

Development of a Geometrically Stabilized, Single-Hand Drive Electric Vehicle for Accessible Mobility

Lipin Paul¹, Muhamed Midlaj A M², Muhammedali Arfas T B³, Safwan C S⁴, Ajmal K S⁵

¹Assistant Professor & Department of EEE & ICET, Mulavoor

²Student, Department of EEE & ICET, Mulavoor

³Student, Department of EEE & ICET, Mulavoor

⁴Student, Department of EEE & ICET, Mulavoor

⁵Student, Department of EEE & ICET, Mulavoor

Abstract -The fundamental right to autonomous mobility and navigational independence remains significantly compromised for individuals afflicted with severe physical impairments, most notably those experiencing upper extremity amputations, partial paralysis, or localized musculoskeletal disabilities. Conventional vehicular architectures inherently demand complex, simultaneous multimodal coordination involving the synchronized application of both upper and lower limbs, thereby establishing an insurmountable operational barrier for this demographic and inadvertently perpetuating their socio-economic marginalization due to a restrictive reliance on inadequate public transit. In response to this critical infrastructural deficiency and the pressing need for accessible engineering solutions, this research presents the comprehensive electromechanical design, structural prototyping, and dynamic validation of a bespoke, single-hand operable four-wheeled auto-rickshaw engineered explicitly for handicapped and differently abled populations. The technological cornerstone of this vehicular innovation is the conceptualization, rigorous calibration, and integration of a highly ergonomic, multi-axis joystick-based human-machine interface. This centralized command module fundamentally redefines traditional automotive control topologies by dynamically consolidating primary longitudinal and lateral driving dynamics—namely, steering trajectory modulation, electronic throttle regulation, hydraulic braking articulation, and mechanical gear transmission—into a singular, intuitively navigable interface requiring only unilateral manual engagement. To achieve seamless and deterministic signal transduction from the human operator to the vehicular powertrain, the underlying control mechanism utilizes a sophisticated network of high-torque electromechanical linear actuators, rotary encoders, and precision position sensors. These specialized components operate within a meticulously

calibrated, closed-loop cyber-physical framework, ensuring microsecond-level responsive fidelity, mitigating mechanical latency, and drastically minimizing the requisite operational exertion forces. This targeted ergonomic optimization effectively mitigates driver neuromuscular fatigue over prolonged navigational periods, ensuring sustained operational safety and cognitive focus. Furthermore, addressing the critical dynamic instabilities and rollover susceptibilities historically associated with conventional asymmetrical three-wheeled auto-rickshaws, the architectural transition to a symmetrical four-wheel chassis exponentially optimizes the vehicle's dynamic center of gravity and lateral roll stability threshold. This expanded vehicular footprint guarantees superior cornering maneuverability, optimal dynamic traction distribution, and unprecedented passenger comfort across highly variable topographical gradients, ranging from heavily congested urban asphalt infrastructures to undulating, unpaved semi-rural terrains. Augmenting the physical electromechanical framework is an integrated, state-of-the-art Internet of Things (IoT) embedded safety ecosystem meticulously designed to pre-emptively mitigate collision risks and enhance overall user confidence in autonomous transit. Utilizing sophisticated intelligent sensor fusion protocols encompassing ultrasonic transducer arrays and infrared proximity detectors, the vehicle facilitates real-time spatial obstacle detection and provides immediate, context-aware haptic and auditory feedback to the operator. In tandem, the onboard micro-controller telemetry module enables continuous remote diagnostic monitoring of critical vehicular subsystems and the autonomous, latency-free dispatch of geolocated emergency distress alerts via cellular networks in the event of systemic anomalies, mechanical failures, or sudden impact detection. Ultimately, by synergistically synthesizing advanced electromechanical actuation

kinematics with intelligent digital safety protocols, this project transcends mere mechanical engineering innovation to establish a transformative paradigm in adaptive, barrier-free mobility. It fundamentally democratizes the modern transportation ecosystem, empowering physically challenged individuals with unprecedented vehicular independence, facilitating their seamless societal reintegration, and unlocking previously inaccessible vocational and commercial employment opportunities within a progressive, globally inclusive automotive landscape [1][2][3].

Key Words: Blind people, single hand control.

1. INTRODUCTION

This The fundamental paradigm of equitable societal enfranchisement, personal dignity, and the holistic enhancement of the human condition is inextricably anchored to the absolute provision of autonomous, dignified, and barrier-free geographical mobility, an infrastructural imperative that fundamentally dictates an individual's capacity to seamlessly participate in critical socio-economic, educational, and cultural ecosystems. However, a profoundly debilitating systemic stratification persists globally wherein a significant demographic of individuals afflicted with severe physical impairments, most specifically those experiencing complex upper extremity musculoskeletal deficits, bilateral or unilateral amputations, congenital malformations, or localized neuromuscular paralysis, remains systematically disenfranchised and marginalized by the pervasive, able-bodied architectural biases inherently embedded within contemporary automotive design methodologies. Conventional vehicular architectures, encompassing both traditional internal combustion engine platforms and modern electric transit systems, are inherently and exclusively optimized for physically uncompromised operators, fundamentally demanding a highly complex, high-frequency, and continuously synchronized multimodal cognitive-motor coordination matrix that rigidly necessitates the simultaneous, dexterous, and high-force utilization of both upper and lower extremities for the execution of critical dynamic operations encompassing longitudinal acceleration modulation, lateral trajectory adjustment via steering column manipulation, and critical deceleration through heavy mechanical or hydraulic braking actuation. This intrinsic and unforgiving operational prerequisite establishes an essentially insurmountable mechanical, ergonomic, and physiological barrier for

