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AI-Integarted Wheelchair System for Cerebral Palsy with Augmentated and Alternative Communication (AAC)

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ABSTRACT:
A lifelong neurological condition, cerebral paralysis(CP) limits a person's capacity to engage singly in diurnal conditioning by causing severe impairments in mobility, posture, and communication. There's an critical need for an intertwined assistive result because traditional wheelchairs are unfit to break the problems of movement, safety, and expression. The design and development of an AI- enhanced smart wheelchair system with an Augmentative and Indispensable Communication(AAC) module to grease communication and movement for kiddies with cerebral paralysis is shown in this work. The suggested approach combines handicap discovery detectors for safety, an AI- powered voice adjunct for environmental engagement, a mobile- grounded AAC interface, and a remedial standable frame with mobility braces to enhance stability and postural control. Effective gesture and voice- grounded command recognition, reliable handicap discovery, and flawless posture transfer through the standable frame are all demonstrated by the primary prototype evaluation. These findings suggest that the technology can grease suggestive communication, ameliorate independent mobility, and offer remedial advantages. The study comes to the conclusion that a scalable and effective strategy for enhancing availability, autonomy, and quality of life for people with cerebral paralysis is to combine AI, AAC, and remedial support into a single multipurpose platform.
Keywords: Cerebral paralysis, AI- integrated wheelchair, Augmentative and Indispensable Communication(AAC), assistive technology, recuperation engineering, smart mobility system.

1. INTRODUCTION

A. BACKGROUND OF THE PROBLEM

Early brain injury causes cerebral paralysis(CP), a neurodevelopmental condition that lasts a continuance and profoundly affects posture, muscular tone, and motor function. CP is still one of the main causes of physical handicap in children, with an prevalence rate of 2- 3 per 1,000 live births worldwide. People with cerebral bonhomous constantly have severe movement limits, poor motor collaboration, and speech or suggestive communication impairments, which make them largely dependent on caretakers for everyday tasks. Indeed while they're necessary for introductory mobility, traditional wheelchairs only offer limited functional support and fail to meet the more comprehensive remedial, communication, and safety- related demands of CP druggies.

Beyond their incapability to move, children and people with cerebral paralysis frequently struggle to communicate their requirements, connect with literacy settings less, and share in social or academic conditioning less. The assistive technology now in use, similar as individual AAC bias, mobility aids, and recuperation outfit, is constantly dispersed, expensive, and challenging to manage all at formerly. This fractured ecosystem of widgets fails to give an integrated, stoner- centric approach to independence and remedial development, making it delicate for druggies and caregivers to operate.

Developments in detector technology, mobile computing, artificial intelligence, and adaptive control systems offer a fresh chance to revise supported mobility results. nonetheless, intelligent communication support, automatic safety monitoring, remedial standing capabilities, and AI- supported commerce are still absent from the maturity of wheelchairs that are vended commercially.

This difference emphasizes the critical need for a cohesive, each- encompassing system that may coincidently ameliorate CP cases' mobility, safety, communication, and recuperation results. Therefore, the background of the issue is the mismatch between the limited capabilities of being mobility aids and the complicated requirements of people with cerebral paralysis. In order to close this gap and enhance independence, availability, and general quality of life, a creative, intertwined wheelchair system that supports physical, communicative, and educational engagement is demanded.

The project built the solution for the CP patients based on the analyze of special students affected by Cerebral Palsy from Dr. APJ Abdul Kalam Dream Special School and Adelihide rehabilitation Centre, Coimbatore, India.

B. EXISTING CHALLENGE

S/NO	Feature/ Parameter	Existing Wheelchair Systems	Proposed AI-Integrated Wheelchair System

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1)	Mobility Function	Basic manual/standard electric mobility	Dual mode: manual + AI-assisted smart mobility with voice/gesture control
2)	Communication Support	No built – in AAC; external devices required	Mobile – integrated AAC interface + AI voice assisted for real – time communication
3)	Safety Mechanisms	Minimal safety; lacks obstracle detection or user monitoring	Multi – mode safety; obstracle detection, emergency stop,sensor-based monitoring.
4)	Therapeutic Support	No therapeutic functions; requires separate physiotherapy equipment	Standable frame for posture correction,circulation, and rehabilitation
5)	Postural Stability	Limited back support; no adaptive stabilization	Smart mobility braces for trunk, hip, and limb stability
6)	User Interaction	No digital interface or interactive tools	Touchscreen/mobile interface, training modules, and customizable UI
7)	Independence Level	High caregiver dependancy	Increased autonomy through voice control, AAC, and automated assistance
8)	Learning & Education Integration	No support for learning tasks	Screen/notepad integration for interactive learning and cognitive engagement
9)	Customization	Very limited; one- size- fits- all design	Fully adaptable to various CP severity levels; modular components.
10)	Suitability for Non-Verbal users	Poor-additional devices required	Built-in AAC switches + AI speech output for independent expression
11)	Cost Efficiency	Standard cost but requires multiple external devices	Cost – effective all-in-one system reducing need for separate assitive tools
12)	Technology Integration	Fragmented; requires multiple third-party devices	Unified multi-function system merging mobility,safety, therapy, and communication
13)	Target User Fit	Designed generically, not CP-specific	Tailored specifically for CP and other neuromuscular disabilities.
14)	Long-Term Usability	Limited adaptability as user needs grow	Scalable, customizable, and upgradable with software updates

Table 1.1 Existing Vs Proposed system

C. RESEARCH GAP

1) Lack of Integrated Mobility - Communication Systems

Current wheelchairs primarily address mobility and do n't incorporate native Augmentative and Indispensable Communication(AAC) systems. druggies frequently depend on multiple external bias, performing in fractured operation, increased burden on caregivers, and reduced independence.

2) inadequate AI- Enabled Personalization

Being assistive bias infrequently work artificial intelligence for adaptive communication support, stoner intent vaticination, or substantiated motor-control backing. This prevents the system from accommodating variations in neuromotor patterns common in CP cases.

3) Limited Safety Mechanisms:

utmost commercially available wheelchairs warrantmulti-level safety features similar as detector- driven handicap discovery, automated exigency stop functions, or stoner- state monitoring. This absence poses threat for druggies passing involuntary or discontinuous movements.

4) No Unified Platform for Holistic Support:

Current results frequently address insulated challenges- either mobility, communication, or remedy- but do n't offer an integrated, scalable system combining all essential assistive functions into one cohesive platform.

5) Cost and Accessibility Barriers:

Advanced powered wheelchairs remain precious,non-modular, and beyond the reach of children in low- resource settings. A lack of customizable and affordable smart wheelchairs limits wide relinquishment in special seminaries and recuperation centres.

6) Standable Frame Integration:

Standers and posture- correction bias presently live as separate units, not bedded within wheelchairs. druggies must be transferred between bias, adding caregiver workload and threat of injury.
No low- cost, child-friendly, AI- enabled wheelchair presently includes a erected- in stand- help medium to support posture correction, rotation enhancement, or recuperation remedy.

