Design of an Automatic Gear Shift Mechanism for Bicycle

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***Abstract*—The rapid growth in urban cycling and the increasing need for accessible, rider-friendly transportation has brought attention to the limitations of conventional manual gear shifting in bicycles. Manual gear changing demands constant rider attention and prior experience, which reduces riding comfort and efficiency, particularly on undulating or mixed terrain. This project presents the design and development of an automatic gear change mechanism for bicycles that operates using real-time sensor data. The proposed system integrates a Hall Effect sensor for wheel speed measurement and an MPU6050 Inertial Measurement Unit (IMU) for road inclination detection. An Arduino Nano microcontroller processes the sensor inputs and executes a gear-selection algorithm that determines the optimal front and rear gear combination based on speed thresholds and terrain angle. An OLED display provides real-time feedback of gear position and riding parameters to the rider. The gear actuation is achieved through a servo motor connected to the bicycle derailleur. The system incorporates anti-cross-chaining logic to prevent mechanically harmful gear combinations, thereby extending drivetrain life. The total component cost is approximately ₹1,000–1,500, making it an affordable and practical solution for everyday use. The project demonstrates a successful application of mechatronics principles to real-world mobility challenges, with significant potential for extension through AI-based adaptive gear logic, GPS terrain prediction, and IoT connectivity.**

***Index Terms*—Automatic Gear Shifting; Arduino Nano; Hall Effect Sensor; MPU6050; Servo Motor; Derailleur Automation; Mechatronics; Embedded Systems**

I. INTRODUCTION

Cycling is one of the most sustainable and health-beneficial modes of transport globally. However, the efficiency of cycling is heavily dependent on appropriate gear selection — a task that requires the rider to assess terrain gradient, riding speed, and physical effort simultaneously. Conventional manual gear-shifting systems demand significant rider attention and experience, often leading to sub-optimal gear choices that result in fatigue, reduced speed, and drivetrain wear.

The concept of automatic transmission is well-established in the automotive industry, yet it remains largely absent in the bicycle market due to cost and complexity constraints. Recent advances in low-cost microcontrollers, MEMS sensors, and embedded electronics have made it feasible to develop compact, reliable, and affordable automatic gear-shifting solutions for bicycles.

This project addresses this gap by designing a sensor-driven, Arduino-based automatic gear change mechanism. By continuously monitoring speed via a Hall Effect sensor and road inclination via an MPU6050 IMU, the system autonomously selects the most appropriate gear combination and actuates the derailleur through a servo motor, reducing the cognitive load on the rider and optimizing pedaling efficiency.

The system is designed to be universal compatible with standard bicycle derailleur systems — and is built using commercially available, low-cost components. This makes the solution accessible to a broad range of users, including beginners, commuters, and riders with physical limitations.

II. LITERATURE REVIEW

Recent developments in mechatronics and smart mobility have led to the integration of sensors and microcontrollers in bicycles to improve rider comfort and efficiency. Conventional bicycles rely on manual gear shifting, which depends on rider experience,

speed estimation, and terrain awareness. Researchers have highlighted that improper gear selection leads to rider fatigue, inefficient pedaling, and reduced performance [1], [2]. Automated gear shifting systems have been proposed to eliminate human error and enhance riding efficiency.

Many studies emphasize the use of Hall effect sensors to measure wheel speed accurately. In addition, inertial measurement units (IMUs) such as MPU6050 are widely used to detect inclination and road gradient [3]. Microcontrollers like Arduino Nano have been commonly adopted due to low cost, compact size, and ease of programming [4]. Previous work shows that combining speed and gradient sensing can significantly improve gear selection accuracy.

Servo motors have been successfully implemented as actuators for gear shifting in experimental prototypes. Research also shows that automatic gear shifting reduces rider distraction and enhances safety. The system is especially beneficial for beginners and physically challenged riders [5], [6]. However, literature also highlights limitations such as sensor noise due to vibration and the need for proper calibration.

Some existing systems lack cross-chaining protection, leading to increased chain wear. Despite these limitations, automated bicycle transmission systems show strong potential for future smart transportation. Integration with IoT, AI, and mobile applications is identified as a key research direction. The following table summarizes key reviewed works and identifies the gap this project addresses.