differently-abled demographics, severely curtailing their fundamental human right to independent, unaided geographical navigation and consequently precipitating a cascading, detrimental sequence of systemic socio-economic isolation that actively restricts their organic integration into competitive employment sectors, higher educational institutions, and broader communal frameworks, thereby significantly degrading their overall quality of life and psychological well-being. This entrenched systemic exclusion is exponentially exacerbated and practically magnified within the complex socio-economic contexts of rapidly developing nations and emerging economies, such as India, where an acute and chronic scarcity of ubiquitously accessible, ADA-compliant public transportation infrastructure, coupled with formidable financial constraints and highly unstructured, congested urban traffic topographies, disproportionately isolates and penalizes highly vulnerable disabled populations who cannot rely on state-sponsored transit mechanisms. A comprehensive, critical engineering review of the current assistive technological landscape reveals that prevailing ad-hoc rehabilitative mobility interventions, which primarily manifest as rudimentary aftermarket retrofitted conventional two-wheel or three-wheel scooters, or highly primitive mechanical hand-controlled linkages haphazardly adapted to legacy automotive platforms, are categorically deficient in addressing the multifaceted kinematic, ergonomic, and safety requirements of the target demographic. These legacy mechanical adaptations are chronically plagued by severe structural and dynamic vulnerabilities, most notably including suboptimal dynamic stability profiles stemming from dangerously elevated centers of gravity inherent in tricyclic architectures, highly restrictive physical operational force thresholds that induce rapid muscular fatigue, extreme dynamic susceptibility to lateral rollover kinematics during cornering maneuvers or sudden evasive actions, and a highly alarming, total absence of modern fail-safe active electronic safety ecosystems, leaving the vulnerable operator entirely exposed to environmental hazards. Furthermore, the prohibitive economic burden associated with commissioning these bespoke, heavily customized mechanical modifications renders them financially unattainable for a vast majority of the socio-economically disadvantaged disabled community, thereby viciously perpetuating an inescapable cycle of immobility, dependency, and localized poverty. However, in direct, innovative response to this pressing, global engineering and humanitarian imperative, the contemporary acceleration

in ubiquitous electric vehicle (EV) propulsion technologies, seamlessly hybridized with sophisticated embedded microprocessor architectures, advanced digital signal processing, and highly deterministic drive-by-wire (DbW) control topologies, has catalyzed an unprecedented, transformative technological paradigm shift, engendering highly fertile research and development avenues for the conceptualization, rapid prototyping, and deployment of radically innovative, digitally mediated assistive mobility solutions explicitly calibrated to mathematically mitigate and physically bypass the specific physiological limitations of disabled operators. Pioneering advancements in aerospace-derived fly-by-wire mechanisms, successfully translated and adapted into automotive x-by-wire paradigms (encompassing steer-by-wire, brake-by-wire, and throttle-by-wire configurations), now scientifically facilitate the complete mechanical decoupling of the traditional physical linkages between the human operator interface and the vehicular electromechanical powertrain, systematically replacing cumbersome, physically demanding steering columns and pressurized hydraulic brake lines with instantaneous, ultra-low-latency digital electronic signal transmission communication networks. This fundamental digital transformation enables the highly novel architectural integration of highly centralized, ergonomically optimized, multi-axis joystick-based human-machine interfaces (HMI), which ingeniously and mathematically amalgamate historically multiplexed driving functionalities into a singular, highly intuitive, low-force control nexus. This unified control architecture thereby empowers physiologically restricted users to effortlessly command complex, multidimensional vehicular kinematics with unprecedented sub-millimeter precision utilizing only unilateral manual dexterity or limited gross motor functions, effectively and permanently neutralizing the discriminatory requirement for bilateral physical coordination and extensive muscular endurance. Therefore, directly addressing these compound socio-technical and biomechanical challenges, this comprehensive engineering research project meticulously delineates the exhaustive computational design, advanced mechatronic prototyping, finite element structural analysis, and rigorous empirical validation of a highly specialized, accessible Single Hand Drive Electric Vehicle (EV). This system is rigorously conceived from the ground up as an unequivocally inclusive, zero-tailpipe-emission mobility architecture that synergistically synthesizes advanced solid-state electric propulsion dynamics with highly bespoke, adaptive

ergonomic control interfaces to systematically deliver a fundamentally safe, dynamically hyper-stable, and intuitively operable transit platform explicitly tailored for physically challenged demographics, seamlessly transforming complex driving tasks into localized, low-effort micro-movements. At the foundational core of this advanced vehicle's motive infrastructure lies a highly efficient, high-torque Brushless Direct Current (BLDC) motor powertrain, strategically selected for its vastly superior power-to-weight ratio, near-zero mechanical maintenance requirements due to the complete absence of degrading mechanical commutators and brushes, and exceptional, flat low-speed torque characteristics. These specific motor dynamics are absolutely critical for smoothly navigating highly congested, stop-and-go urban topographies and overcoming initial static chassis inertia without inducing abrupt, destabilizing jerking motions that could severely compromise the postural stability of an operator with limited torso or core muscle control. The complex longitudinal propulsion dynamics of this high-performance BLDC motor are intrinsically governed by a sophisticated, high-frequency solid-state motor controller unit, which is programmed to seamlessly execute highly complex field-oriented control (FOC) or trapezoidal commutation algorithmic paradigms. This controller continuously receives high-resolution pulse-width modulated (PWM) duty cycle instruction sets directly from the central processing unit, calculated precisely based on the real-time, analog proportional displacement of the joystick manipulator's primary Y-axis, translating minute physical inputs into smooth, continuous forward or reverse velocity vectors. Powering this entire electromechanical drivetrain and auxiliary sensor network is a state-of-the-art, high-energy-density lithium-ion (Li-ion) or Lithium Iron Phosphate (LiFePO₄) electrochemical battery pack, architecturally configured with advanced active thermal liquid-cooling management and highly sophisticated Battery Management System (BMS) electronic topologies. This integrated BMS continuously and autonomously monitors individual cellular voltage disparities, state-of-charge (SoC) percentages, state-of-health (SoH) degradation metrics, internal resistance, and dynamic thermal gradients across the pack to strictly and preemptively prevent catastrophic thermal runaway events, overcharging, or deep discharging scenarios, thereby ensuring absolute operational safety and maximizing the cyclic longevity of the energy storage matrix to provide the differently-abled user with a highly reliable, extended operational geographic range that definitively liberates them from the chronic range

