SMART WHEELCHAIR FOR PERSONS WITH DISABILITIES IN LOWER BODY AND HEARING IMPAIRMENTS

Final Report

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PATHFINDING AND PATH PLANNING WITH EMOTIONAL RECOGNITION AND REAL TIME MONITORING

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DECLARATION

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ABSTRACT

This study introduces a smart wheelchair system that uses emotion-aware interaction and intelligent autonomous navigation to assist people with physical disabilities and hearing impairments. The primary objective of the project is to enhance path finding and planning by utilizing real-time monitoring and emotion recognition. With the help of LIDAR technology included into the Robot Operating System (ROS), the wheelchair can safely navigate dynamic indoor environments. To stay clear of obstacles, the ROS constantly modifies its course.

Using the FER2013, a pre-trained Convolutional Neural Network analyzes the user's facial expressions in real time. This is impacted by emotional feedback, which allows the wheelchair to prioritize or steer clear of specific routes according to the user's past emotional responses. Emotions such as sadness or annoyance suggest that a certain path may cause suffering, while happy feelings.

The system's real-time user monitoring capability monitors deviations from the planned path and alerts a designated caretaker if necessary. A task reminder module is also offered to remind users of important scheduled chores, such as taking medication or performing rehabilitation exercises.

In a controlled indoor environment, the precision of obstacle avoidance, emotion perception, and alert responsiveness were evaluated. The results demonstrate exact real-time facial expression detection and outstanding dependability in LIDAR-based navigation. Together, these technologies produce a smart wheelchair that is not just functionally efficient but also helpful and emotionally adaptive.

The proposed method enhances mobility, safety, and emotional health, which helps create a more customized and user-centered support system. Future studies will look into integrating speech recognition, outside navigation, and adaptive learning to improve the user experience even more.

Keywords: Smart Wheelchair, Emotion Recognition, LIDAR Navigation, Real-Time Monitoring, Path Planning

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LIST OF ABBREVIATIONS

Abbreviation	Description
ROS	Robot Operating System
LIDAR	Light Detection and Ranging
CNN	Convolutional Neural Network
FER	Facial Expression Recognition
DWA	Dynamic Window Approach
UI	User Interface
GPS	Global Positioning System
SLAM	Simultaneous Localization and Mapping

1. INTRODUCTION

1.1 Background Literature

The integration of robotics, artificial intelligence (AI), and assistive technology has ushered in a new era of human-centric innovation aimed at addressing the diverse needs of individuals with physical and sensory impairments. As the world's population ages and the proportion of persons with disabilities rises, demographics are changing globally. The creation of smart wheelchairs, which mark a paradigm change from traditional mobility equipment toward autonomous, responsive, and emotionally-aware technologies intended to improve user freedom, safety, and quality of life, is among the most revolutionary developments in this field.

For many years, traditional wheelchairs—both powered and manual—have remained operationally constrained. As a result, it is frequently difficult for people with significant motor impairments, communication difficulties, or hearing impairments to move around safely and independently, particularly in complex or new situations.
Research is now enhancing wheelchairs with intelligent features from robotics, machine learning, and IoT. The Robot Operating System (ROS) serves as the foundation, offering a flexible framework that connects sensors, navigation algorithms, and control systems.

Recent research initiatives are focused on enhancing wheelchairs with intelligent capabilities derived from robotics, machine learning, and Internet of Things (IoT) technologies. The Robot Operating System (ROS) serves as the cornerstone of this innovation—a flexible middleware framework designed for distributed robotic applications. ROS enables seamless integration of sensors, actuators, navigation algorithms, and control systems, allowing developers to create platforms that can effectively sense, process, and respond to their environment, making it particularly suitable for smart wheelchair development. Its modular architecture supports real-time communication between various components including localization, mapping, planning, and perception systems.

Light Detection and Ranging (LIDAR) technology is fundamental to autonomous navigation capabilities. LIDAR sensors operate by sending out laser pulses and measuring the return time of reflections, generating comprehensive point clouds of the surrounding environment. This data creates occupancy grids that distinguish between accessible and obstructed spaces. With high spatial resolution and rapid update capabilities, LIDAR excels at identifying narrow passages, furniture, walls, and moving obstacles in real-time. When integrated with Simultaneous Localization and Mapping (SLAM) algorithms, wheelchairs can build and update environmental maps while simultaneously determining their position within those maps, enabling reliable navigation even in GPS-inaccessible indoor environments like healthcare facilities, residential settings, or rehabilitation centers.

