audio PLL or external clock
  - SDIO interface
- Advanced connectivity
  - USB 2.0 full-speed device/host/OTG controller with on-chip PHY
- CRC calculation unit
- 96-bit unique ID
- RTC: subsecond accuracy, hardware calendar
- All packages are ECOPACK2

Table 1. Device summary

Reference	Part number
STM32F401xB	STM32F401CB, STM32F401RB, STM32F401VB
STM32F401xC	STM32F401CC, STM32F401RC, STM32F401VC

Figure 9.1 Datasheet STM32F401CCU6

Datasheet Touch Sensor TTP223:

1 KEY TOUCH PAD DETECTOR IC

GENERAL DESCRIPTION

The TTP223 is a touch pad detector IC which offers 1 touch key. The touching detection IC is designed for replacing traditional direct button key with diverse pad size. Low power consumption and wide operating voltage are the contact key features for DC or AC application.

FEATURES

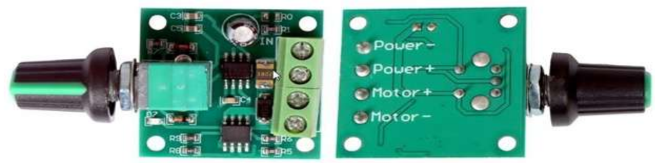
- Operating voltage 2.0V~5.5V
- Operating current @VDD=3V, no load, SLRFTB=1
  At low power mode typical 1.5uA, maximum 3.0uA
  At fast mode typical 3.5uA, maximum 7.0uA
  @VDD=3V, no load, SLRFTB=0
  At low power mode typical 2.0uA, maximum 4.0uA
  At fast mode typical 6.5uA, maximum 13.0uA
- The response time max about 60mS at fast mode, 220mS at low power mode @VDD=3V
- Sensitivity can adjust by the capacitance(0~50pF) outside
- Have two kinds of sampling length by pad option(SLRFTB pin)
- Stable touching detection of human body for replacing traditional direct switch key
- Provides Fast mode and Low Power mode selection by pad option(LPMB pin)
- Provides direct mode、toggle mode by pad option(TOG pin)
  Open drain mode by bonding option, OPDO pin is open drain output,
  Q pin is CMOS output
- All output modes can be selected active high or active low by pad option(AHLB pin)
- Have the maximum on time 100sec by pad option(MOTB pin)
- Have external power on reset pin(RST pin)
- After power-on have about 0.5sec stable-time, during the time do not touch the key pad,
  And the function is disabled
- Auto calibration for life
  And the re-calibration period is about 4.0sec, when key has not be touched

APPLICATION

- Wide consumer products
- Water proofed electric products
- Button key replacement

Figure 9.2: Datasheet Touch Sensor

Datasheet PWM Speed Controller:



Description:

The DC Motor PWM Speed Regulator 1.8V, 3V, 5V, 6V, 12V-2A speed control switch function for DC Motors allows controlling the direction of a DC motor using a Pulse-Width-Modulated (PWM) DC voltage with a Duty Cycle fully adjustable from 0%-100%.

The motor speed controller can easily provide a continuous current of 2A to your DC motor or other DC load. This motor speed controller allows controlling the direction of a DC motor using a pulse-width-modulated (PWM) DC voltage. With a resettable fuse, it can automatically break the connection and automatically recover. With a LED indicator and a rotary switch, convenient to use.

Features:

1. Output current: 2A(Max).
2. With a resettable fuse.
3. Equipped with LED indicator.
4. Potentiometer with switch function for PWM adjustment.

Specifications:

- Input Voltage Range: 1.8V- 15V DC.
- The maximum output power: 30W
- Output current: 2A(Max).
- Duty Cycle adjustable: 5%-100%
- Diameter of PCB holes: 3mm
- Pitch of screw terminal block: 5.08mm
- Dimension: 32x32mm
- Weight (gm): 16

Operating instructions:

- Connect your DC motor (or DC load) to the motor terminals as indicated on the wiring diagram.
- Connect a voltage of 1.8V-15V DC to the circuit making sure of the correct polarity of the connection. Note that the voltage applied to the motor will be the supply voltage applied to the circuit.
- You can now control the speed of the motor through the potentiometer.