anxiety often associated with early-generation, deeply flawed electric mobility devices. The absolute neural epicenter and algorithmic brain of this sophisticated drive-by-wire architecture is an advanced, high-clock-speed, 32-bit automotive-grade microcontroller operating deterministically on a highly stable Real-Time Operating System (RTOS), which flawlessly orchestrates the continuous, hyper-low-latency sampling of highly sensitive analog signals originating from precision, non-contact Hall-effect sensors embedded deeply within the internal gimbals of the multi-axis joystick assembly. These continuous analog voltage variations, precisely mathematically representing the operator's exact kinematic intentions for both longitudinal velocity adjustments and lateral steering angle deflections, are instantaneously and rapidly digitized via high-fidelity, multi-channel Analog-to-Digital Converters (ADCs). Following digitization, these raw signals are dynamically subjected to highly rigorous digital signal processing (DSP) algorithms, crucially including adjustable low-pass filtering, moving average computations, and configurable dead-zone mathematical calibrations. These specialized DSP techniques are absolutely essential to actively filter out and eliminate the adverse kinematic effects of involuntary neuromuscular tremors, muscular spasticity, or road-induced vibratory noise that could otherwise precipitate highly erratic and dangerous vehicular behavioral responses, ensuring that only deliberate, intentional commands are passed to the actuation subsystems. For the execution of lateral vehicular dynamics and directional control, the mathematically parsed and smoothed steering command algorithms are transmitted instantaneously via a highly robust, differential-signaling Controller Area Network (CAN) bus communication protocol to high-torque, closed-loop electromechanical rotary or linear servomotor actuators physically coupled to the vehicle's optimized steering rack. These industrial-grade actuators seamlessly execute the commanded wheel articulation and angular displacement with sub-millimeter precision and near-instantaneous responsiveness, utilizing integrated absolute rotary encoders for continuous positional feedback, effectively and entirely eliminating the intense physical exertion previously mandated by traditional, friction-heavy rack-and-pinion mechanical linkages, thereby ensuring the operator can navigate tight corners and execute complex parking maneuvers using only fractions of an ounce of lateral finger or wrist pressure. Similarly, highly critical deceleration and stopping protocols are seamlessly and logically integrated into the joystick's proximal or backward axis

configuration, where a negative physical displacement instantly triggers a highly sophisticated, dual-redundant braking architecture designed for maximum safety and fail-safe operation. Initially, this system intelligently engages a non-friction regenerative braking protocol executed via the BLDC motor inverter, programmed to simultaneously and smoothly decelerate the chassis while intelligently recuperating otherwise lost kinetic energy back into the primary battery matrix, drastically improving overall system efficiency. This is mathematically followed, in a perfectly linear and blended progression, by the algorithmic deployment of high-speed, high-force electromechanical linear actuators physically connected to the primary hydraulic brake master cylinder, applying intense friction braking across the wheel rotors for aggressive, time-critical emergency stopping scenarios, guaranteeing absolute stopping reliability under maximum dynamic payload conditions and steeply graded descents without requiring any foot actuation. Transcending these fundamental electromotive functionalities, the comprehensive safety architecture of this groundbreaking Single Hand Drive EV is vastly augmented by the seamless integration of a highly intelligent, multi-layered Advanced Driver-Assistance Systems (ADAS) sensor suite, strategically deploying a tightly fused computational network of high-frequency ultrasonic transducers, infrared proximity sensors, and solid-state Light Detection and Ranging (LiDAR) modules meticulously distributed across the vehicle's exterior spatial perimeter to establish a continuous, impenetrable 360-degree environmental perception and digital mapping field. This highly complex sensory array continuously streams gigabytes of high-density spatial point-cloud data to a dedicated, high-performance edge-computing coprocessor, which dynamically utilizes sophisticated Kalman filtering techniques and deterministic spatial obstacle detection algorithms to mathematically identify, classify, and track potential collision vectors, static impediments, or dynamic pedestrian encroachment in real-time. Upon the algorithmic detection of an imminent, mathematically unavoidable physical obstruction or hazard entering a strictly pre-defined critical safety threshold zone, the central computational system is intelligently engineered to instantly and autonomously override the user's manual joystick inputs, immediately executing highly calibrated Emergency Autonomous Braking (EAB) protocols, while simultaneously disengaging motive power to the drivetrain. This autonomous intervention is intricately coupled with immediate, high-frequency haptic vibration feedback directly integrated into the joystick grip and