Table I. Literature Review Summary and Gap Analysis

Paper	Authors & Year	Key Contribution	Gap
Fuzzy Logic-Based Auto Gear-Shifting for E-Bikes	Lee & You (2025)	FLC-based shifting using acceleration, slope, cadence.	Limited to e-bikes; no low-cost hardware.
Auto Gear Shifting from Physiological Info	Lin & Wu (2021)	Random Forest ML with physiological sensors.	High cloud dependency; not real-time embedded.
Moving Cassette Electronic Gear-Shift for HPVs	Baldissera et al. (2019)	Cadence & torque sensors; performance validated.	Complex; high cost — not viable for retrofit.
Automation of Gears in Bicycle	Thakkar et al. (2022)	Arduino + speed sensor + servo + LCD display.	Speed only; no terrain or cross-chain logic.
Semi-Automated Transmission for Bikes	Catenaro et al. (2024)	Data-driven control for smooth shifting.	Designed for motorcycles; not bicycles.
Two-Speed Transmission for EVs	Various (2020)	Torque trajectory control for shift quality.	Electric drivetrains only; impractical for pedaling.

From the literature, it is evident that while automatic gear shifting has been explored extensively in powered vehicles and high-end e-bikes, there exists a clear gap for a low-cost, sensor-based, retrofit solution applicable to conventional bicycles. This project fills that gap by combining speed and terrain sensing with simple decision logic executable on an Arduino Nano.

III. OBJECTIVES

The key objectives of this project are:

- Design a sensor-based automatic gear shifting mechanism compatible with standard bicycle drivetrains.
- Measure bicycle speed in real time using a Hall Effect sensor and wheel-mounted magnets.
- Detect road gradient and terrain type using the MPU6050 IMU sensor.
- Implement a gear-selection algorithm on an Arduino Nano for automatic front and rear gear selection based on speed and inclination.
- Actuate the derailleur using an HS-755 MG servo motor for smooth and reliable gear changes.
- Incorporate anti-cross-chaining protection logic to prevent harmful gear combinations.
- Display real-time speed, inclination, and gear position data on an SSD1306 OLED display.
- Achieve the complete system within a budget of approximately ₹1,000–1,500.

IV. THEORY

- The theoretical foundation of the proposed system is based on sensor-driven speed and inclination measurement, deterministic gear selection logic, anti-cross-chaining constraint enforcement, and

servo actuation control.

- Wheel speed is derived from Hall Effect sensor pulse frequency. Each magnet pass generates a falling-edge interrupt. Speed is computed as:

Speed (km/h) = Pulse Count × Circumference × 3.6 (1)

- Road inclination is computed from MPU6050 raw accelerometer data using:

Angle (°) = atan2(accelY, accelZ) × (180 / π) (2)

- Terrain is classified into three zones:

Uphill: Angle > 10°, Flat: −5° ≤ Angle ≤ 10°, Downhill: Angle < −5° (3)

- The gear actuation command maps the selected gear index to a servo PWM duty cycle. Anti-cross-chaining constraints are enforced as hard limits:

If (FG = 1 AND RG = 7) → RG := 5 (4)

If (FG = 3 AND RG = 1) → RG := 3 (5)

- Where FG = Front Gear index, RG = Rear Gear index. This theoretical framework enables deterministic, explainable, and scalable gear automation.

V. PROPOSED SYSTEM & BLOCK DIAGRAM

The proposed system is a closed-loop mechatronic assembly that continuously reads sensor data, computes the appropriate gear, and commands the servo actuator accordingly.

A. System Architecture

The Hall Effect sensor is mounted on the bicycle fork, facing magnets fixed to the wheel spoke. Each magnet pass generates a pulse; the pulse frequency is converted to wheel speed in km/h. The MPU6050 IMU, mounted on the frame, measures the pitch angle of the bicycle to classify terrain as uphill, flat, or downhill. The Arduino Nano integrates both readings, applies the gear-selection logic, and drives the servo motor to shift the derailleur. Real-time parameters are continuously displayed on the OLED.

Table II. System Components, Functions, and Specifications

Component	Function	Specifications
Arduino Nano	Central microcontroller; processes sensor data and executes gear logic	ATmega328P, 16 MHz, 14 digital I/O
MPU6050	Measures 3-axis acceleration & gyroscope data for tilt angle computation	3-axis accel + gyro, I2C interface
Hall Effect Sensor	Detects wheel rotation pulses for speed calculation	Digital output, 5V supply
SSD1306 OLED	Displays real-time speed, angle, and gear position	128×64 px, I2C, 0.96"
HS-755 MG Servo	Actuates derailleur for gear changes	Metal gear, 180° rotation, 6V
Wheel Magnets	Trigger Hall sensor per wheel revolution	Neodymium, spoke-mounted

VI. METHODOLOGY

The project follows a structured mechatronics design approach spanning hardware selection, embedded programming, and system validation.