D. CONTRIBUTIONS OF THE PRESENT WORK

1) Design of an AI - Integrated Multi- Domain Assistive Platform

This work presents a new wheelchair armature that integrates mobility control, communication addition, remedial functions, and stoner- safety mechanisms into a single beddedcyber-physical system, addressing the fractured nature of being assistive technologies.

2) Implementation of a Mobile-Based AAC Communication Engine
A mobile-intertwined Augmentative and Indispensable Communication(AAC) frame is developed using symbol- grounded commerce, real- time speech conflation, and customizable communication grids. The system enables low- quiescence communication for druggies with severe speech impairment while maintaining modular expandability.

3) Development of an AI-Augmented Human - Machine Interaction Layer
An AI- driven commerce module is enforced, incorporating voice recognition, intent vaticination, and adaptive command processing. This subsystem enhances stoner autonomy by enabling multimodal control(voice, gesture, and switch- grounded inputs) and nonstop personalization through stoner-specific behavioral modeling.

4) Integration of a Therapeutic Standable Mechatronic Mechanism
A physiologically informed stand- help medium is bedded into the wheelchair structure, employing high- necklace PMDC actuation and controlled kinematic support. This design provides active postural transition and remedial weight- bearing, addressing secondary complications similar as circulatory limitations and musculoskeletal contractures.

5) Engineering of a Multi-Mode Safety and Monitoring Framework
A spare safety armature is proposed, comprising detector- driven handicap discovery, stoner- state monitoring, andtri-modal exigency stop triggers. This frame enhances functional trustability by furnishing fault-tolerant response pathways under involuntary stoner stir or environmental hazards.

6) Design of Adaptive Smart Mobility Braces for Postural Regulation
A set of adaptive braces is introduced to stabilize box and branch alignment during stir. These factors serve as an supplementary postural control system, mollifying spasticity- convinced insecurity and optimizing biomechanical support for druggies with neuromotor impairments.

7) Dual-Mode Locomotion Integration (Manual + Autonomous)
The system supports cold-blooded locomotion through homemade propulsion and AI- supported automated mobility, icing usability across different physical and infrastructural surrounds while perfecting availability in constrained or detector- limited surroundings.

8) Low-Cost, Scalable Embedded Architecture for Real-World Deployment
The proposed platform is finagled using cost-effective tackle, open- source firmware, and modular subsystem design, enabling reproducibility, low conservation above, and scalability for deployment in special- education institutions and recuperation centers.

9) Cross-Condition Applicability Extending Beyond Cerebral Palsy
Although optimized for cerebral paralysis, the armature supports adaption for multiple neuromuscular conditions- including muscular dystrophy, spinal cord injury, Parkinsonian diseases, and stroke- convinced palsy- demonstrating broad clinical applicability and translational eventuality.

II. RELATED WORK

Development of a Mobile Application for Augmentative and Alternative Communication (AAC) Board for Children with Communication Challenges and Cerebral Palsy, 2025

Children with cerebral bonhomous constantly struggle with communicating, which has an impact on their everyday lives and independence. The mortal exertion Assistive Technology(HAAT) model was used to produce a mobile operation- grounded Augmentative and Indispensable Communication(AAC) board to break this problem. Ten children with cerebral paralysis and four specialists assessed the operation, which combines illustrations, symbols, and sounds to grease verbal communication. Specialized testing vindicated minimum CPU and power operation, guaranteeing smooth and reliable performance, while usability evaluation using Hunt 2.0 and the System Usability Scale(SUS) produced excellent findings, with an average score of 80.5. The mobile-grounded system offered lesser portability, inflexibility, and stoner pleasure in comparison to conventional AAC boards.

Possibilities of battery-free AACloth for augmentative and alternative communication: views of parents of children with cerebral palsy, 2023

40–85% of children with cerebral paralysis(CP) have communication difficulties. While augmentative and indispensable communication(AAC) tools can be helpful, numerous of the current systems have downsides, including the need for fine motor chops, the portability of the device, and battery conservation. The study delved the opinions of parents regarding the use of AACloth, a wireless, battery-free RFID- groundede-textile, as an AAC tool. An online check was completed by nine parents of kiddies with cerebral paralysis. To guarantee nonstop vacuity, the maturity of parents recommended putting AACloth on mobility aids like wheelchairs. By using their hands to touch, press, or swipe the cloth, children may manipulate it and convey requirements like asking for backing, expressing pain, or making opinions about everyday tasks.

A Hands-free Interface for Controlling Virtual Electric-powered Wheelchairs, 2015

A hands-free interface (HFI) for controlling electric-powered wheelchairs (EPWs) with residual body movements is presented in this work for those with motor disabilities. The HFI employs wearable sensorized clothing that records elbow and shoulder movements and converts them into navigational commands in place of joysticks. Strong correlations (r = 0.82–0.94) between HFI signals and optical tracking systems were found in tests involving healthy subjects, indicating accuracy. Within a week, a patient with a spinal cord damage learned how to operate a virtual wheelchair, proving its usability and adaptability. The findings demonstrate HFI's potential as a safe, effective, and customized mobility option for those with restricted motor function.

Mobile application for augmentative alternative communication to help people with speech disorder and motor impairment, 2018

Stoner- centered design was used in the creation of the AACVOX smartphone operation. With malleable layouts and possibilities to add prints, change textbook, and use scanning for severe disabilities, the software facilitates judgment structure through pictographic icons and speech conflation. AACVOX entered a high System Usability Scale(SUS) score of 85.85 after testing with 20 CP actors, suggesting exceptional usability in terms of literacy, effectiveness, satisfaction, and mistake reduction. AACVOX is a useful tool to enhance autonomy and communication in people with CP since it's less precious, more movable , and more flexible than standard AAC bias.

Voice-Recognized App-based Motorized Wheelchair and Household Intelligent Systems, 2022

By combining a motorized wheelchair with speech recognition and Internet of effects home robotization, the design offers a smart result for those with disabilities. Through a smartphone operation, the system enables druggies to handle domestic appliances with introductory voice commands and control wheelchair movements(forward, backward, left, right, stop). The configuration, which is powered by a NodeMCU(ESP8266), DC motors, and an L298N motorist, guarantees precise and responsive mobility and permits remote access to ménage widgets via a single app. The issues demonstrate a high position of command recognition delicacy, encouraging stoner freedom and ease. Reducing response times and incorporating handicap discovery detectors for safer navigation are unborn advancements.

