Design and Development of a 3D-Printed Scaled Electric Vehicle Model for Educational Purposes

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***Abstract* — We built a sub-meter electric vehicle for our undergraduate lab as first-year B.Tech students. It runs at 12 V, weighs 3 kg, and fits on a workbench. The point was simple: give first-year students a real EV they can take apart, break, fix, and instrument — without the cost or the danger of a high-voltage rig. The chassis is 3D-printed in PLA and PETG, but the floor plate is hard aluminium because the polymer alone twisted under cornering loads in early trials. Two gear-reduced 12 V brushed motors drive the rear wheels through L298N H-bridges. An ESP32 handles PWM, runs a discrete PID loop, and pushes telemetry over Wi-Fi to a small browser dashboard. Battery management is simulated rather than implemented in silicon, which is a deliberate teaching choice. Bench tests showed the structure took roughly twice the design load before any visible flex, and runtime per charge sits near 30 minutes on the 5200 mAh pack. Total bill of materials: a little under INR 20,000 per unit.**

***Index Terms* — 3D printing, battery management, electric vehicle, mechatronics education, motor control, sustainable mobility.**

I. INTRODUCTION

EV courses are showing up everywhere right now, but the labs aren't keeping pace. Most undergraduate programs that teach electric mobility hit the same wall: the equipment that lets you actually demonstrate a working drivetrain — dynamometers, traction inverters, real battery packs — is expensive, hazardous, or both. So students learn EV theory in lecture and never touch a motor, particularly in the early years of a B.Tech program where high-voltage exposure is restricted.

As first-year B.Tech students, we wanted to fix that for ourselves and for the cohorts that follow us. The brief was modest. Build something an undergraduate can pick up, plug in, drive across the lab floor, and instrument with their own code. Keep it under 24 V so we don't need a safety annex every time someone wants to use it. And keep the parts list cheap enough that if a wishbone snaps, we just print another one.

This paper describes what we built and what we learned. Section II lays out the design objectives and the resulting specifications. Section III covers the mechanical design and the printing parameters. Section IV covers the electrical stack. Section V describes the firmware and the PID loop. Section VI reports what worked, what didn't, and what surprised us.

II. DESIGN OBJECTIVES AND SYSTEM OVERVIEW

A. Design Objectives

Four constraints drove the design. First, sub-one-metre length, so the vehicle fits on a benchtop and inside a standard storage crate. Second, fabrication using 3D printing and off-the-shelf components, keeping the parts list within a typical departmental budget. Third, every electrical node sits at or below 12 V — this single rule eliminated the bulk of the safety paperwork. Fourth, no black boxes. Students should be able to see and probe each subsystem: battery, motor driver, controller, sensor bus.

B. System Specifications

The finished platform is 0.8 m long, 0.45 m wide, and 0.35 m tall. Wheelbase is 0.50 m. Curb mass is 3 kg. Two rear wheels are independently driven, and the front uses an Ackermann steering linkage actuated by a single hobby servo. Top scaled speed is roughly 2 km/h — slow on purpose, because the goal is observability, not racing. A 3S 12 V 5200 mAh lithium-polymer pack gives about 30 minutes of continuous drive time before the low-voltage cutoff trips. Structural parts are split between PLA, where stiffness matters more than impact, and PETG, where they take a knock or sit near the motors. The ESP32 acts as the master controller, generating PWM for the drivers and the steering servo while pushing live telemetry over Wi-Fi. A USB-serial fallback channel is provided for indoor testing, where the Wi-Fi at the lab is occasionally unreliable.

III. MECHANICAL DESIGN

A. Chassis Architecture

The chassis is a space-frame lattice. We chose this topology after a brief detour through monocoque sketches that proved too heavy in PLA. The body splits into three modules. The front module carries the steering servo and the suspension wishbones. The middle module holds the battery, the controller PCB, and the wiring harness. The rear module integrates the motor mounts and the power distribution bus.

One detail matters more than it sounds: the floor of the central module is not printed. It is a hard-aluminium plate fitted into a recess in the printed frame. We added this after early prototypes flexed visibly during tight turns, throwing the wheel alignment off enough that the PID loop started fighting the chassis instead of the road. The aluminium plate fixes that. PLA and PETG, even at 100% infill, simply will not give you the torsional stiffness you need at this scale.

Geometry was developed in Autodesk Fusion 360 and exported as STL for slicing. Fig. 1 shows the assembled CAD model.

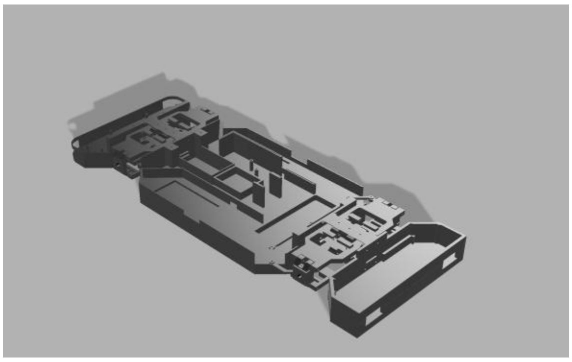

Fig. 1. CAD Render of the 3D-Printed Chassis.

B. Print Specifications

Print parameters are listed in Table I. The 10% gyroid infill was a compromise. Higher infill made parts heavier without meaningfully improving stiffness in the directions we cared about, and gyroid in particular gives near-isotropic properties, which mattered because we couldn't predict every load direction the chassis would see in student hands. Wall thickness was set at 3.0 mm so the outer skin alone could carry most of the bending load.