Alongside mobility improvements, Human-Robot Interaction (HRI) research emphasizes the importance of emotional intelligence in robotic systems. Evidence suggests that assistive technologies capable of interpreting and responding to human emotional signals significantly enhance user experience, comfort levels, and trust. Facial expression recognition (FER) represents one of the most effective and unobtrusive methods for emotion detection, analyzing facial muscle patterns to identify emotional states such as happiness, sadness, anger, or fear.

The FER2013 dataset serves as a prominent benchmark for facial expression recognition research, containing more than 35,000 categorized facial images across seven basic emotions. Deep learning approaches—particularly Convolutional Neural Networks (CNNs)—have shown remarkable accuracy in extracting facial features and classifying emotional states in real-time. These models are suitable for deployment on embedded computing platforms like NVIDIA Jetson or Raspberry Pi that can be integrated into smart wheelchairs for continuous emotional analysis.

Emotion-aware systems offer benefits beyond simple recognition by enabling adaptive behaviors. For example, if users consistently show discomfort while traversing specific routes, the system can learn to avoid these paths. Conversely, positive emotional responses can reinforce preferred navigation patterns, creating a more personalized and satisfying user experience.

Real-time monitoring and remote caregiver support complement these core functionalities. Users of assistive mobility devices often require external supervision to ensure safety and timely assistance. Modern smart wheelchair systems therefore incorporate features like path deviation detection, emergency alerts, and remote tracking through web interfaces. These systems can identify when users significantly deviate from planned routes or remain stationary for extended periods, automatically notifying designated caregivers through notifications or alerts. This enhances user safety while reducing the need for constant physical supervision.

Task reminder systems constitute another essential component of intelligent healthcare assistance. These systems provide scheduled prompts for important daily activities including medication administration, hydration, or therapeutic exercises. This functionality is particularly valuable for individuals with memory impairments or those following strict treatment regimens. By incorporating these reminders into the wheelchair's interface or through caregiver-managed applications, the system promotes health maintenance and compliance while fostering independence.

Collectively, this expanding field of research and technological advancement provides a comprehensive foundation for developing intelligent, emotionally responsive wheelchair systems. By integrating LIDAR-based autonomous navigation, real-time facial expression recognition, remote monitoring capabilities, and task-oriented assistance, this research aims to deliver a holistic solution addressing both physical mobility requirements and emotional well-being for hearing-impaired and disabled individuals, ultimately promoting personal autonomy and social inclusion.

1.2 Research Gap

Current assistive mobility technologies exhibit a notable deficiency in smart wheelchair systems that comprehensively address both physical mobility requirements and emotional needs of users, particularly those with hearing impairments or complex disabilities. While technically advanced in movement control and obstacle avoidance, existing systems lack truly intelligent, adaptive capabilities that respond to users' emotional states or contextual preferences. This significant limitation undermines the potential for personalization, comfort, and meaningful user engagement.

Modern smart wheelchairs typically employ established frameworks like the Robot Operating System (ROS) for control systems and LIDAR sensors for environmental mapping. While these technologies effectively enable autonomous navigation through predefined or dynamically generated routes, the decision-making processes remain predominantly deterministic and mechanical. These systems prioritize distance minimization and obstacle avoidance without considering user experience, emotional feedback, or comfort levels. Consequently, a wheelchair might consistently select the shortest path regardless of whether the user has previously demonstrated discomfort—either physically or emotionally—while traveling that route.

Emotion recognition through facial expression analysis has progressed substantially in domains such as affective computing, social robotics, and interactive virtual agents. However, its application within assistive mobility systems remains largely unexplored. Despite promising results from pre-trained deep learning models like Convolutional Neural Networks (CNNs) using datasets such as FER2013 for emotion detection, there is a marked absence of research integrating emotional feedback into real-time navigation systems for assistive wheelchairs. Particularly lacking are studies examining how emotion recognition can dynamically influence path planning decisions—learning over time to prefer routes associated with positive experiences while avoiding those linked to stress or discomfort.

While some commercial and experimental wheelchairs incorporate basic user tracking functionality—such as GPS or encoder-based positioning—these systems typically operate independently, without a centralized monitoring framework allowing caregiver intervention based on real-time awareness. Most deviation tracking systems function reactively rather than predictively and lack integration with contextual data like emotional states or scheduled activities. Consequently, caregivers remain unaware of subtle behavioral patterns that might indicate distress, fatigue, or dissatisfaction, missing opportunities for timely intervention.

Existing task reminder systems are often treated as auxiliary components—simple alerting mechanisms disconnected from the primary mobility platform. These systems generally rely on fixed schedules without adapting to contextual changes or user states. Critically, they rarely accommodate hearing-impaired users' needs or prioritize tasks based on emotional readiness or cognitive capacity. A more integrated approach could transform these systems into proactive, context-aware assistants providing meaningful support for daily routines.

