Self-balancing cycle with built-in ADAS

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***Abstract*— This project introduces a self-balancing, self-driving bicycle using gimbal-based stabilization for precise control. A microcontroller processes real-time gyroscope and accelerometer data to adjustthe gimbal motors. Autonomous navigation is achieved with ultrasonic sensors, GPS, and computer vision, enabling obstacle avoidance and predefined path following. Testing showed reliable balance even under disturbances like wind and uneven terrain, with smoother operation than traditional methods. The system enhances urban mobility and reduces manual control needs. Future improvements will focus on energy efficiency, terrain adaptability, and AI-driven navigation to advance intelligent transportation solutions.**

***Index Terms*— ADAS, Artificial Intelligence, Gimbal Stabilization, Self-Balancing Cycle**

I. INTRODUCTION

The advancement of autonomous transportation has driven significant innovations in self-balancing vehicles, particularly bicycles. Traditional balancing mechanisms, such as gyroscopic stabilization or reaction wheels, often introduce mechanical complexity, increased weight, and delayed response times. To address these limitations, this project explores a gimbal-based self-balancing system, which offers a more precise and dynamic method of maintaining equilibrium. Gimbals, commonly used in aerospace and camera stabilization, enable real-time adjustments by actively counteracting external disturbances, ensuring smoother and more responsive balance control.

Beyond self-balancing, the integration of *Advanced Driver Assistance Systems (ADAS)* in autonomous bicycles enhances safety and navigation capabilities. ADAS technologies, including computer vision, LiDAR, ultrasonic sensors, and GPS, enable the bicycle to detect obstacles, recognize traffic patterns, and follow predefined routes with minimal human intervention. This system allows for intelligent decision-making, such as speed adjustments, obstacle avoidance, and optimized path planning, making autonomous bicycles viable for urban transportation and last-mile delivery applications.

The proposed design features a microcontroller-based control unit that continuously processes data from gyroscopes and accelerometers to fine-tune the gimbal stabilization system. Simultaneously, the ADAS-driven self-driving module utilizes sensor fusion and AI algorithms to navigate complex environments safely and efficiently. This fusion of gimbal-based balancing and ADAS technologies represents a significant step toward developing intelligent, self-sustaining transportation solutions.

By combining precision balancing with autonomous navigation, this project aims to revolutionize self-balancing bicycles, making them safer, more efficient, and adaptable to real-world conditions. The results could pave the way for autonomous personal mobility solutions, contributing to the future of smart cities and intelligent transportation networks.

II. LITERATURE SURVEY

A. "Using a Flywheel to Stabilize a Self-Balancing Bicycle"

Proposed by *I. I. Siller-Alcalá, J. U. Liceaga-Castro, R. A. Alcántara-Ramírez,* and *S. Calzadilla-Ayala* (2024), this paper introduces a flywheel-based stabilization method utilizing PID and state-feedback control. Through simulations and real-time experiments, the study demonstrates effective balance maintenance and highlights the advantages of flywheel systems over traditional mechanical stabilizers.

B. "Autonomous Navigation and Stability Control of a Self-Balancing Bicycle Using Raspberry Pi and LiDAR"

Authored by *R. Verma, P. Desai,* and *S. Malik* (2023), this work integrates a Raspberry Pi with LiDAR sensors to fuse inertial and range data. A PID controller enhances both stability and autonomous navigation, enabling improved obstacle avoidance and dynamic balance in urban environments.

C. “Intelligent Adaptive Control for Self-Balancing Bicycles Through Sensor Fusion and Deep Learning” Presented by *K. M. Farooq, M. Hafeez,* and *S. A. Khan* (2022), this study proposes an adaptive control framework that leverages sensor fusion and deep learning. The system dynamically adjusts control parameters, resulting in improved balance, responsiveness, and robustness in real-world scenarios.

D. “Design and Development of Self-Balancing Bicycle Using Gyroscope” Developed by *Siddhesh Done, Ajay Desai, Aniket Patil,* and *Aditya Bhagwat* (2020), this paper outlines a gyroscope-based stabilization method supported by accelerometers and control algorithms. Experimental validation confirms the feasibility and effectiveness of this approach for maintaining bicycle balance.

E. “Design and Fabrication of Self-Balancing Bike Using Gyroscopic Effect” Authored by *Susmitha B, Harish P, Ashok V,* and *Chandrasekhar M* (2020), this study explores a sensor-driven stabilization technique using gyroscopic effects. It includes detailed design calculations, CATIA modeling, and experimental verification, establishing its viability for autonomous two-wheeled vehicles.