Parameter	Value
Wall thickness	3.0 mm
Infill pattern	10% gyroid
Layer height	0.2 mm
Filament	PETG (~2 kg total)
Underbody material	Hard aluminium plate
Assembly fasteners	M2, M3, M4 stainless

Table I. 3D Printing and Assembly Parameters

C. Suspension and Transmission

The front axle uses an independent double-wishbone setup. Linkages are printed; the wheels are 90 mm rubber tyres. The rear wheels couple straight to gear-reduced DC motors rated 150 rpm and 5 kg·cm at 12 V. We considered putting a belt or chain drive in for educational value, but the direct coupling proved more reliable and freed up firmware cycles for control rather than mechanical compensation. Torque balance between left and right rear wheels is handled in software — each motor's PWM duty cycle is trimmed independently using PWM control feedback.

IV. ELECTRICAL AND ELECTRONIC SUBSYSTEMS

Component selection prioritised availability over performance. Everything in Table II can be sourced from common online retailers. Two L298N dual H-bridges drive the rear motors. The ESP32 handles all timing-critical work. The battery pack is a 3S lithium-ion build at 12 V nominal, 8 Ah capacity, fused at the bus to limit fault currents.

Subsystem	Configuration
Battery pack	3S Li-ion, 12 V, 8 Ah
Traction motors	12 V brushed DC × 2
Motor driver	L298N dual H-bridge × 2
Controller	ESP32 (dual-core, Wi-Fi/BLE)

Table II. Powertrain Configuration

V. CONTROL SYSTEM ARCHITECTURE

A. Signal and Power Topology

Power flows battery → fuse → L298N → motors. Signals flow ESP32 → driver enable + PWM pins → motors and steering servo. Sensor data goes the other way: an ultrasonic ranger feeds the ESP32 for lowspeed obstacle detection during semi-autonomous runs. Telemetry leaves the ESP32 over Wi-Fi to a browser-based dashboard.

B. Software Layers

Firmware is layered, summarised in Table III. The intent is that the high-level mission code can be modified without breaking PWM timing, since the low-level layer is isolated.

Layer	Function
Low-level	PWM generation, sensor sampling
Mid-level	Speed and direction PID control
High-level	Mission logic, battery supervision
Telemetry	Wi-Fi dashboard, live plotting

Table III. Software Stack

C. PID Control Law

Each rear motor runs an independent parallel PID loop:

$$PWM_{out}(t) = K_p\, e(t) + K_i \int e(t)\, dt + K_d\, de(t) / dt \quad (1)$$

where $e(t) = \omega_{ref} - \omega_{meas}$ is the difference between the commanded and measured wheel speeds. Gains were tuned empirically. We started broad, watched the response on the live telemetry plot, and tightened from there until step changes settled cleanly without overshoot.

VI. RESULTS AND DISCUSSION

A. Educational Outcomes

As first-year B.Tech students working on this build, we engaged directly with battery sizing, motor selection, signal conditioning, sensor calibration, and the bridge between the printed chassis and the firmware. The fast print-test-revise cycle matters more than we initially expected. A part can break, get redesigned in Fusion, print overnight, and be on a working vehicle the next morning. That kind of turnaround simply does not exist on machined parts, and it changes how willing you are to experiment.

B. Technical Observations

The PETG structure with 10% gyroid infill held up well. Bench loading went to roughly twice the calculated operating load before any visible flex appeared — comfortable margin for classroom handling. The simulated regenerative braking demonstrated the principle of energy recovery during deceleration, although the recovered fraction was modest. The real win was the telemetry layer. Current draw spikes show up on the live dashboard the instant a wheel slips or hits a seam in the floor. That kind of visceral feedback is hard to manufacture in a lecture.

C. Advantages

Sub-12 V operation eliminates most of the safety paperwork. Total BOM lands a little under INR 20,000 per unit, which puts per-team replication within reach for a typical departmental budget. FDM printing and standard-size fasteners mean a broken part is a 2-hour fix, not a 2-week wait.

D. Limitations

The car is slow. Gear-reduced motors trade speed for torque, and we picked torque. Top scaled speed is around 2 km/h, which is fine for educational demos but boring if a student wants to race. PETG also softens above about 45 °C, which becomes a problem for any outdoor testing in hot conditions. The regenerative braking is open-loop — it shows the principle but doesn't implement closed-loop charge management on the storage element. We're aware of this and it's on the future-work list.

VII. SUSTAINABILITY AND SAFETY

Sub-12 V operation makes the platform inherently safe for unsupervised use during scheduled lab hours. Mechanical sections are PETG — recyclable, and broadly biodegradable in industrial composting streams. Because the vehicle is fully electric and emits nothing, we run all testing indoors without ventilation considerations. None of this is novel; it is just a consequence of building small.

VIII. FUTURE WORK

Five upgrades are queued. A 10 W rooftop solar panel will let students experiment with renewable harvesting on a real platform. A TinyML prediction layer will run on-device, forecasting remaining range from instantaneous current draw and historical drive cycles. The drivetrain will move from brushed DC to a rear-wheel BLDC pair with a mechanical differential, which opens the door to teaching field-oriented control. Closed-loop regenerative braking with a supercapacitor buffer is the natural successor to the current open-loop demo. Finally, a ROS 2 digital twin is in early scoping; the goal is to let a student write navigation code in simulation, then deploy the same code unchanged onto the physical vehicle. A modest battery thermal-management board, monitoring per-cell temperature, will round out the hardware additions.

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