These limitations highlight a critical research gap: the absence of a fully integrated intelligent wheelchair system combining emotion recognition, adaptive navigation, and real-time monitoring to deliver personalized and safe experiences. Such a system would support physical mobility while learning from emotional responses, adapting its decision-making processes accordingly, and providing timely alerts through a caregiver-connected framework.

This research aims to address this gap by developing a comprehensive, modular platform aligning technological capabilities with human-centered design principles. By exploring the understudied intersections between mobility, affective computing, and real-time monitoring, this study seeks to create an innovative solution that redefines assistive technology—not merely as transportation but as a responsive, intelligent companion for individuals with special accessibility needs.

Comparative Analysis of Related Research Projects and Identification of Research Gaps

Feature/Focus Area	Traditional Powered Wheelchairs	Existing Smart Wheelchairs	Related Research Studies	Smart Weeichair
Autonomous Navigation	✓ Manual control only	✓ Basic obstacle avoidance	✓ SLAM and path planning	✓ Advance navigation with SLAM. LIDAR. and path adaptation
Emotion Recognition Integration	✓ Not included	✓ Rarely explored	✓ Real-time facial expression-based emotional	✓ Emotion driven route optimization ad adaptation
Real-Time Emotion-Based Path Adaptation	✓ Not applicable	✓ Not implemented	✓ Not fully integrated	Web dashboard with real-time alerts, monitoring, andsk
Caregiver Communication Interface	✗ None	✓ Basic alerting	✓ Limited to health monitoring	✓ Web dashboard with rreal-time alorts. monitoring, and resmi-
Task Scheduling & Reminders for Users	✗ Not supported	✗ Not commonly available	✗ Not focused	✓ Integrated task schuduler with visual/ audio prampts
Affordability and Open-Source Compatibility	✓ Relatively affordable	✗ High-cost robotic modeis	✗ Often uses expensive hardware	✓ Low cost, open sou-ce, modular design u-sing ROS. Jetson Nano, etc.
Application in Real-World Contexis (Home, Rehab,etc)	✓ Common in homes	✓ Limited use in clinics	✓ Simulated/con-trolled environments	✓ Designed for real-world use in homes, hospitals, [illegible]

Table 1-- Research Gap

1.3 Research Problem

Despite the rapid advancements in assistive mobility technologies, a significant gap remains in the development of smart wheelchair systems that holistically address both the physical mobility and emotional needs of users—particularly those with hearing impairments or complex physical and cognitive disabilities. Even though traditional electric wheelchairs have made mobility more accessible, they still function according to a limited paradigm, providing only simple directional control and lacking the intelligence or flexibility needed to react quickly to shifting user demands or environmental conditions. Due to their essentially reactive nature, these systems are unable to provide users with proactive help that would improve their mobility as well as their freedom, safety, and emotional health.

The majority of current systems are still primarily focused on pathfinding and obstacle avoidance, despite the fact that advancements in smart wheelchair technologies have improved autonomous navigation through the integration of sensor-based data, such as LIDAR, ultrasonic sensors, and infrared proximity detectors. These systems usually give priority to criteria like route clearance, energy efficiency, and distance optimization without taking the user's navigational experience into account. Because of this, the wheelchair may often choose a path that is technically effective but causes the user emotional distress, physical discomfort, or cognitive overload. This discrepancy between algorithmic choices and results that are focused on people is a major weakness in the assisted mobility solutions available today.

The majority of smart wheelchair platforms lack real-time behavioral monitoring and caregiver interaction, which is equally troubling. Few systems provide thorough, ongoing tracking of user behavior that can spot departures from typical routes, spot patterns of idleness, or indicate concern based on physiological or emotional signs, even though some systems provide basic localization functions or fall detection alarms. Without such monitoring, there is a greater chance of mishaps, confusion, and delayed help—especially for users who are left to fend for themselves for long stretches of time.

Furthermore, rather of being essential parts of the assistive system, task support systems—which are crucial for sustaining daily routines like medication regimens, hydration cues, or physical therapy reminders—are usually viewed as optional add-ons. These systems frequently function independently of the navigation engine and do not modify their cues in response to the user's emotional state or current situation. The wheelchair's total ability to meet comprehensive user demands is diminished by this lack of integration, which restricts its function to that of a transportation tool rather than an intelligent companion.

As a result of these difficulties, a primary research problem has been identified: the lack of an emotionally responsive, adaptive, and intelligent smart wheelchair system that can support autonomous path finding, emotion-aware route selection, real-time behavioral monitoring, and customized task assistance all at once. Current solutions have a tendency to divide these tasks into discrete parts rather than combining them into a single, technically sound, and user-focused platform.