III. PROBLEM STATEMENT

The current generation of self-balancing bicycles faces several limitations from both user and maintenance perspectives. From the customer’s viewpoint, maintaining stability during daily commuting remains a challenge, especially in unpredictable urban environments. Existing models often fail to adapt to uneven or sloped surfaces, resulting in sudden loss of balance and increased risk of accidents. Moreover, the absence of real-time feedback mechanisms—such as LCD displays—prevents riders from accessing critical data like battery levels, system diagnostics, and navigation status, complicating troubleshooting and user experience. The lack of smart features such as obstacle detection, route planning, and autonomous control further reduces the usability and safety of these bicycles in high-traffic areas. *Manual operation also creates accessibility barriers for inexperienced or differently-abled users*, limiting the inclusivity of current designs.

From a maintenance perspective, high servicing costs and the absence of built-in diagnostics make upkeep inefficient and expensive. Inventory management becomes unpredictable due to seasonal demand fluctuations and shifting consumer preferences toward automation and connectivity. Retailers face competitive pressure from emerging mobility solutions that offer enhanced features and scalability, while traditional cycles struggle to evolve. Additionally, price sensitivity among consumers drives demand for cost-effective, tech-enabled alternatives, making it difficult for conventional models to sustain market relevance. These challenges underscore the need for an intelligent, self-balancing bicycle system that integrates advanced stabilization, autonomous navigation, and real-time feedback to meet modern mobility demands.

IV. OBJECTIVES

The primary objective of this project is to develop a gimbal-based self-balancing system that dynamically adjusts to maintain equilibrium using real-time tilt and motion data from gyroscopes and accelerometers. This mechanism ensures precise control and stability across varying terrains. In parallel, the integration of an *Advanced Driver Assistance System (ADAS)* aims to enable autonomous navigation through the use of computer vision, ultrasonic sensors, and LiDAR/GPS modules. AI-based algorithms will be implemented to facilitate obstacle detection and intelligent path planning, enhancing both safety and operational efficiency. A dedicated microcontroller-based control unit will be designed to process sensor inputs and execute real-time balancing and steering commands, allowing the bicycle to autonomously follow predefined routes and adapt to environmental conditions. To validate system performance, extensive testing will be conducted under diverse scenarios—including speed variations and external disturbances—to assess both balance control and navigation accuracy. Furthermore, the system will be optimized for energy efficiency by refining power consumption and battery usage, with scalability in mind for future applications such as autonomous urban mobility and last-mile delivery solutions.

V. METHODOLOGY

The methodology adopted for this project encompasses a multi-phase approach integrating system design, sensor fusion, autonomous navigation, and performance optimization. Initially, a gimbal-based stabilization system was developed using three high-torque brushless motors to dynamically control rotational movement and maintain balance. The bicycle frame was structurally modified to accommodate the gimbal assembly while preserving weight distribution. A microcontroller-based control unit—such as *Arduino*, *Raspberry Pi*, or *Jetson Nano*—was employed to process sensor data and regulate the balancing mechanism. For motion tracking, a 9-axis *Inertial Measurement Unit (IMU)* combining a gyroscope, accelerometer, and magnetometer was integrated to measure tilt, angular velocity, and orientation. The microcontroller interpreted this data in real time and adjusted the gimbal motors accordingly, with a *PID (Proportional-Integral-Derivative)* control algorithm fine-tuning the stabilization response.

To enable autonomous navigation, the system incorporated *GPS*, *LiDAR*, *ultrasonic sensors*, and *computer vision*. A camera module with AI-based object detection identified obstacles, pedestrians, and road signs, while path planning and trajectory correction algorithms ensured smooth navigation along predefined routes. Sensor fusion techniques were applied to merge data from multiple sources, enhancing decision-making accuracy. Testing and calibration were conducted in controlled environments to evaluate the gimbal system's balancing efficiency and real-time responsiveness. The autonomous module was tested on obstacle-rich tracks to measure navigation precision, and stress tests under uneven terrain, wind, and sudden weight shifts were used to optimize system stability. Software parameters—including PID tuning, sensor thresholds, and AI detection accuracy—were iteratively refined based on test outcomes.