Pin function:

Motor+	Motor Positive Terminal
Motor-	Motor Negative terminal
Power+	DC 1.8V- 15V
Power-	GND

Applications:

- For Speed Control Of all Types of DC Brush Motors
- For Controlling Automotive Cooling Fan Speed, Auto Fan Speed, Windshield Wipers, Auto Air Conditioning.
- For Controlling Belt Speed, Pipeline Exhaust Fan Speed, Treadmill Speed, Multi-Speed Parallel Computer Fan, Electronic Fan Speed.

Figure 9.3 : Datasheet PWM Speed Controller

Datasheet L298N Motor Driver:

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L298

Datasheet

Dual full-bridge driver

Features

- Operating supply voltage up to 46 V.
- Total dc current up to 4 A.
- Low saturation voltage.
- Overtemperature protection.
- Logical "0" input voltage up to 1.5 V (high noise immunity).

Applications

- Dual brush DC motors
- Stepper motors

Description

The L298 is an integrated monolithic circuit in a 15-lead multiwatt and PowerSO-20 packages. It is a high-voltage, high-current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors.

Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

Product summary
L298

Product label
SUSTAINABLE TECHNOLOGY

Pin description

Figure 2. Pin configuration

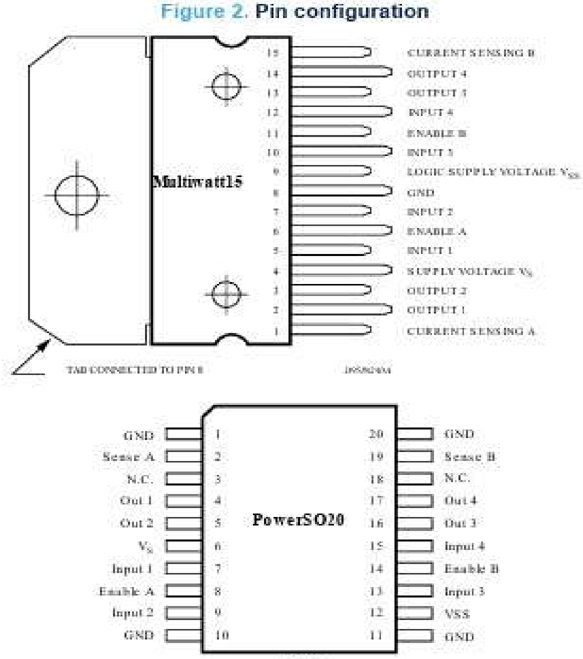

Table 3. Pin function

Figure 9.4 Datasheet L298N Motor Driver

Datasheet DC-DC 12V LDO:

Description:

12V to 3.3V 5V 12V DC-DC Voltage Converter power module efficiently converts a 6V to 12V DC input into three distinct outputs: 3.3V, 5V, and a direct pass-through of the input voltage (12V nominally). Also known as a buck converter or step-down voltage converter, this module regulates the input voltage to provide stable and reliable power to your connected devices.

Its multi-output design makes it an invaluable tool for electronics projects, allowing you to power multiple components with different voltage requirements simultaneously. Ideal for DIY enthusiasts and professional engineers alike, this compact and easy-to-use module simplifies power management in a wide range of applications, from hobbyist projects to embedded systems. Keep a few of these essential power supplies on hand for your next electronic design or repair.

Specification:

- Input Voltage: 6~12V
- Connector: 5.5mm Power Jack
- Output Voltage: 3.3V and 5V
- Error Voltage: 0.05V

Features:

- Output power on/off switch
- Two-row multiple-pin outputs, easy to use and connect
- Red LED illuminates when input DC power is supplied and output is turned ON.
- Outputs
    - 3.3V DC at 800mA maximum current
    - 5.0V DC at 800mA maximum current
    - 12V DC (the 12V output is directly connected to the input, i.e. with 12VDC input, this output will be 12VDC; with 9VDC input, this output will be 9VDC)
- Small and Handy Module.
- Dual-side plate design
- Easy to use.