high-decibel auditory alarms within the cabin, thereby providing an active, highly intelligent fail-safe protective envelope that perfectly compensates for any potential cognitive delays, visual impairments, or physical reaction-time deficiencies on the part of the disabled operator, practically nullifying the probability of low-speed frontal or rear-end collisions. Furthermore, explicitly addressing and rectifying the historical, highly documented mechanical vulnerabilities and fatal instability metrics of legacy tricyclic assistive vehicles, this newly proposed electric platform fundamentally and categorically abandons the inherently unstable three-wheel architecture in favor of a structurally robust, geometrically optimized, and symmetrically balanced four-wheel chassis configuration. This fundamental structural paradigm shift is meticulously engineered to drastically lower the vehicle's dynamic center of gravity and significantly expand its lateral track width, thereby fundamentally enhancing the kinematic roll center geometry. This provides unparalleled mechanical stability, optimal dynamic traction distribution across all contact patches, and profound physical resistance to lateral overturning moments, ensuring the vehicle remains firmly planted and highly secure even when navigating highly challenging, heavily undulating semi-rural terrains, steeply graded urban inclines, negotiating deep potholes characteristic of developing infrastructure, or executing sudden, high-speed evasive lateral maneuvers. Structurally, the chassis is fabricated from high-yield-strength, lightweight tubular steel or advanced aluminum alloys, optimizing the strength-to-weight ratio to maximize battery efficiency while providing a highly rigid protective safety cell around the occupant, further enhanced by independent MacPherson strut or double-wishbone suspension geometries that actively absorb and dissipate road-induced kinetic shocks, thereby isolating the operator's fragile musculoskeletal system from detrimental vibratory fatigue and ensuring a highly comfortable, ergonomically sound transit experience over extended durations. Augmenting the physical electromechanical framework is the profound integration of state-of-the-art Internet of Things (IoT) telematics and cloud-connected telemetry modules, effectively transforming the vehicle into a highly intelligent, perpetually connected node within a broader smart-city infrastructure. An embedded Global System for Mobile Communications (GSM) and Long-Term Evolution (LTE) cellular modem, continuously interfaced with a high-precision Global Positioning System (GPS) receiver, facilitates the continuous, real-time geographic tracking of the vehicle, allowing designated caregivers,

medical personnel, or family members to remotely monitor the user's location via secure mobile applications, drastically enhancing the psychological security of both the user and their support network. Furthermore, this IoT integration enables the continuous, autonomous remote diagnostic monitoring of all critical vehicular subsystems, wherein the microcontroller continuously logs sensor data, battery health metrics, and motor thermal signatures to a secure cloud server, allowing predictive maintenance algorithms to identify potential mechanical or electronic failures long before they physically manifest, scheduling preemptive servicing and completely eliminating the risk of sudden, catastrophic breakdowns in isolated locations. In the extreme event of a systemic anomaly, sudden loss of power, or the detection of a high-G physical impact via onboard solid-state accelerometers, the system is programmed to autonomously dispatch latency-free, highly detailed emergency distress alerts containing precise geolocated coordinates to local emergency response networks and pre-programmed emergency contacts, ensuring rapid medical or mechanical assistance is immediately routed to the operator. Ultimately, by synergistically synthesizing the absolute vanguard of highly efficient electric propulsion technology, sophisticated zero-latency drive-by-wire mechatronics, highly bespoke and physiologically adaptive ergonomic control interfaces, state-of-the-art battery management electronics, and intelligent, sensor-driven autonomous active safety ecosystems into a singular, highly cohesive, mechanically robust, and remarkably affordable transportation platform, this multifaceted engineering project actively and systematically dismantles the persistent structural, physical, and economic barriers to independent geographical mobility. It unequivocally provides a profoundly transformative, technologically advanced, and ecologically sustainable zero-emission solution that explicitly empowers highly marginalized individuals with severe upper limb disabilities to permanently reclaim their navigational autonomy, facilitating their unequivocal, dignified reintegration into the broader socio-economic fabric, vastly expanding their access to educational and vocational opportunities, and fundamentally bridging the previously insurmountable chasm between biological physiological limitations and the highly equitable, universally designed application of advanced automotive engineering, thereby establishing an entirely new, highly progressive, and deeply humanitarian benchmark for inclusive, user-centric

transportation infrastructure design in the digitally interconnected twenty-first century [3][4][5][6][7].

2. WORKING PRINCIPLE OF SYSTEM

The Single Hand Drive Electric Vehicle (EV) represents a highly sophisticated, mechatronically integrated assistive mobility paradigm engineered meticulously to rectify the systemic disenfranchisement of physically challenged demographics, specifically those afflicted with severe upper extremity limitations, by providing an unprecedented degree of vehicular autonomy through a centralized, fundamentally intuitive single-hand control architecture that seamlessly synergizes advanced electrical, solid-state electronic, and precision mechanical subsystems to deliver a hyper-stable, profoundly safe, and exceptionally user-centric transit experience. At the foundational core of this advanced cyber-physical ecosystem lies a meticulously calibrated human-machine interface (HMI) manifesting as a multi-axis, ergonomically optimized joystick control unit, an engineering innovation that effectively amalgamates traditionally disparate, highly multiplexed, and physically demanding vehicular operations—namely, longitudinal acceleration modulation, lateral steering trajectory articulation, and critical deceleration or hydraulic braking application—into a singular, dynamically responsive input nexus designed to drastically minimize musculoskeletal exertion and cognitive load.