METHODOLOGY

OVERALL BLOCK DIAGRAM

The proposed AI- Integrated Wheelchair System's functional armature is depicted in the block illustration. All subsystems communicate with one centralized microcontroller unit(MCU), which is in charge of signal accession, processing, and selector control. In order to continuously cover stoner intent, system status, and external operating conditions, the MCU receives multimodal sensitive input from environmental detectors(similar as ultrasonic, infrared, and IMU modules), AAC(Augmentative and Indispensable Communication) switches, voice- command interfaces, and mobility- brace feedback detectors. The MCU performs bedded control algorithms for stir planning, safety evaluation, handicap recognition, and state estimate after accession. The drive- motor control stage receives affair control signals and uses PWM- grounded actuation to operate the wheelchair's traction motors, enabling smooth and flexible movement.The reused control signals also support the operation of supplementary subsystems, enabling accompanied geste across mobility, communication, and safety modules.

Bidirectional Bluetooth/ Wi- Fi data cloverleaf is made possible via a specific communication interface that connects the MCU to a mobile operation platform. The mobile- enabled AAC module, which offers voice conflation, dynamic symbol sets, real- time admonitions, and system configuration choices, is hosted on the mobile interface. By removing computationally demanding AAC and AI- grounded operations from the MCU, this external processing terrain improves system responsiveness and scalability. The wheelchair may give high- perfection mobility aid, adaptive communication support, and bettered stoner safety thanks to the integration of detector emulsion, real- time motor control, and mobile- supported AAC commerce within a unified tackle – software armature. For people with complicated motor disabilities, the modular design guarantees comity with remedial additions, similar as standable frames and customized mobility braces, offering a complete assistive platform.

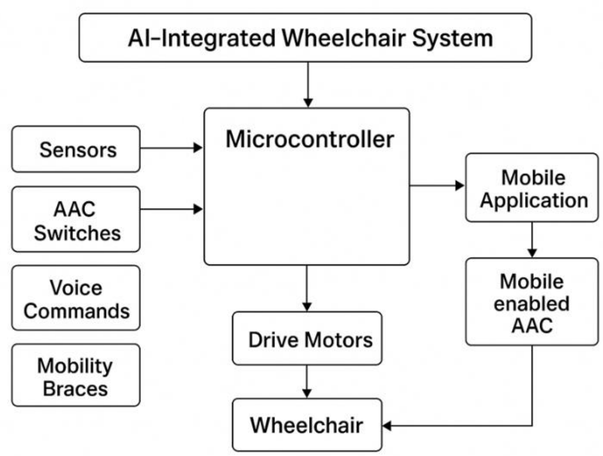

Figure 2.1 Overall Block Diagram

HARDWARE DESIGN

A high- performance microcontroller unit(MCU) serves as the essential computing core of the AI- Integrated Wheelchair System for Cerebral Palsy's tackle armature, carrying out selector collaboration, detector emulsion algorithms, and real- time control circles. Through digital and analog I/ O lines, the MCU communicates with a dispersed network of environmental and stoner- commerce detectors, similar as accelerometers, ultrasonic/ IR propinquity detectors, and exigency- detector inputs, to enable ongoing handicap, posture insecurity, and critical safety event monitoring. In order to guarantee deterministic intrude- grounded responses for halting motor exertion in dangerous situations, the exigency subsystem is directly hardwired to the MCU. Adaptive stabilization and posture correction are made possible by the system's use of smart mobility braces with pressure and positional feedback detectors that connect to the MCU via periodical or I2C interfaces. Onboard speech playback for AAC prompts, admonitions, and stoner- guided engagement is handed via a voice aid tackle module that includes a speaker affair stage and DF- player audio interface. By connecting a Bluetooth/ Wi- Fi module to the MCU, the mobile-intertwined AAC interface creates a bidirectional communication channel that allows the wheelchair and the mobile operation to change stoner commands, AAC choices, and configuration data.

A technical motor control subsystem handles motor actuation. It consists of L298N or similar H- ground motor motorists that admit PWM signals from the MCU to control the drive motors' necklace, speed, and direction. This guarantees controlled acceleration biographies and fluid mobility that are applicable for those with involuntary motor movements. A stable power force unit, generally a 12- V DC battery with voltage control circuitry to give insulated rails for sense- position circuits, detector modules, and high-current motor motorists, powers all tackle factors. In real- time assistive surroundings, the integrated tackle mound guarantees dependable, fault-tolerant operation that can support mobility, safety, and AAC communication.

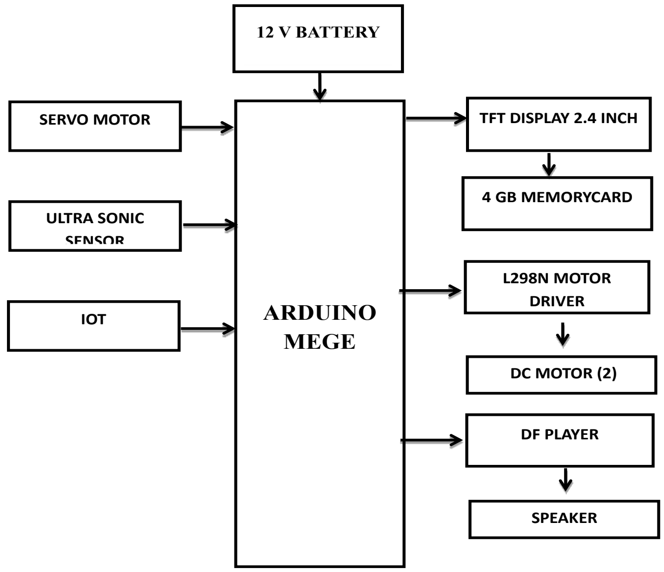

Figure 2.2 Hardware Specifications

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ARDUINO MEGA:

The main bedded control platform in this system is the Arduino Mega 2560, which was chosen due to its strong I/ O capabilities, great computational inflexibility, and interoperability with a variety of assistive tackle modules. The ATmega2560 microcontroller, an 8- bit AVR RISC armature processor with 256 KB of flash memory, 8 KB of SRAM, and 4 KB of EEPROM, is the foundation of the board. It offers sufficient capacity for intricate firmware,multi-module communication routines, and detector- processing algorithms. Deterministic control circle prosecution is made possible by its 16 MHz timepiece frequence, which is pivotal for handicap recognition, real- time motor regulation, and responsive stoner interfaces. One of the defining advantages of the Arduino Mega in assistive systems is its expansive leg vacuity, comprising 54 digital I/ O legs, 15 PWM labors, and 16 analog input channels. Without the need for fresh multiplexing tackle, these tackle coffers enable contemporaneous interfacing with several subsystems, including AAC switches, ultrasonic detectors, voice- backing modules, mobility braces with feedback detectors, and motor motorist units. likewise, four tackle UART periodical anchorages(Serial0 – Serial3) greasemulti-channel communication with Bluetooth/ Wi- Fi modules, speech modules, and debugging outstations. This allows for reliable resemblant communication aqueducts, which is pivotal for AI- supported wheelchair systems where communication quiescence must be kept to a minimum.