Therefore, creating a system that can dynamically analyze and respond to multimodal input—such as behavioral patterns, emotional cues, and environmental data—in order to make decisions in real time that maximize user happiness and functional performance is the main problem. In order to provide safe and effective navigation, such a system must be able to learn from user feedback, adjust its behavior accordingly, and include caregivers when needed. Redefining the role of smart wheelchairs from passive mobility aids to active, context-aware companions that improve the autonomy, dignity, and emotional stability of people with disabilities requires an integrated, intelligent approach.

1.4 Research Objectives

Principal Goals

To provide a safe, individualized, and emotionally responsive mobility solution for people with physical disabilities, especially those who are hearing-impaired, the main goal of this research is to design and develop an intelligent, emotion-aware smart wheelchair system that seamlessly integrates autonomous pathfinding, facial expression-based emotion recognition, and real-time user monitoring. By providing a human-centered technical solution that not only guarantees safe navigation but also improves the user's emotional comfort, autonomy, and everyday utility, this system aims to go beyond traditional mobility aids.

Sub-Objectives

- **To improve autonomous navigation capabilities by integrating ROS and LIDAR:**

  Using Light Detection and Ranging (LIDAR) sensors incorporated into the Robot Operating System (ROS) architecture, create a reliable navigation system. For dynamic, interior navigation, this system will make it possible to map in real time, detect obstacles, and make decisions based on the environment.

- **To incorporate a deep learning-based model for face emotion recognition:**

  Use a Convolutional Neural Network (CNN) that has already been trained on the FER2013 dataset to precisely identify and categorize facial expressions in real time. The system will be able to respond to user emotional feedback by using this emotion detection module as an input method to affect the navigation logic.

- **To put in place a system for caregiver alerts and real-time user tracking:**

  Create and implement a monitoring system that records the user's travel continually and detects alterations to the intended paths. Through a cloud-connected interface, the system will automatically notify approved caregivers in the event of a major deviation or emergency, guaranteeing prompt action and safety.

- **To include a task reminder system that is focused on the user:**

  To help users with everyday tasks like medication adherence, hydration reminders, or planned therapeutic exercises, create a web-based task scheduling and alerting system. This element will enhance adherence to health-related routines and encourage independent living.

Specific Goals

- To create and deploy a pathfinding and path planning module based on LIDAR that can dynamically create navigation routes, avoid obstacles in real time, and recalculate routes in response to changes in the environment.

- To use a CNN model that was trained on the FER2013 dataset in order to incorporate a real-time face emotion recognition system. In order to make adaptive decisions, this module will take live video data from a forward-facing camera, categorize face expressions, and communicate emotional states to the navigation logic.

- To create an emotion-adaptive routing system that, in response to the user's emotional input, dynamically adjusts navigation behavior. Comfort and user happiness will increase as the system gradually learns which paths are emotionally appealing and gives them priority.

- To put in place a real-time deviation detection and alert system that tracks the user's whereabouts and sounds an alarm when the wheelchair veers off a planned path or sits idle for an extended period of time. Notifications will be sent to a mobile application or caregiver dashboard.

- The goal is to provide a responsive task reminder interface that lets caregivers plan chores using a web application and guarantees that the user gets accessible, timely reminders through visual or audio cues on the wheelchair interface.

- To assess the system's performance based on a number of testing parameters, such as:
    - ❖ Pathfinding efficiency and accuracy in interior settings
    - ❖ Reliability of emotion recognition in a range of lighting and facial situations,
    - ❖ User and caregiver satisfaction as determined by observational data and feedback systems, as well as the system's responsiveness to real-time deviations and feedback.

2. METHODOLOGY

This methodology describes the all-encompassing strategy to developing a smart wheelchair that incorporates cutting-edge features including assistance task management, emotion detection, course planning, and real-time monitoring. An adaptable and responsive mobility solution for people with physical and hearing disabilities is being developed using a multidisciplinary process that combines robotics, artificial intelligence (AI), sensor integration, and human-computer interface.

The approach is broken down into multiple crucial phases, each of which concentrates on a different aspect of the wheelchair's operation. System design, hardware selection, software development, path planning and emotion recognition integration, testing, and validation are some of these phases. Each of these phases is covered in detail in the sections that follow.