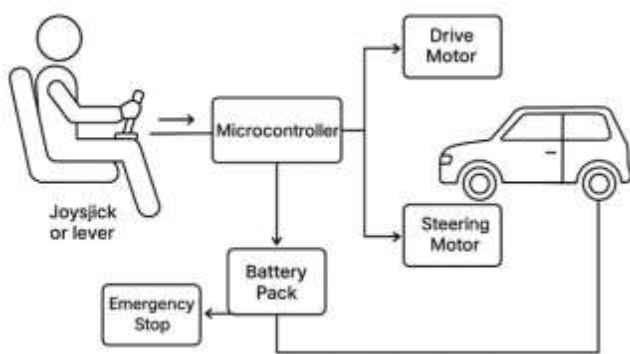


Fig -1: Block diagram of Single Hand Drive Electric Vehicle

When the human operator introduces physical multidimensional displacement to the joystick gimbal, high-precision, non-contact Hall-effect transducers continuously map these minute spatial variations into a continuous spectrum of proportional analog voltage

signals, which serve as direct, high-fidelity quantitative representations of the user's kinematic intentions regarding directional vectors and targeted velocity magnitudes. These analog electrical signals are instantaneously routed via highly robust, electromagnetically shielded, low-latency transmission pathways to an advanced, automotive-grade 32-bit microcontroller operating on a deterministic Real-Time Operating System (RTOS), which acts as the algorithmic central processing unit (CPU) of the entire vehicular network, where the raw sensor data is subjected to rapid, high-resolution analog-to-digital conversion (ADC) and rigorous digital signal processing (DSP) algorithms, including sophisticated low-pass filtering and moving-average computational techniques designed specifically to actively filter out involuntary neuromuscular tremors, muscular spasticity, and road-induced vibratory noise, thereby ensuring that only deliberate, intentional control commands are synthesized and propagated through the system. Operating upon strictly defined, proprietary deterministic control logic, this central microcontroller functions as the supreme algorithmic brain of the advanced drive-by-wire mechanism, systematically evaluating the digitized user inputs against a complex, multidimensional matrix of predefined operational parameters, dynamic kinematic constraints, and critical safety thresholds to dynamically generate precisely calibrated, high-frequency pulse-width modulated (PWM) control signals that are subsequently distributed across the vehicle's myriad electromechanical subsystems via a highly reliable Controller Area Network (CAN) bus communication protocol. The primary longitudinal propulsion infrastructure is robustly anchored by a high-efficiency electric drive powertrain, fundamentally reliant upon a high-energy-density, thermally managed 48-volt electrochemical battery matrix—typically utilizing advanced Lithium Iron Phosphate (LiFePO₄) chemistry for superior cyclic longevity and thermal stability—that serves as the centralized power reservoir, seamlessly supplying heavily regulated direct current (DC) to an advanced solid-state motor controller and auxiliary distributed electronic modules. This sophisticated motor controller functions as a highly responsive, intelligent electronic inverter executing complex Field-Oriented Control (FOC) algorithms, actively regulating the continuous flow of high-amperage voltage and current to a high-torque, structurally integrated Brushless Direct Current (BLDC) motor based precisely on the duty cycle commands received from the central microcontroller, thereby facilitating exceptionally smooth, linear

acceleration profiles, optimal low-speed torque delivery essential for overcoming initial static inertia on graded inclines, and meticulously controlled deceleration phases while completely eliminating the mechanical friction, excessive acoustic noise, thermal inefficiencies, and chronic mechanical maintenance liabilities historically associated with traditional brushed DC motor commutators or legacy internal combustion engine architectures, ultimately ensuring a highly eco-friendly, thermally efficient, and mechanically reliable transit experience optimized for sustained operational longevity. Concurrently, the complex execution of lateral steering dynamics and critical frictional braking operations is entirely and deliberately decoupled from antiquated, physically exhaustive, and friction-heavy mechanical linkages such as traditional rack-and-pinion steering columns or pressurized hydraulic brake pedals, relying instead upon an intricate network of high-fidelity electromechanical linear and rotary servo-actuators that are continuously governed by the microcontroller's sophisticated Proportional-Integral-Derivative (PID) closed-loop feedback algorithms. In direct response to mathematically processed lateral joystick deflections, these industrial-grade actuators engage the vehicle's optimized steering geometry—typically adhering to strict Ackermann steering principles to minimize tire scrub and optimize cornering radii—with sub-millimeter positional precision and near-instantaneous actuation speeds, translating minimal digital operator commands into exact, mathematically optimal wheel articulation angles to ensure superior handling characteristics, unparalleled maneuverability in severely constricted spatial environments, and a profound reduction in operator neuromuscular fatigue over extended navigational durations. Similarly, the critical deceleration framework is electronically mediated and intelligently tiered; when the joystick is dynamically returned to a centralized, mathematically defined neutral dead-band or actively pulled into a reverse vector, the microcontroller simultaneously modulates the motor driver inverter to immediately initiate non-friction regenerative electromagnetic braking—thereby intelligently recuperating otherwise lost kinetic energy back into the primary 48-volt battery matrix to significantly optimize overall system range and electrical efficiency—while concurrently deploying highly responsive electromechanical brake actuators physically coupled to the primary wheel rotors to apply proportional, high-friction stopping forces, guaranteeing rapid, reliable, and fail-safe deceleration under maximum dynamic payload conditions, steeply graded descents, and critical