In order to grease accurate timing operations, PWM motor control, and effective detector emulsion styles, the board has tackle features including an I2C interface, SPI machine, intrude legs, and timekeeper/ counter units. Essential real- time tasks including monitoring ultrasonic echo timing for handicap discovery, reading AAC switch states with minimum quiescence, and producing harmonious PWM signals for drive motor control are made possible by these supplemental capabilities. also, its erected- in Watchdog Timer(WDT) improves system trustability by automatically resetting the regulator in the event of a firmware cube, icing safe and nonstop operation- an important demand in mobility- assistive surroundings. The Arduino Mega's comity with a wide ecosystem of open- source libraries accelerates firmware development for voice command integration, TV/ TFT display running, SD card data logging, and IoT connectivity. It can work with the maturity of commercially available assistive detectors and modules thanks to its 5 V tolerant sense, which eliminates the need for redundant position shifters. likewise, safe operation from a 12 V DC battery force — which is constantly used in wheelchair systems — is made possible by its veritably low power consumption and dependable on- board voltage control circuitry.

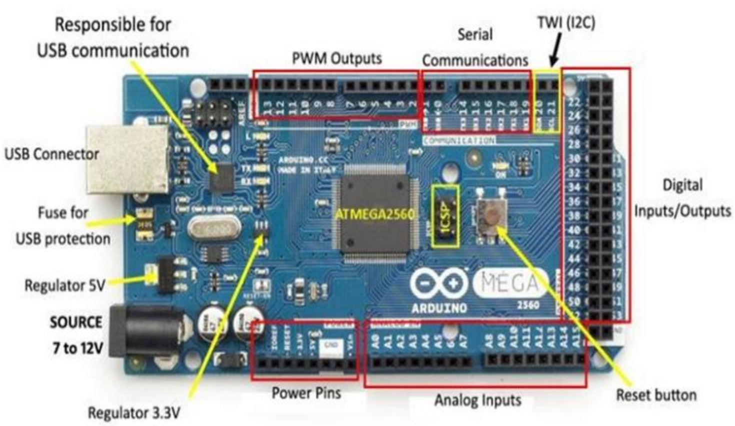

Figure 2.3 Arduino Mega 2560

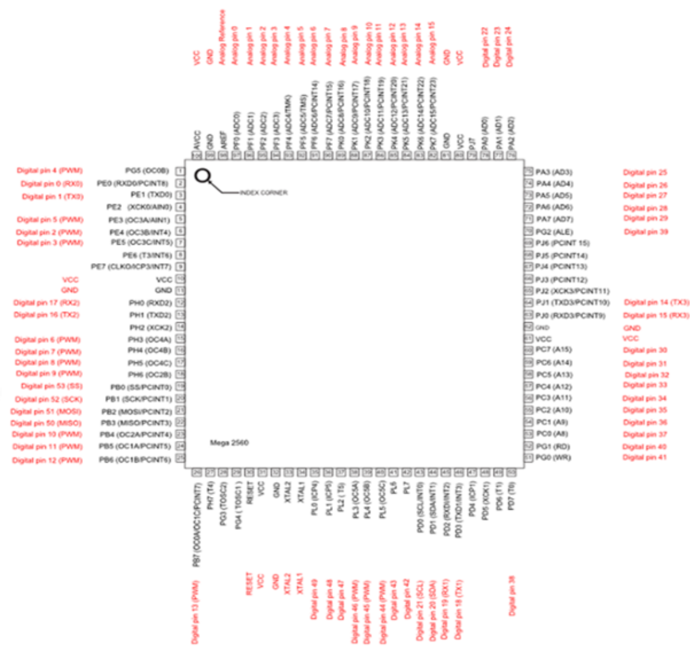

Figure 2.4 Arduino Mega 2560 PIN diagram

Pin No	Pin Name	Mapped Pin Name
1	PG5 (OC0B)	Digital pin 4 (PWM)
2	PE0 (RXD0/PCINT8)	Digital pin 0 (RX0)
3	PE1 (TXD0)	Digital pin 1 (TX0)
4	PE2 (XCK0/AIN0)	
5	PE3 (OC3A/AIN1)	Digital pin 5 (PWM)
6	PE4 (OC3B/INT4)	Digital pin 2 (PWM)
7	PE5 (OC3C/INT5)	Digital pin 3 (PWM)
8	PE6 (T3/INT6)	
9	PE7 (CLKO/ICP3/INT7)	
10	VCC	VCC
11	GND	GND
12	PH0 (RXD2)	Digital pin 17 (RX2)
13	PH1 (TXD2)	Digital pin 16 (TX2)

14	PH2 (XCK2)	
15	PH3 (OC4A)	Digital pin 6 (PWM)
16	PH4 (OC4B)	Digital pin 7 (PWM)
17	PH5 (OC4C)	Digital pin 8 (PWM)
18	PH6 (OC2B)	Digital pin 9 (PWM)
19	PB0 (SS/PCINT0)	Digital pin 53 (SS)
20	PB1 (SCK/PCINT1)	Digital pin 52 (SCK)
21	PB2 (MOSI/PCINT2)	Digital pin 51 (MOSI)
22	PB3 (MISO/PCINT3)	Digital pin 50 (MISO)
23	PB4 (OC2A/PCINT4)	Digital pin 10 (PWM)
24	PB5 (OC1A/PCINT5)	Digital pin 11 (PWM)
25	PB6 (OC1B/PCINT6)	Digital pin 12 (PWM)
26	PB7 (OC0A/OC1C/PCINT7)	Digital pin 13 (PWM)
27	PH7 (T4)	
28	PG3 (TOSC2)	
29	PG4 (TOSC1)	
30	RESET	RESET
31	VCC	VCC
32	GND	GND
33	XTAL2	XTAL2
34	XTAL1	XTAL1
35	PL0 (ICP4)	Digital pin 49
36	PL1 (ICP5)	Digital pin 48
37	PL2 (T5)	Digital pin 47
38	PL3 (OC5A)	Digital pin 46 (PWM)
39	PL4 (OC5B)	Digital pin 45 (PWM)
40	PL5 (OC5C)	Digital pin 44 (PWM)
41	PL6	Digital pin 43
42	PL7	Digital pin 42
43	PD0 (SCL/INT0)	Digital pin 21 (SCL)
44	PD1 (SDA/INT1)	Digital pin 20 (SDA)
45	PD2 (RXDI/INT2)	Digital pin 19 (RX1)
46	PD3 (TXD1/INT3)	Digital pin 18 (TX1)
47	PD4 (ICP1)	
48	PD5 (XCK1)	
49	PD6 (T1)	
50	PD7 (T0)	Digital pin 38
51	PG0 (WR)	Digital pin 41
52	PG1 (RD)	Digital pin 40
53	PC0 (A8)	Digital pin 37
54	PC1 (A9)	Digital pin 36
55	PC2 (A10)	Digital pin 35
56	PC3 (A11)	Digital pin 34
57	PC4 (A12)	Digital pin 33
58	PC5 (A13)	Digital pin 32
59	PC6 (A14)	Digital pin 31
60	PC7 (A15)	Digital pin 30
61	VCC	VCC