A. Speed Measurement

A Hall Effect sensor is mounted on the bicycle fork aligned with spoke-mounted neodymium magnets. Each magnet pass generates a falling-edge interrupt registered by Arduino pin D2. An interrupt service routine increments a pulse counter. Every 1,000 ms, the pulse count is sampled, and speed is calculated. This method provides accurate real-time speed data independent of GPS or external systems.

B. Inclination Measurement

The MPU6050 IMU is mounted on the bicycle frame. Raw acceleration data from X, Y, Z axes (16-bit, ±2g range) is read via I2C. The pitch angle is computed and used to classify the terrain as uphill, flat, or downhill.

C. Gear Actuation

An HS-755 MG metal-gear servo motor is mechanically linked to the front derailleur cable. The Arduino outputs a PWM signal corresponding to the selected gear position. A 2-second shift delay (shiftDelay = 2000 ms) prevents rapid gear hunting during transient speed fluctuations.

D. Anti-Cross-Chaining Logic

To protect the drivetrain, the following gear combinations are prohibited and automatically corrected by the firmware:

- Front Gear 1 (Small Chainring) + Rear Gear 7 (Smallest Sprocket) — extreme cross-chain, capped at Rear Gear 5.

- Front Gear 3 (Large Chainring) + Rear Gear 1 (Largest Sprocket) — opposite extreme, rear gear raised to 3.

VII. GEAR SELECTION LOGIC

A. Front Gear Selection (Terrain-Based)

Table III. Front Gear Selection Based on Road Inclination

Road Condition	Tilt Angle	Front Gear	Rationale
Uphill	> 10°	1 (Small)	High torque; easier climbing
Flat Road	−5° to 10°	2 (Middle)	Balanced cruising speed
Downhill	< −5°	3 (Large)	Speed efficiency on descent

B. Rear Gear Selection (Speed-Based)

Table IV. Rear Gear Selection Based on Speed

Speed Range	Rear Gear	Application Context
0 – 5 km/h	1	Starting; maximum mechanical advantage
5 – 8 km/h	2	Low-speed city riding or slow climbs
8 – 11 km/h	3	Moderate urban speed
11 – 15 km/h	4	Standard commuting pace
15 – 20 km/h	5	Faster commuting or light trail riding
20 – 27 km/h	6	High-speed cycling on flat roads
Above 27 km/h	7	Maximum speed; downhill or sprinting

VIII. RESULTS AND DISCUSSION

The developed automatic gear change mechanism successfully demonstrated autonomous gear selection based on real-time speed and terrain data. Experimental testing confirmed that the Hall Effect sensor accurately computed wheel speed, and the MPU6050 reliably classified terrain inclination across uphill, flat, and downhill conditions.

The deterministic gear-selection logic proved highly effective. The anti-cross-chaining protection consistently prevented harmful gear combinations during testing, and the servo motor reliably actuated the derailleur across all seven rear gears. The 2-second shift delay effectively suppressed gear hunting under transient speed conditions.

The OLED display refreshed every 100 ms, providing the rider with continuous feedback on speed, inclination, and gear position without requiring manual intervention. The total component cost was maintained below ₹1,500, demonstrating the commercial viability of the proposed solution for everyday cyclists.

Overall, the system effectively reduced rider cognitive load, improved pedaling efficiency, and extended drivetrain service life. It performed reliably within laboratory and field conditions and is particularly beneficial for beginner cyclists, commuters, and users with physical limitations.

IX. CONCLUSION

This project successfully demonstrated the design and implementation of a low-cost, sensor-based automatic gear change mechanism for bicycles using an Arduino Nano microcontroller. By combining Hall Effect speed sensing with MPU6050 inclination measurement, the system autonomously selected the optimal front and rear gear combination based on real-time riding conditions, closely replicating the decisions of an experienced cyclist.

The integrated anti-cross-chaining logic provided active drivetrain protection, while the OLED display ensured rider awareness without manual intervention. With a total component cost of approximately ₹1,000–1,500 and compatibility with standard derailleur-based bicycle systems, the proposed solution is both accessible and practical for everyday use.

The modular architecture of the codebase allows straightforward future upgrades including cadence sensing, machine learning-based adaptive shifting, Bluetooth connectivity, and GPS terrain prediction. This project validates the feasibility of intelligent, automated bicycle transmission systems and lays a strong foundation for the development of a fully commercial, smart cycling product.

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