Figure 9.5 Datasheet DC-DC 12V LDO

Appendix B: Program

Program for STM32:

```
#define BLYNK_TEMPLATE_ID "TMPL3IrLgo1-Q"
#include "main.h"

// Define your GPIO pins for touch inputs, motors, and RGB
#define TOUCH_RGB_Pin      GPIO_PIN_0
#define TOUCH_RGB_GPIO_Port GPIOA

#define TOUCH_MOTOR1_Pin   GPIO_PIN_1
#define TOUCH_MOTOR1_GPIO_Port GPIOA

#define TOUCH_MOTOR2_Pin   GPIO_PIN_2
#define TOUCH_MOTOR2_GPIO_Port GPIOA

#define TOUCH_MOTOR3_Pin   GPIO_PIN_3
#define TOUCH_MOTOR3_GPIO_Port GPIOA

#define RGB_LED_Pin        GPIO_PIN_4
#define RGB_LED_GPIO_Port  GPIOA

// Motor 1 Pins (Vertical)
#define M1_IN1_Pin        GPIO_PIN_5
#define M1_IN2_Pin        GPIO_PIN_6
#define M1_GPIO_Port       GPIOA

// Motor 2 Pins (Horizontal)
#define M2_IN1_Pin        GPIO_PIN_7
#define M2_IN2_Pin        GPIO_PIN_8
#define M2_GPIO_Port       GPIOA

// Motor 3 Pins (Recline)
#define M3_IN1_Pin        GPIO_PIN_9
#define M3_IN2_Pin        GPIO_PIN_10
#define M3_GPIO_Port       GPIOA

// Variables
uint8_t rgb_state = 0;

void SystemClock_Config(void);
static void MX_GPIO_Init(void);

// Motor control helper
void move_motor(GPIO_TypeDef* port, uint16_t in1, uint16_t in2, uint8_t dir) {
  if (dir) {
    HAL_GPIO_WritePin(port, in1, GPIO_PIN_SET);
    HAL_GPIO_WritePin(port, in2, GPIO_PIN_RESET);
  } else {
    HAL_GPIO_WritePin(port, in1, GPIO_PIN_RESET);
    HAL_GPIO_WritePin(port, in2, GPIO_PIN_SET);
  }
}

void stop_motor(GPIO_TypeDef* port, uint16_t in1, uint16_t in2) {
  HAL_GPIO_WritePin(port, in1, GPIO_PIN_RESET);
  HAL_GPIO_WritePin(port, in2, GPIO_PIN_RESET);
}

int main(void) {
```

```
    HAL_Init();
    SystemClock_Config();
    MX_GPIO_Init();

    while (1) {
      // RGB Toggle
      if (HAL_GPIO_ReadPin(TOUCH_RGB_GPIO_Port, TOUCH_RGB_Pin) == GPIO_PIN_SET) {
        HAL_Delay(200);  // debounce delay
        rgb_state = !rgb_state;
        HAL_GPIO_WritePin(RGB_LED_GPIO_Port, RGB_LED_Pin, rgb_state);
        while (HAL_GPIO_ReadPin(TOUCH_RGB_GPIO_Port, TOUCH_RGB_Pin) == GPIO_PIN_SET);
      }

      // Motor 1 (Vertical)
      if (HAL_GPIO_ReadPin(TOUCH_MOTOR1_GPIO_Port, TOUCH_MOTOR1_Pin) == GPIO_PIN_SET)
  {
        move_motor(M1_GPIO_Port, M1_IN1_Pin, M1_IN2_Pin, 1); // direction = 1
      } else {
        stop_motor(M1_GPIO_Port, M1_IN1_Pin, M1_IN2_Pin);
      }

      // Motor 2 (Horizontal)
      if (HAL_GPIO_ReadPin(TOUCH_MOTOR2_GPIO_Port, TOUCH_MOTOR2_Pin) == GPIO_PIN_SET)
  {
        move_motor(M2_GPIO_Port, M2_IN1_Pin, M2_IN2_Pin, 1);
      } else {
        stop_motor(M2_GPIO_Port, M2_IN1_Pin, M2_IN2_Pin);
      }

      // Motor 3 (Recline)
      if (HAL_GPIO_ReadPin(TOUCH_MOTOR3_GPIO_Port, TOUCH_MOTOR3_Pin) == GPIO_PIN_SET)
  {
        move_motor(M3_GPIO_Port, M3_IN1_Pin, M3_IN2_Pin, 1);
      } else {
        stop_motor(M3_GPIO_Port, M3_IN1_Pin, M3_IN2_Pin);
      }

      HAL_Delay(10);  // Small delay for CPU load
    }
  }
```

Appendix C: Bill of Materials (Component List & Costing)

Table 9.1: Bill Of Material

Sr.No	Hardware/Components	Cost
1	DC-DC 12V LDO	50
2	STM32F401CCU6	300
3	L298N Motor Driver	290
4	DC Motor 12V 2A	195
5	Blower Fan	160
6	RGB LED	10
7	PWM Motor Speed Controller	50
8	Touch Sensor TTP223	80
9	Zero PCB	80
10	Charging Adapter 12V	180