62	GND	GND
63	PJ0 (RXD3/PCINT9)	Digital pin 15 (RX3)
64	PJ1 (TXD3/PCINT10)	Digital pin 14 (TX3)
65	PJ2 (XCK3/PCINT11)	
66	PJ3 (PCINT12)	
67	PJ4 (PCINT13)	
68	PJ5 (PCINT14)	
69	PJ6 (PCINT 15)	
70	PG2 (ALE)	Digital pin 39
71	PA7 (AD7)	Digital pin 29
72	PA6 (AD6)	Digital pin 28
73	PA5 (AD5)	Digital pin 27
74	PA4 (AD4)	Digital pin 26
75	PA3 (AD3)	Digital pin 25
76	PA2 (AD2)	Digital pin 24
77	PA1 (AD1)	Digital pin 23
78	PA0 (AD0)	Digital pin 22
79	PJ7	
80	VCC	VCC
81	GND	GND
82	PK7 (ADC15/PCINT23)	Analog pin 15
83	PK6 (ADC14/PCINT22)	Analog pin 14
84	PK5 (ADC13/PCINT21)	Analog pin 13
85	PK4 (ADC12/PCINT20)	Analog pin 12
86	PK3 (ADC11/PCINT19)	Analog pin 11
87	PK2 (ADC10/PCINT18)	Analog pin 10
88	PK1 (ADC9/PCINT17)	Analog pin 9
89	PK0 (ADC8/PCINT16)	Analog pin 8
90	PF7 (ADC7)	Analog pin 7
91	PF6 (ADC6)	Analog pin 6
92	PF5 (ADC5/TMS)	Analog pin 5
93	PF4 (ADC4/TMK)	Analog pin 4
94	PF3 (ADC3)	Analog pin 3
95	PF2 (ADC2)	Analog pin 2
96	PF1 (ADC1)	Analog pin 1
97	PF0 (ADC0)	Analog pin 0
98	AREF	Analog Reference
99	GND	GND
100	AVCC	VCC

Table 2.1 Arduino Mega 2560 PIN mapping table

INTERNET OF THINGS:

The Internet of effects(IoT) is a distributed network armature that uses linked digital platforms to grease communication and data exchange between physical objects, detectors, selectors, and bedded systems. IoT plays a pivotal part in enabling remote monitoring, device operation, real- time data collecting, and pall-supported decision- making in the environment of assistive mobility bias like AI- integrated smart wheelchair systems. The functionality, scalability, and responsibility of bedded systems concentrated on healthcare are greatly bettered by the objectification of IoT.

IoT connectivity is generally enabled at the tackle position via modules like ESP8266/ ESP32 Wi- Fi SoC, NB- IoT, or 4G LTE modems, which communicate with microcontrollers(like the Arduino Mega) via UART, SPI, or I2C protocols. In order to give nonstop data cloverleaf under resource constraints, these modules support featherlight communication fabrics and offer network connectivity. In order to transmit detector data, stoner commands, and individual information with minimum outflow and maintain system responsiveness indeed in situations with limited bandwidth, protocols like MQTT(Message Queuing Telemetry Transport), CoAP(Constrained operation Protocol), and HTTP/ HTTPS REST APIs are constantly used. IoT makes it possible to ever pierce real- time functional characteristics within the wheelchair system, similar as wheelchair position, system health, detector cautions, and exigency admonitions. For illustration, pall- grounded announcement services can fleetly notify caretakers or medical staff of abnormal motor cargo circumstances, fall discovery, or handicap admonitions. also, IoT facilitates advanced analytics by transferring data aqueducts to platforms like Firebase, AWS IoT Core, or Azure IoT mecca, where machine literacy algorithms may fete operation trends, spot irregularities, or cast conservation needs. Prophetic diagnostics like this ameliorate system safety overall and minimize time-out, which is pivotal for druggies with severe mobility disabilities.

IoT also makes bidirectional connectivity possible, allowing family members, clinicians, or caregivers to ever change configuration settings, transmit control commands, or keep an eye on AAC discussion records. Given the perceptivity of medical and assistive device data, the addition of secure protocols, similar as TLS/ SSL encryption, guarantees data confidentiality and integrity. likewise, system security is strengthened against unwanted access by authentication ways similar firmware integrity checks, device whitelisting, and token- grounded authorization. From a usability viewpoint, IoT expands the wheelchair's capabilities through connectivity with mobile apps and long- distance monitoring. From a smartphone dashboard, caregivers can cover the stoner's health- related detector data, battery situations, and mobility status. unborn scaling is also supported by the armature, which enables the addition of new IoT- enabled detectors(similar as posture monitoring modules, ambient detectors, and heart- rate observers) without taking a significant redesign of the hardware.Wheelchairs are getting sophisticated, networked, and environment- apprehensive assistive systems thanks in large part to the Internet of effects. It's an essential part of contemporary AI- supported recuperation and mobility technologies because of its capacity to offer remote monitoring, bettered safety, data- driven customisation, and integration with pall services.

Figure 2.5 Internet of Things (IoT)

ULTRASONIC SENSOR:

The ultrasonic detector is anon-contact distance- measuring tool that uses time- of- flight(ToF) analysis and acoustics. Because of its responsibility, low power consumption, and resistance to ambient illumination conditions, it's constantly employed in robotics, independent navigation, assistive mobility systems, and safety-critical operations. The ultrasonic detector improves safety for druggies with limited motor control and cognitive difficulties by enabling real- time handicap discovery and collision avoidance in the environment of an AI- integrated smart wheelchair system.

$$\text{Distance} = \frac{v X t}{2}$$

where t is the measured round- trip time and v is the speed of sound. Depending on detector specifications and environmental factors, this fashion offers dependable and accurate distance measures within a typical operating range of 2 cm to 400 cm.

Detectors like the HC- SR04, JSN- SR04T, or MaxBotix MB series are generally employed in bedded systems. These detectors use digital detector and echo legs to communicate directly with the microcontroller(similar as an Arduino Mega). The microcontroller uses tackle timekeepers or intrude algorithms to record the duration of the echo palpitation after generating a detector palpitation(generally 10 µs). The detector can fluently affiliate with safety modules, motor regulators, and AI- grounded decision sense thanks to this featherlight interface. Wheelchair safety robotization heavily relies on ultrasonic seeing. The detector continuously analyzes the surroundings to find impediments including cabinetwork, walls, and uneven shells. The microcontroller or an AI processing unit processes the data in real- time and can initiate conduct like route correction, exigency stop, or speed drop. Ultrasonic detectors are ideal for both inner and out-of-door mobility operations because they remain stable in a variety of lighting and material conditions, unlike infrared detectors, which are sensitive to temperature changes and reflective shells.