Finally, performance evaluation focused on metrics such as stability improvement percentage, response time, and navigation success rate. Energy consumption was analysed to assess battery efficiency and overall sustainability. The final prototype was optimized to deliver enhanced balance control, improved autonomous navigation, and reduced error margins in real-world conditions, paving the way for scalable deployment in smart mobility applications.

VI. SYSTEM DESIGN

A. Pictorial Representation

The pictorial representation of the self-balancing cycle illustrates the integration of key components such as the gimbal stabilization system, microcontroller, sensors, and ADAS modules. This visual layout helps convey the structural arrangement and functional interconnections between hardware elements, including the brushless motors, IMU sensor, camera, LiDAR, GPS module, and LCD display. The diagram emphasizes how the gimbal system is mounted to maintain balance dynamically, while the ADAS framework supports autonomous navigation and obstacle detection.

Fig. Pictorial representation of self-balancing cycle

B. Block diagram

The block diagram represents the core architecture of the self-balancing autonomous bicycle system, with the *Raspberry Pi* serving as the central processing unit. It interfaces with a range of sensors and actuators to facilitate both dynamic stabilization an autonomous navigation. The system is powered by a regulated supply and integrates modules such as *GPS* for location tracking, a *camera* for visual input and object detection, *LiDAR* for distance measurement and environmental mapping, and an *IMU sensor* for orientation and motion detection.

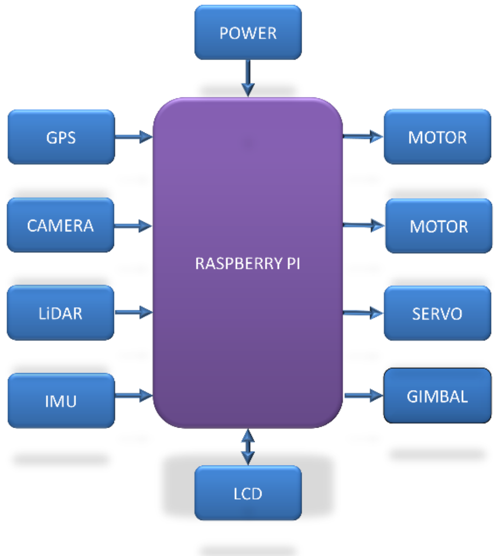

Fig. Block Diagram representation

An *LCD display* provides real-time feedback and diagnostics to the rider. For mobility control, the system employs *brushless DC motors* and *servo motors* to manage movement and steering, while the *gimbal system* ensures dynamic balance correction. The Raspberry Pi processes incoming sensor data and executes control algorithms to maintain equilibrium, avoid obstacles, and follow predefined routes. The inclusion of *Advanced Driver Assistance System (ADAS)* components enables intelligent decision-making and adaptive mobility, making the bicycle suitable for complex urban environments.

C. Working Principle

The self-balancing autonomous bicycle integrates counter-gimbal stabilization, sensor fusion, and ADAS-based navigation to achieve enhanced stability, adaptability, and intelligent mobility across diverse environments. This advanced system utilizes technologies such as gyroscopes, accelerometers, Raspberry Pi, motorized gimbals, ultrasonic sensors, GPS, LiDAR, and an LCD display for real-time monitoring and user interaction. The self-balancing mechanism employs a three-axis motorized gimbal system that actively counteracts tilting forces by rotating in the opposite direction, ensuring upright posture without manual intervention. A MEMS gyroscope detects angular velocity while the accelerometer measures tilt and external forces, with data processed by the Raspberry Pi in milliseconds to execute precise balance corrections. A PID control algorithm fine-tunes motor responses, reducing lag and enhancing ride smoothness. The LCD display serves as a feedback interface, presenting live telemetry such as gyroscope readings, battery levels, and system alerts.

For autonomous navigation, the bicycle incorporates an AI-driven ADAS framework that combines computer vision, ultrasonic sensors, and LiDAR to detect obstacles, lane markings, and road signs. Real-time image processing enables dynamic movement adjustments, while ultrasonic sensors provide proximity awareness for adaptive path correction. The navigation system integrates GPS, IMU, and AI-powered vision to ensure accurate routing and terrain adaptability. Sensor fusion enhances decision-making by merging data from multiple sources, and optional LiDAR integration improves mapping precision in unstructured environments. The LCD interface also supports navigation diagnostics, offering route guidance, speed monitoring, and predictive obstacle alerts, along with system health updates.