emergency stopping scenarios. Furthermore, aggressively addressing the historical mechanical vulnerabilities, inherent architectural flaws, and highly documented dynamic roll-center instabilities intrinsically linked to legacy tricyclic assistive scooters and heavily modified two-wheelers, this proposed vehicular architecture definitively and scientifically adopts a geometrically optimized, symmetrically balanced four-wheel chassis configuration. This fundamental structural engineering paradigm shift is meticulously calculated to drastically lower the vehicle's dynamic center of gravity and significantly expand its lateral track width, thereby fundamentally enhancing the kinematic roll stability profile, optimizing dynamic traction distribution across all four tire contact patches under varying load conditions, and severely mitigating the critical risk of hazardous tipping or lateral rollover events, particularly when navigating high-speed cornering maneuvers, executing sudden evasive lateral actions, or traversing heavily undulating, asymmetric, and highly unpredictable semi-rural topographies commonly encountered in developing infrastructure environments. The structural integrity of this four-wheel chassis is further augmented by the integration of an advanced, independent suspension geometry designed to systematically isolate the vehicle's structural frame and the occupant's fragile musculoskeletal system from harsh, road-induced kinetic shocks and high-frequency vibrations, thereby ensuring a highly comfortable, ergonomically sound ride quality that critically prevents the exacerbation of existing physiological conditions. Augmenting this incredibly robust physical, kinematic, and electromechanical foundation is the comprehensive and seamless integration of a highly intelligent, multi-layered active safety and environmental perception ecosystem, structurally heavily reliant upon a continuous, high-speed sensor fusion network comprising arrays of ultrasonic spatial transducers, infrared proximity detectors, and potentially highly advanced solid-state obstacle detection algorithms. This intricate embedded sensor suite establishes a continuous, impenetrable 360-degree digital perimeter and environmental map around the vehicle, ceaselessly monitoring the dynamic operational environment for static structural impediments, dynamic vehicular or pedestrian encroachment, sudden topographical drop-offs, or impending high-probability collision vectors in absolute real-time with microsecond latency. Should the environmental telemetry detect an imminent, mathematically unavoidable physical hazard or a sudden critical operational anomaly within a strictly pre-defined

spatial safety threshold, the embedded system architecture is explicitly engineered with an absolute, hard-coded hierarchical safety override protocol, enabling the central microcontroller to instantaneously and autonomously bypass all manual user inputs to rapidly execute Emergency Autonomous Braking (EAB) procedures, forcibly arresting the vehicle's kinetic momentum and intelligently disengaging motive power to the drivetrain to pre-emptively prevent catastrophic vehicular accidents, thereby providing an active, highly intelligent fail-safe protective envelope that perfectly compensates for any potential cognitive delays or physical reaction-time deficiencies on the part of the disabled operator and ensures absolute occupant preservation. Ultimately, the meticulous synergistic integration of these highly advanced, zero-latency drive-by-wire control mechanisms, highly efficient solid-state power electronics, mathematically precise electromechanical actuation frameworks, robust geometric chassis stability parameters, and highly intelligent, sensor-driven algorithmic safety protocols culminates in the realization of a highly compact, technologically sophisticated, highly reliable, and deeply economically viable assistive mobility solution meticulously tailored to decisively overcome the multifaceted physiological, environmental, and socio-economic limitations historically faced by differently-abled users. By fundamentally prioritizing unprecedented ease of operation through singular intuitive interfaces, guaranteeing enhanced, continuously active and passive safety envelopes, optimizing energy efficiency for prolonged independence, and significantly improving navigational autonomy through a highly resilient, low-maintenance, and strictly user-centric design philosophy, this complex Single Hand Drive Electric Vehicle stands not merely as a functional prototype, but as a profoundly transformative engineering achievement that seamlessly bridges the historical chasm between cutting-edge automotive mechatronic automation and the urgent, highly critical real-world requirements of modern, equitable, and universally inclusive assistive transportation ecosystems, thereby redefining the global standard for accessible, barrier-free vehicular independence [5][6][7][8][9][10]

2.1 System Initialization

System initialization is the first and essential step in the operation of the Single Hand Drive Electric Vehicle (EV). It ensures that all components of the system are properly powered, configured, and ready for operation before the vehicle begins to move. When the

system is powered ON, the 48V battery supplies energy to all the electrical and electronic components through appropriate voltage regulation units. The microcontroller initializes by loading the programmed control algorithm and setting up all input and output ports. It checks the status of connected components such as the joystick module, motor driver, sensors, and actuators. The joystick module is calibrated during initialization to detect its neutral (center) position. This ensures that the vehicle remains stationary when there is no user input. Any deviation from the neutral position is later interpreted as a control command.

The motor driver/controller is also initialized and set to a safe default state, ensuring that no unintended motor movement occurs during startup. Similarly, the steering actuator and braking system are checked for proper functionality. The system then performs a basic safety check, where inputs from sensors such as obstacle detection modules and emergency switches are verified. If any fault or abnormal condition is detected, the system prevents operation and alerts the user. Once all components are verified and functioning correctly, the system enters the ready state, where it continuously waits for user input from the joystick. Only after successful initialization does the vehicle become operational [1][2].