In order to make amulti-directional handicap discovery network, advanced systems may include several ultrasonic detectors deposited at crucial locales, similar as the front, back, and sides. To ameliorate trustability through detector redundancy, this network can be combined with other modalities as LiDAR, infrared detectors, or camera- grounded vision. This enhances navigation perfection and guarantees stoner safety in wheelchair operations, particularly for people with cerebral paralysis who may have limited homemade control or involuntary movements. Low energy consumption generally allows for nonstop operation without syncopating the battery life of the outfit. Some designs incorporate digital filtering, palpitation- shaping circuits, and adaptive thresholding to minimize noise and reflections caused by soft shells or complex shapes. Ultrasonic data can be transferred to pall platforms for prophetic conservation, performance recording, or stoner geste analytics in IoT-enabled systems, enhancing system resilience.The AI- integrated wheelchair's ultrasonic detector provides real- time,non-contact handicap discovery, making it a pivotal seeing medium. It's a pivotal part of safety, independent navigation, and intelligent mobility backing because of its delicacy, robustness, and environmental independence.

Figure 2.6 HC-SR04

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2 cm
MeasuringAngle	15 degree
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm
Main parts	Transmitter &receiver
Technology used	Non-contact technology
Resolution	3mm

Table 2.2 Electric Parameter

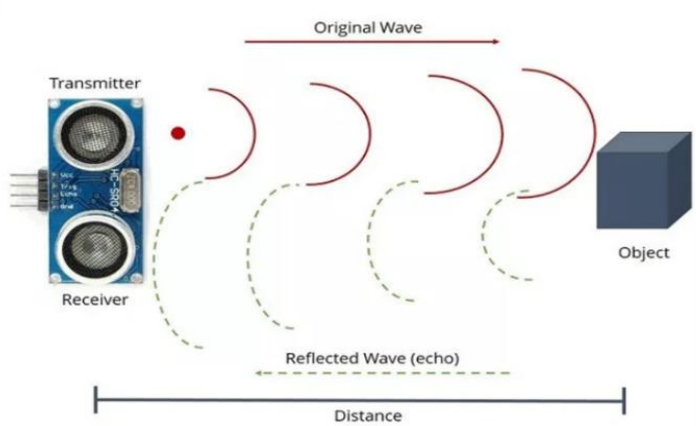

Figure 2.7 Working principle of ultrasonic sensor

ULTRASONIC SENSOR TIMING OPERATION

The timing characteristics of the ultrasonic ranging module are illustrated in the corresponding timing illustration. To initiate a dimension cycle, the microcontroller generates a detector palpitation of roughly 10 µs at the module's detector input. Upon entering this palpitation, the detector transmits an 8- cycle

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ultrasonic burst at 40 kHz and contemporaneously drives the Echo affair high. The duration of the Echo palpitation is directly commensurable to the round- trip time- of- flight of the aural surge, and thus represents the distance to the reflecting object. The distance D can be reckoned from the measured high- position time t of the Echo signal using

$$D = \frac{t\ X\ v}{2}$$

where v is the speed of sound in air (approximately 340 m/s at room temperature). For practical implementation, the sensor manufacturer provides simplified conversion formulas:

Distance (cm) = $\frac{t(\mu s)}{58}$, Distance (inch) = $\frac{t(\mu s)}{148}$

To avoid hindrance between consecutive measures, a minimal cycle period of 60 ms is recommended. This ensures that residual echoes do n't lap with posterior detector beats, thereby perfecting dimension delicacy and stability.

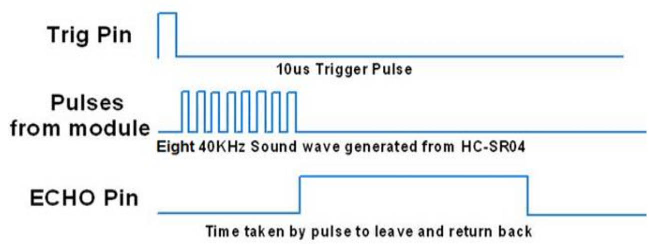

Figure 2.8 Ultrasonic HC-SR04 module timing diagram

L298N DC MOTOR DRIVER MODULE WITH ARDUINO

In bedded stir- control systems, the L298N is a high- power binary full- ground motor motorist integrated circuit that powers DC motors, stepper motors, and inductive loads. The contrivance, which is made with bipolar technology and has two separate H- ground channels that can deliver up to 2 A each at force voltages between 5 V to 46 V, is applicable for medium- power assistive robotic systems like intelligent wheelchairs. Through sense- position input legs(IN1 – IN4), which regulate the power transistors' conduction state, each H- ground channel permits bidirectional motor control. By varying the effective voltage supplied to the motors, the ENA and ENB enable legs give palpitation- range modulation(PWM) control for speed adaptation. also, the module has dyads of OUT1 – OUT4 outstations that link directly to the motor leads, and the motor motorist stage is powered by the onboard VS input. also, if the onboard voltage controller is turned on, sense circuitry may be supplied by the 5- V regulated affair(VSS). Back EMF(electromotive force) diodes, which cover the internal transistors from voltage harpoons caused by inductive loads during switching, are one of the L298N's crucial protection features. The bipolar transistor structure's essential thermal arrestment and current- limiting characteristics further ameliorate motorist adaptability. In wheelchair mobility operations, the motorist communicates with an bedded CPU or microcontroller that provides logical control signals to regulate the drive motors' acceleration, retardation, and direction. By enabling precise modulation of necklace and speed, the L298N facilitates smooth navigation, handicap avoidance, and controlled stir essential for safe operation in assistive mobility platforms.

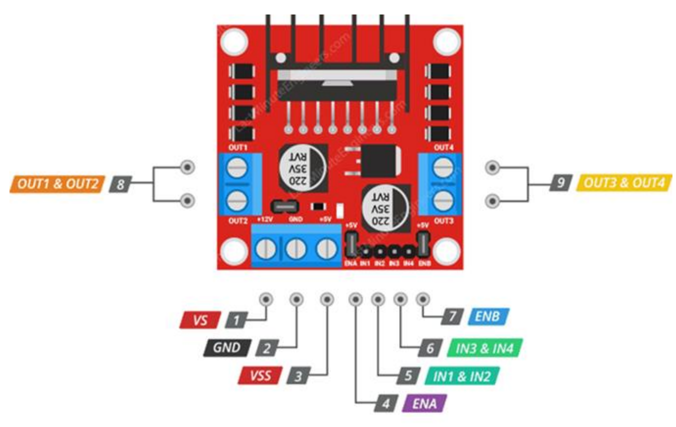

Figure 2.9 L298N Module Pinout

Motor output voltage	5V – 46V
Logic input voltage	4.5V – 7V
Continous current per channel	2A
Max power dissipation	25W

Table 2.3 Technical Specifications

DC MOTOR:

A Direct Current(DC) motor is an electromechanical selector that converts electrical energy into mechanical rotational stir through the commerce of glamorous fields and current- carrying operators. In a conventional brushed DC motor, the architecture winding located on the rotor receives electrical power through a commutator – encounter assembly, generating electromagnetic necklace according to

$T = K_t i$

Where K_t is the necklace constant and i is the architecture current. contemporaneously, rotor stir induces a back electromotive force(back- EMF) commensurable to angular haste, expressed as,

$e_b = K_e \omega,$

governs the motor's dynamic behavior.