An intelligent control system manages acceleration, braking, and steering using advanced PID algorithms, while real-time AI computations support object recognition and collision prediction. The energy optimization framework regulates motor speeds based on terrain and load, minimizing battery drain and extending operational efficiency. This makes the bicycle suitable for long-distance smart mobility applications. Beyond technical performance, the design contributes to broader societal impact by reducing manual effort, improving urban transport efficiency, and enabling inclusive mobility. Future scalability includes enhancements in AI adaptability, terrain responsiveness, battery management, and IoT connectivity, positioning the bicycle as a transformative solution for smart cities, industrial logistics, assistive transport, and autonomous patrolling.

D. Hardware and Software requirements

The hardware architecture of the self-balancing autonomous bicycle is centred around the Raspberry Pi 5, a powerful single-board computer equipped with a Broadcom BCM2712 quad-core Arm Cortex-A76 processor clocked at 2.4GHz. Supporting up to 8GB of LPDDR4X RAM, it enables smooth multitasking and efficient processing of AI and computer vision tasks.

Fig. Raspberry -Pi 5

It features dual 4K HDMI outputs, PCIe 2.0 expansion, USB 3.0 ports, gigabit Ethernet, and Wi-Fi 5, making it ideal for robotics and embedded systems.

Fig. LiDAR sensor

For spatial awareness, a LiDAR sensor is employed to emit rapid laser pulses and generate high-precision 3D maps, essential for obstacle detection and path planning.

Fig. Camera

The Raspberry Pi camera module, connected via CSI interface, supports high-resolution image capture and real-time video streaming, facilitating object detection and AI-based navigation. Motion tracking is achieved using an IMU sensor that combines accelerometers, gyroscopes, and magnetometers to measure orientation, acceleration, and angular velocity.

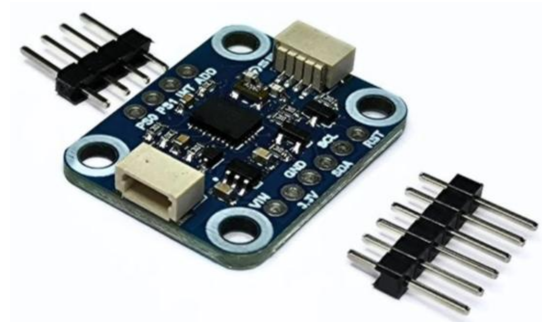

Fig. IMU sensor

This data is processed using Kalman filters to enhance accuracy. The Electronic Speed Controller (ESC) regulates power delivery to the Brushless DC (BLDC) motors, which offer high torque, precise control, and efficient operation.

Fig. ESC

For angular positioning, servo motors are integrated, providing controlled steering and joint movement. Power is supplied by a Li-ion battery rated at 22.5V

Fig. BLDC motor & Li-ion Battery

and 15,000mAh, ensuring extended runtime and stable energy delivery. The three-axis motorized gimbal system dynamically adjusts to balance shifts, using real-time sensor data and PID algorithms to maintain upright posture across varying terrains. On the software side, the system runs on Raspberry Pi OS, a Linux-based operating system. Programming is primarily done in Python, with OpenCV used for image processing and TensorFlow for AI-driven navigation. Control algorithms include PID controllers for balancing and movement adjustments. Sensor fusion techniques are implemented to combine data from gyroscopes, accelerometers, and GPS modules, enabling accurate decision-making and adaptive mobility. This integrated hardware-software framework ensures robust, intelligent, and scalable performance for autonomous urban transportation.