2.2 Control operation using joystick

The advanced multidimensional joystick control mechanism functions as the foundational Human-Machine Interface (HMI) and the absolute operational epicenter of the Single Hand Drive Electric Vehicle (EV), engineered specifically to empower individuals with severe physical disabilities by facilitating comprehensive vehicular command through a strictly unilateral manual interface. This highly sophisticated mechatronic module systematically eradicates the restrictive necessity for conventional, physically demanding automotive control architectures—specifically cumbersome mechanical steering columns, heavy hydraulic brake pedals, and manual gear transmission linkages—by seamlessly consolidating these disparate, multiplexed driving dynamics into a singular, highly intuitive, and ergonomically optimized drive-by-wire nexus. Operationally, the joystick transducer translates physical mechanical displacement across a two-dimensional Cartesian coordinate system into a continuous, proportional spectrum of high-resolution analog voltage signals. As the operator manipulates the gimbal along its designated longitudinal and lateral planes, integrated precision non-contact Hall-effect sensors generate exact differential voltage

variations that quantitatively map to specific vehicular kinematic commands, including forward acceleration vectors, reverse propulsion, precise bidirectional steering articulation, and graded deceleration protocols. When the user deviates the joystick from its precisely calibrated mechanical dead-center, these instantaneous analog voltage fluctuations are rapidly transmitted via shielded electrical conduits to a central, high-performance, 32-bit automotive-grade microcontroller unit operating on a deterministic Real-Time Operating System. Serving as the primary digital signal processor and algorithmic brain of the cyber-physical system, this microcontroller continuously samples the incoming analog data streams via high-frequency Analog-to-Digital Converters. The digitized signals are subsequently subjected to rigorous deterministic control algorithms and advanced digital filtering techniques, designed to mathematically evaluate the precise directional vector and amplitude of the user's input while actively mitigating the adverse effects of involuntary neuromuscular tremors or environmental vibratory noise. Upon calculating the required dynamic response, the microcontroller synthesizes these processed inputs into highly regulated Pulse Width Modulation (PWM) instruction sets. These high-frequency PWM signals are synchronously routed to a solid-state electronic motor driver inverter, which intelligently modulates the direct current and voltage parameters supplied from the primary traction battery matrix to the high-torque Brushless Direct Current (BLDC) motor, ensuring exceptionally smooth, linear acceleration curves and meticulously controlled longitudinal velocity profiles. Concurrently, the central processing unit mathematically decouples the lateral input data to generate discrete control signals transmitted via a robust Controller Area Network bus to precision electromechanical servo-actuators coupled to the vehicle's steering rack geometry, facilitating rapid, optimal wheel deflection for accurate directional navigation. Similarly, negative longitudinal displacement logic instantly triggers the integrated electronic braking subsystem, dynamically blending regenerative motor deceleration with high-force linear actuator engagement for highly reliable stopping power. Crucially, the entire closed-loop control architecture is engineered with microsecond computational latency to guarantee deterministic, real-time vehicular responsiveness. Furthermore, the joystick assembly incorporates a mechanically spring-loaded neutral dead-band; when physical operator input ceases, the kinematic system autonomously reverts to this absolute zero-state, immediately disengaging dynamic

motive power to ensure the vehicle remains entirely stationary. This provides a critical fail-safe mechanism that categorically prevents unintended kinematic drift, fundamentally guaranteeing operational security for the differently-abled user within complex navigational environments [1][2].

2.3 Braking and safety operation

The comprehensive braking apparatus and integrated active safety architecture constitute a mission-critical, highly robust subsystem within the Single Hand Drive Electric Vehicle (EV), meticulously engineered to guarantee highly secure, fault-tolerant, and reliable dynamic operation across continuously fluctuating and unpredictable environmental conditions. The primary deceleration framework is fundamentally governed by a sophisticated electronic braking protocol seamlessly interfaced with the Brushless Direct Current (BLDC) traction motor's electronic commutation sequence. When the operator-controlled multi-axis joystick is mathematically returned to its predefined neutral dead-band or actively engaged in a reverse kinematic vector, the central 32-bit microcontroller algorithmically modulates the high-power motor driver inverter, initiating a highly controlled, gradual reduction in rotational velocity and kinetic momentum, often leveraging regenerative principles to achieve a smooth, non-disruptive halt while simultaneously recuperating kinetic energy. Augmenting this primary electronic deceleration phase, the vehicular architecture incorporates a highly resilient, secondary mechanical or high-force electromechanical braking matrix specifically designed to address acute emergency scenarios; this redundant electromechanical actuation provides critical, near-instantaneous frictional stopping capabilities directly to the wheel assemblies, ensuring absolute compliance with strict automotive deceleration safety standards when immediate kinetic arrest is critically mandated by sudden environmental hazards. Beyond dynamic braking mechanisms, the system integrates a deeply embedded, multi-tiered active safety ecosystem explicitly designed to proactively shield the physically challenged operator and actively prevent catastrophic collision events during navigation. A primary component of this protective digital envelope is an advanced, continuously active array of environmental perception sensors—typically comprising high-frequency ultrasonic transducers and infrared proximity detectors—which execute uninterrupted, real-time spatial monitoring of the vehicle's immediate operational perimeter. Upon the deterministic algorithmic detection of an impending physical obstacle, structural