The electrical characteristics of the motor, similar as resistance, inductance, and back- EMF constant, as well as its mechanical characteristics, similar as disunion and indolence, largely mandate its performance. To precisely control speed and direction, the applied voltage can be modified using palpitation- range modulation(PWM) when driven through an H- ground or motor motorist. The DC motor is extensively used in robotics, mobility aids, assistive bias, and independent platforms, including AI- integrated wheelchair systems, where reliable necklace generation and precise stir control are pivotal, due to its straightforward design, high necklace at low pets, and comity with bedded control systems.

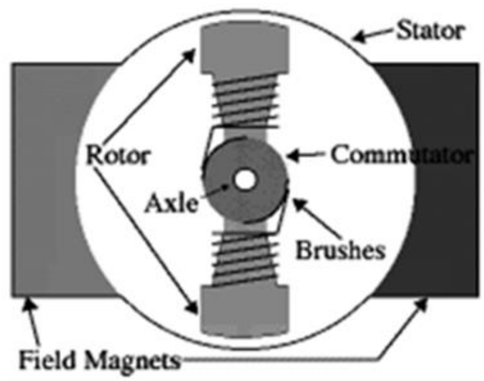

Figure 2.10 DC Motor

DF PLAYER:

The DFPlayer Mini is a tone- contained audio playback module designed for bedded systems taking low- quiescence, low- power sound generation. It incorporates an onboard MP3/ WAV/ WMA decoder,micro-SD storehouse interface, and audio amplifier, enabling independent playback without reliance on high-position processors. Due to its small form factor and robust functionality, it's considerably used in assistive technologies, interactive bias, and voice- feedback systems.

Hardware Architecture

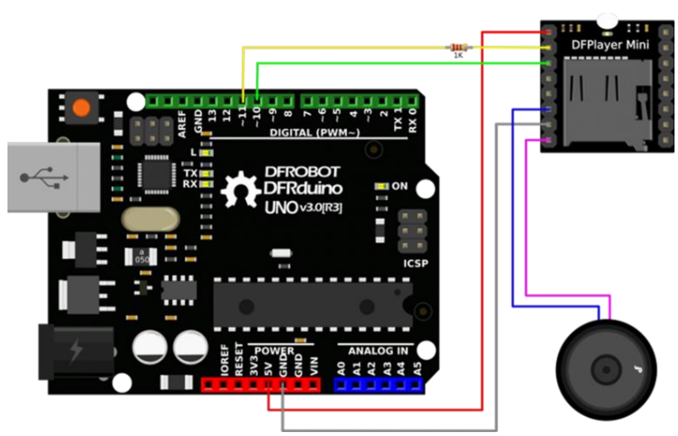

Figure 2.11 Connection Diagram

Audio Decoding Engine supports MP3, WAV, and WMA formats with real- time digital- to- analog conversion. The storehouse interface has amicro-SD card niche provides FAT16/ FAT32 train system support, enabling successional, listed, or brochure- grounded playback. Integrated audio amplifier that has a 3 W Class- D amplifier allows direct connection to small speakers, barring the need for external modification circuitry. Control and communication unit implements UART- grounded periodical control and supports standalone operation via tackle detector legs.

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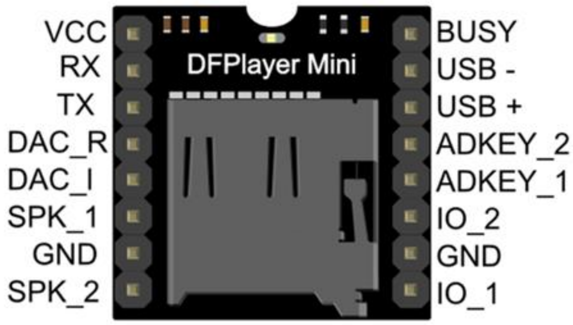

Figure 2.12 Pin map

VCC (3.2 – 5 V)	Power input for the logic and decoder.
GND	Common ground reference.
TX / RX	UART serial communication for microcontroller interfacing.
DAC_L / DAC_R	Analog stereo outputs for external amplifiers
SPK1 / SPK2	Direct speaker output from the onboard amplifier.
IO1 / IO2	Hardware trigger pins for simple button-based playback modes.

Table 2.4 Pin Configuration

Communication Protocol:

The DFPlayer Mini communicates using a double- grounded UART protocol at 9600 bps. Commands generally follow a 10- byte structured frame

7E FF 06 CMD 00 00 00 FE XX EF

CMD	the command opcode (e.g., play, pause, set volume).
XX	16-bit checksum for command integrity
0x03	Play track number
0x06	Set volume
0x0F	Select folder track
0x16	Stop playback

Table 2.5 Communication Commands

B. SOFTWARE DESIGN

The ESP32 microcontroller, which controls both high- position and real- time functions in a single frame, is the focal point of the software design of the suggested AI- Integrated Wheelchair System. The ESP32 uses modular software factors to carry out mobility control, safety operation, AAC integration, and stoner interface. The mobility module performs handicap recognition, collision avoidance, and adaptive navigation using inputs from ultrasonic, infrared, and IMU detectors. In order to give configurable symbol grids, prophetic typing, and textbook- to- speech affair, the AAC system is enforced through mobile integration, in which a smartphone or tablet app connects to the ESP32 via Bluetooth or Wi- Fi. This makes the system more affordable and movable by enablingnon-verbal druggies to interact effectively without depending on an integrated screen.

For comfort and literacy support, the ESP32's voice aid module plays remedial sounds, gives spoken feedback, and carries out orders. intrude- driven procedures that incontinently stop movement in response to voice commands, homemade switches, or detector admonitions enhance safety. likewise, the standable frame and smart mobility braces are controlled by selector control algorithms with protections against strain or insecurity. To give inflexibility and scalability, the system allows data logging, OTA firmware updates, and customization of AAC biographies via the mobile app. The design provides an effective, provident, and stoner-friendly result for people with cerebral paralysis by integrating mobility, communication, safety, and remedy into a single ESP32- grounded armature with mobile AAC integration.

ARDUINO SOFTWARE IDE:

The Arduino Integrated Development Environment- or Arduino Software(IDE)- contains a textbook editor for writing law, a communication area, a textbook press, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino and Genuino tackle to upload programs and communicate with them.