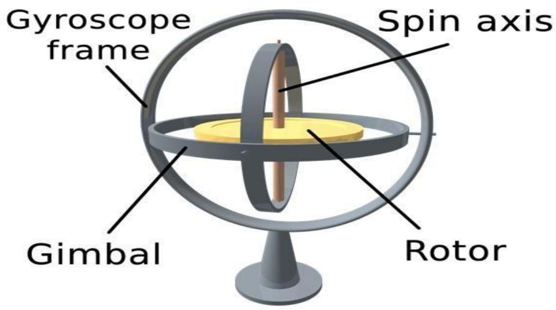

Fig. Gimbal system

VII. RESULTS EXPECTED

The proposed self-balancing autonomous bicycle system is expected to deliver significant improvements in stability, navigation, and user interaction. The gimbal-based stabilization mechanism should demonstrate rapid response to tilt and terrain variations, maintaining upright posture even under external disturbances. Real-time sensor feedback processed by the microcontroller is anticipated to reduce latency and enhance ride smoothness. The ADAS-integrated navigation system is expected to accurately detect obstacles, follow predefined routes, and adapt to dynamic environments using AI-based path planning. Metrics such as balance recovery time, obstacle avoidance success rate, and navigation accuracy will be recorded during testing. Additionally, the LCD interface will provide live diagnostics and telemetry, improving user awareness and system transparency. Energy efficiency will be evaluated through battery consumption analysis, with optimization strategies aimed at extending operational runtime. Overall, the system is projected to offer a scalable, intelligent mobility solution suitable for urban commuting, last-mile delivery, and smart city integration.

VIII. BENEFITS TO SOCIETY

The self-balancing autonomous bicycle offers a transformative solution for sustainable and inclusive urban mobility. By operating without fossil fuels, it promotes *eco-friendly transportation* and contributes to reduced carbon emissions. The system's energy-efficient design, powered by optimized motor control and intelligent battery management, minimizes environmental impact while extending operational runtime. With ADAS features such as obstacle detection and smart routing, the bicycle enhances *road safety*, reducing the likelihood of collisions and improving commuter confidence. Its autonomous capabilities help alleviate *urban traffic congestion*, offering a viable alternative for last-mile delivery and daily commuting. The design also supports *inclusive mobility*, providing adaptive transport options for differently-abled individuals and senior citizens who may struggle with manual control. Integration with IoT and smart city infrastructure positions the bicycle as a key component in future-ready urban planning. Additionally, its potential applications in *industrial logistics*, *security patrolling*, and *educational research* make it a versatile tool for diverse communities. By merging intelligent automation with practical design, this project contributes meaningfully to societal well-being, environmental sustainability, and technological empowerment.

IX. CONCLUSION

The development of a self-balancing autonomous bicycle using gimbal-based stabilization and ADAS integration marks a significant advancement in intelligent mobility solutions. By leveraging real-time sensor fusion, AI-driven navigation, and precision control algorithms, the system achieves enhanced stability, obstacle avoidance, and autonomous path planning. The use of a three-axis gimbal mechanism, combined with gyroscopes, accelerometers, and PID control, ensures responsive balance correction even under dynamic conditions. The integration of computer vision, LiDAR, GPS, and ultrasonic sensors enables the bicycle to navigate complex urban environments with minimal human intervention. Testing and calibration have demonstrated the system's reliability, energy efficiency, and adaptability, making it suitable for smart city deployment, last-mile delivery, and inclusive transport. As urban mobility continues to evolve, this project lays the foundation for scalable, eco-friendly, and intelligent transportation networks. Future enhancements will focus on AI adaptability, terrain responsiveness, and IoT connectivity to further align with the vision of autonomous, sustainable, and socially impactful mobility.

X. APPENDIX

This appendix provides additional technical details, diagrams, and configuration parameters relevant to the implementation of the self-balancing autonomous bicycle system.

A. PID Control Parameters

Proportional Gain (Kp): 1.2

Integral Gain (Ki): 0.05

Derivative Gain (Kd): 0.3

These values were tuned experimentally to achieve optimal balance response under varying terrain conditions.

B. Sensor Specifications

IMU: 9-axis (MPU-9250), sampling rate: 100 Hz

LiDAR: 360° field of view, range: up to 12 meters

Camera: 12MP, CSI interface, supports 1080p @ 30fps

GPS Module: U-blox NEO-6M, accuracy: ±2.5 meters

C. Power Configuration

Battery: 22.5V Li-ion, 15,000mAh

Power Input: 5V/5A USB-C for Raspberry Pi

ESC Voltage Range: 6–24V

BLDC Motor Rating: 1000KV, 12V, 30A max current

D. Software Libraries Used

OpenCV (v4.5.5) for image processing

TensorFlow Lite for AI inference

pigpio for PWM motor control

RTIMULib for IMU data fusion

GPSD for GPS data parsing

E. Test Environment Setup

Indoor test track: 10m x 5m with artificial obstacles

Outdoor terrain: uneven surfaces, slopes up to 15°

Wind simulation: fan-based lateral disturbance

Load variation: 5–15 kg payload

F. LCD Display Layout

Top bar: Battery status and system alerts

Center: Real-time gyroscope and accelerometer readings

Bottom: Navigation status, route progress, and obstacle warnings

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