impediment, or hazardous dynamic encroachment within a mathematically pre-calculated critical spatial safety threshold, these sensors instantaneously transmit high-priority interrupt signals to the central processing unit; this subsequently triggers a hard-coded autonomous override protocol that proactively decelerates the drive motor or completely arrests all vehicular motion, thereby neutralizing the physical threat completely independent of the operator's physiological reaction times. Furthermore, directly addressing the paramount necessity for immediate, human-in-the-loop safety interventions, the electromechanical system strategically incorporates a highly visible, physically accessible emergency stop (E-stop) switch. This crucial, heavy-duty fail-safe mechanism allows either the differently-abled primary user or adjacent external assisting personnel to instantaneously sever the main high-current power transmission pathways bridging the primary electrochemical energy storage unit and the primary propulsion drivetrain. The activation of this latching switch executes a rapid, unalterable system shutdown during unexpected critical emergencies, cognitive overload scenarios, or uncontrollable dynamic anomalies, thereby functioning as an absolute failsafe against runaway vehicle conditions. Complementing these active physical interventions, the entire cyber-physical control network is firmly undergirded by a comprehensive, algorithmic fail-safe control philosophy, wherein continuous internal diagnostic subroutines evaluate system health; any detected systemic malfunction, sensor degradation, communication latency, or abnormal operational state automatically forces the vehicle's powertrain into a predefined, secure, and entirely stationary default mode, effectively preventing any unpredictable or hazardous kinematic behavior. Finally, strict adherence to foundational electrical engineering safety standards is maintained throughout the vehicle's intricate structural topology; meticulous high-voltage wire insulation, rigorous chassis grounding protocols to prevent parasitic leakage currents, and the strategic deployment of protective electronic isolation devices, such as fast-acting ceramic fuses and intelligent circuit breakers, are comprehensively implemented to systematically eliminate severe electrical hazards, thereby ensuring absolute operational integrity, profound electrical reliability, and paramount user security within this highly specialized assistive mobility platform [1][2].

3. CONCLUSIONS

The braking and active safety architecture of the Single Hand Drive Electric Vehicle (EV) is engineered as a highly robust, fault-tolerant subsystem to ensure secure dynamic operation. The primary deceleration mechanism utilizes an electronic braking protocol integrated with the Brushless Direct Current (BLDC) motor's commutation sequence. When the user returns the control joystick to its neutral dead-band or initiates a reverse kinematic vector, the central 32-bit microcontroller modulates the motor inverter to gradually reduce rotational velocity, employing regenerative braking to recuperate kinetic energy and achieve a smooth halt. To handle acute emergencies, a redundant electromechanical friction braking matrix supplements the primary electronic system, providing immediate kinetic arrest directly at the wheel assemblies in compliance with strict automotive safety standards. Furthermore, the vehicle incorporates a multi-tiered active safety ecosystem utilizing a continuous array of ultrasonic and infrared sensors for real-time environmental perception. If an obstacle breaches a predefined spatial safety threshold, the central processing unit triggers a hard-coded autonomous override protocol to decelerate or completely stop the vehicle, mitigating collision risks independently of operator reaction time. For immediate manual intervention, a physically accessible emergency stop (E-stop) switch allows the user or assisting personnel to instantly sever the high-current power transmission between the battery and the drivetrain. This physical fail-safe is reinforced by continuous algorithmic diagnostics that force the powertrain into a secure, stationary default state upon detecting systemic anomalies. Finally, the vehicle adheres to rigorous electrical safety standards, utilizing high-voltage insulation, precise chassis grounding, and fast-acting circuit breakers to prevent electrical hazards and guarantee overall operational integrity.

ACKNOWLEDGEMENT

We are extremely thankful to our Honorable principal of ICET, Dr. Prof. K A Navas for inspiring and encouraging us for such astonishing work. We are incredibly grateful to our guide Prof. Lipin Paul for his suggestion and prejudice among students as well as we are probably thankful to other faculties and our best friends of the department for their support and motivation. Especially we are heartily thankful and indebted to our beloved parents for their love and support.

REFERENCES

1. V. Pandey, S. Sharma, R. Gupta, and P. Singh, "IoT-Based Safety System for Physically Challenged Vehicle Drivers," in *Proc. IEEE Int. Conf. on IoT and Smart Cities*, 2022.
2. S. Ramesh, P. J. Varghese, and A. Kumar, "Design and Implementation of a Hand-Controlled Vehicle for Physically Challenged Persons," in *Proc. IEEE Int. Conf. on Smart Technologies*, 2021.
3. R. Kumar, P. Mehta, and D. Roy, "Ergonomic Design Considerations for Physically Challenged Vehicle Drivers," *IEEE Access*, vol. 8, pp. 12345–12353, 2020.
4. M. Gupta, R. Sharma, S. Verma, and K. Raj, "Smart Adaptive Vehicle for Differently-Abled People Using Arduino and Sensors," in *Proc. IEEE Int. Conf. on Communication and Signal Processing*, 2020.
5. C. Sachin, S. Srihari, K. Prajeesh, N. Prem, B. Sreevasudev, and K. R. Bharath, "Increasing Accessibility of Electric Vehicles with Joystick Based Drive-By-Wire Model," in *Proc. IEEE Int. Conf. on Control, Automation and Robotics (ICCAR)*, pp. 435–439, 2020.
6. C. Huang, F. Naghdy, H. Du, and H. Huang, "Shared Control of Highly Automated Vehicles Using Steer-By-Wire Systems," *IEEE/CAA J. Autom. Sinica*, vol. 6, no. 2, pp. 371–382, Mar. 2019.
7. A. Khan, S. Gupta, R. Kaur, and M. Singh, "Design and Simulation of Adaptive Hand Controlled Driving System," *IEEE Trans. Human-Machine Systems*, vol. 49, no. 6, pp. 654–662, 2019.
8. A. M. Abdul Rahman and N. Yusof, "Assistive Driving Control System Using Joystick Interface for Disabled Drivers," in *Proc. IEEE Symp. on Computer Applications and Industrial Electronics*, 2019.
9. P. B. Kalbande, S. Patil, and R. Deshmukh, "Development of Modified Vehicles for Physically Handicapped Persons," in *Proc. IEEE Int. Conf. on Advances in Communication and Computing Technology (ICACCT)*, 2018.
10. D. S. Singh, N. Sharma, M. Gupta, and S. Sharma, "Development of System for Early Fire Detection Using Arduino UNO," *Int. J. Eng. Sci.*, vol. 10857, 2017.