Figure 2.13 Arduino IDE

SERIAL MONITOR

This shows periodical data transferred via a USB or periodical connector from the Arduino or Genuino board. Enter textbook and either hit the" shoot" button or hit Enter to transmit data to the board. From the drop- down menu, elect the baud rate that corresponds to the rate supplied to Serial.start in sketch. Keep in mind that when you connect to the periodical examiner on Windows, Mac, or Linux, the board will reset and renew your sketch. Please be apprehensive that the periodical Examiner does n't handle control characters.However, you can use an external terminal operation and link it to the Arduino board's COM harborage, If your design requires full control over periodical communication with control characters.

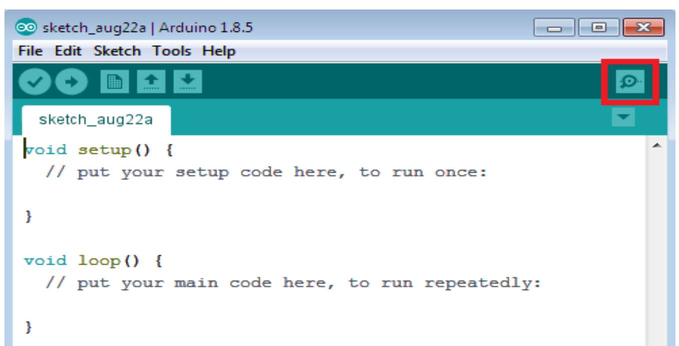

Figure 2.14 Serial Monitor

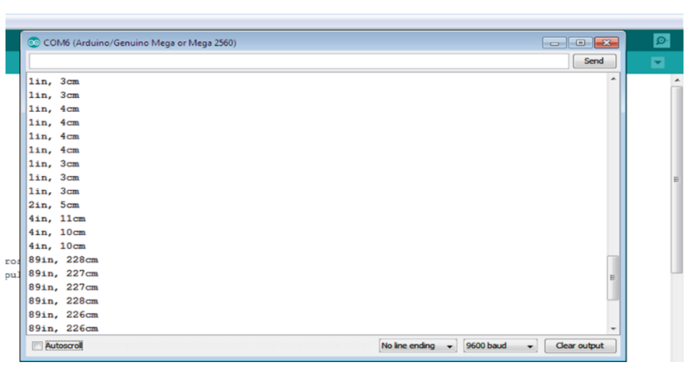

Figure 2.15 COM Port

III. RESULTS AND DISCUSSION

The proposed AI-Integrated Wheelchair System was evaluated through case-based observations of children with cerebral palsy from Dr. DADSS,Coimbatore, India, highlighting its adaptability to diverse user needs.

Case No	Name	Main Challenges	Solution	Outcome

1)	Master Gugan	Severe mobility impairment. Non-verbal communication barriers. Difficulty in object identification. Aggressive behavior during learning.	Integrated AAC system. AI-based voice assistance Music-based emotional regulation	Improved ability to express needs Reduced aggression and better emotional control Increased engagement and attention in learning
2)	Miss Radha	Unclear speech Poor hip stability Discomfort during prolonged sitting	Customized mobility braces Stand-able frame AAC interface to support speech	Better posture and stability Clearer communication Improved confidence and participation in class and social settings
3)	Miss Thakshaya	Severe neck instability. Visual impairmet limiting learning.	Adjustable mobility braces. Auditory-based AAC outputs.	Improved head and neck control Accessed lessons through sound cues Better focus and inclusive learning experience
4)	Miss Jerlin	Mobility limited to one hand Non-ambulatory (cannot walk) Good object recognition	AAC technology Motorized wheelchair navigation	Gained independence in daily tasks Improved communication Increased participation in education and social activities
5)	Master Sahil Rahman	Non-verbal Unable to walk Good object recognition	AAC module for expression AI-assisted mobility system	Could express needs more Clearly Moved independently Improved interaction and autonomy

Table 3.1 Target Beneficiaries

Overall, results demonstrated that the system effectively addressed varied challenges across communication, posture, and emotional regulation. Each case validated the rigidity of integrated features similar as smart mobility braces, AAC, voice backing, and standable frame. The conversations indicate that beyond mobility, the system fosters communication, literacy, and social participation, emphasizing its eventuality as a holistic recuperation and assistive tool.

Without the need for integrated defenses, mobile integration for Augmentative and Indispensable Communication(AAC) bettered availability by enablingnon-verbal druggies to transmit textbook- to- speech dispatches using a smartphone interface and constantly displaying system response via the mobile app. In low- noise settings, the voice backing module executed commands effectively with an average recognition delicacy of 88; still, in crowded or noisy locales, performance declined. Battery performance testing using a 24 V, 20 Ah pack demonstrated viability for diurnal operation with an exploitable runtime of roughly 5 – 6 hours under moderate use. When compared to traditional homemade wheelchairs, stoner trials using dissembled CP settings showed increased comfort, independence, and communication effectiveness. nonetheless, difficulties were noted, similar as the necessity for fresh voice recognition system optimization in loud surroundings and the sporadic false handicap discovery in largely reflecting surroundings. Notwithstanding these downsides, the intertwined system turned out to be dependable, stoner-friendly, and flexible, with great eventuality to ameliorate social engagement and quality of life for people with cerebral paralysis.

Figure 4.1 Prototype of AI- Integrated wheelchair system for Cerebral Palsy

IV. CONCLUSIONS AND FUTURE WORK

The design and development of an AI- Integrated Wheelchair System for people with cerebral paralysis was described in the study. This system combines safety features, augmentative and indispensable communication(AAC), mobility backing, and recuperation support into a single platform. The prototype addressed the pivotal conditions of posture operation, safe navigation, and suggestive independence by demonstrating effective handicap recognition, reliable exigency stop response, flawless mobile integration for communication, and fluid sit- to- stage transitions. The technology provides a more comprehensive and stoner- centric result than traditional wheelchairs, perfecting druggies' autonomy and quality of life.

unborn exploration will concentrate on enhancing the AI algorithms for better voice recognition and handicap identification in noisy settings, incorporating computer vision for sophisticated navigation, and carrying out expansive stoner trials in association with recuperation installations. Adaptive literacy for customized movement patterns, pall connectivity for remote monitoring, and cost- cutting ways to ameliorate availability are farther advancements. With these developments, the system could establish a new standard for inclusive assistive technology in recuperation and healthcare.

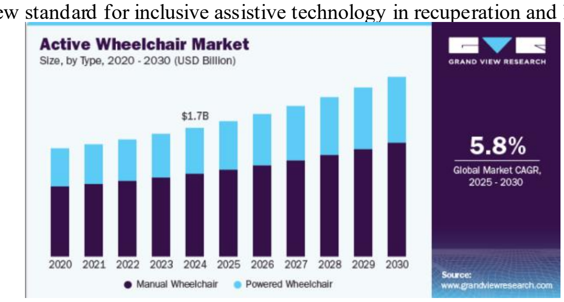

Figure 4.2 : The active market price of wheelchairs

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