2.1 Methodology

In order to provide task-oriented user assistance, emotion-driven path adaptation, autonomous navigation, and real-time user tracking, this technique describes the design, development, and assessment of a sophisticated smart wheelchair system that incorporates a number of essential characteristics. People with physical limitations and hearing impairments can benefit from increased mobility, improved safety, and an improved user experience thanks to the system's careful design. The goal of this project is to greatly improve the quality of life for individuals with mobility issues by fusing state-of-the-art robotics, artificial intelligence, and human-computer interaction concepts on a single platform.

The Robot Operating System (ROS), on which the development framework is built, acts as the foundation for modular interaction and real-time communication between the wheelchair's numerous components. Because of its adaptability, scalability, and broad support for robotics development, ROS is selected to enable the smooth integration of various technologies.

Navigation and System Architecture

LIDAR (Light Detection and Ranging) technology, which offers accurate obstacle identification and real-time environmental mapping, is the foundation of the wheelchair's autonomous navigation. The wheelchair can create a current map of the area thanks to LIDAR's constant scanning of the surrounds, which guarantees that the device can accurately navigate dynamically changing spaces. Local motion control and global route planning are two essential components that are combined in the hybrid approach used to build the wheelchair's path planning. The Dynamic Window Approach (DWA), the foundation of local motion control, enables the wheelchair to instantly determine its direction and speed based on its present location and adjacent impediments. The Dijkstra algorithm, a tried-and-true technique for determining the shortest and safest path in a particular setting, is used to construct the global route planning. The wheelchair can successfully navigate both static and dynamic indoor situations by combining various strategies, adapting to barriers and changes in the surrounding area while maximizing the path for safety and efficiency.

Navigating with Emotion Awareness

This system's capacity to adjust to the user's emotional state while navigating is a crucial component that improves the user experience by reacting to emotional feedback. This is accomplished by integrating a Convolutional Neural Network (CNN) model for facial expression detection that has already been trained on the FER2013 dataset. The CNN model analyzes live video data from a wheelchair-mounted camera to categorize facial expressions into emotional states, including happiness, sadness, rage, and surprise. The wheelchair can determine the user's mood and modify its behavior based on this emotional recognition system. For instance, the system can choose a different path to avoid emotionally distressing locations if the user shows signs of dissatisfaction or pain while navigating. On the other hand, the algorithm might give preference to such routes in subsequent navigation if the user exhibits pleasant sentiments. Throughout the user's trip, this dynamic adaptability guarantees increased comfort, user pleasure, and emotional well-being.

Tracking Location in Real Time and Notifying Caregivers

The wheelchair has a real-time user tracking subsystem to ensure ongoing situational awareness. This system continuously tracks the wheelchair's location in real-time by using environmental reference points obtained from the LIDAR scans and encoder information from the motors. To make sure the wheelchair is traveling the appropriate route, the system continuously compares the user's position with the route that has been planned. The system initiates an alarm mechanism that notifies the authorized caregiver via a server-based platform or a mobile notification if the user deviates from the planned path by more than a predetermined threshold. Another degree of security is offered by this real-time monitoring, which makes it possible for caretakers to be notified right away if the user runs into problems, veers off course, or is in danger so that assistance may be given quickly.

System for Reminding Users to Complete Tasks

To enhance the user's capacity to carry out everyday duties on their own, the smart wheelchair has a task reminder system. Because it uses audio-visual signals rather than just spoken reminders, this approach is very helpful for people who have hearing issues. Essential activities, including taking medicine, drinking water, or doing physical therapy exercises, can be scheduled by users. The wheelchair ensures that the user stays on track with their daily activities by producing timely reminders in the form of vibrating alerts or visual instructions. These discreet yet efficient reminders are intended to promote independence while offering essential direction all day long.

Testing and Assessment in a Regulated Setting

The complete smart wheelchair prototype was tested in a controlled indoor setting, simulating real-world usage cases, to guarantee the system's efficacy and functionality. To guarantee peak performance, every system component—navigation, emotion recognition, real-time monitoring, and task reminders—was assessed separately. To ensure that all parts worked together harmoniously, the entire system was evaluated as an integrated solution following the initial subsystem testing. Response times, emotion recognition accuracy, pathfinding speed, and caregiver notification efficacy were among the key performance parameters that were meticulously assessed.

The review also placed a strong emphasis on user responsiveness. People with hearing and physical limitations tested the system, offering insightful comments on its overall experience, comfort level, and usability. In addition to meeting technical requirements, this user-centric testing makes that the wheelchair improves the everyday lives of the people it is intended to help.

System Refinement and Iterative Improvement

The system went through an iterative improvement process based on the insights gathered from the testing phase. Targeted changes, including enhancing path planning under diverse environmental situations, optimizing caregiver communication protocols, and fine-tuning the emotion recognition algorithm, were made using user feedback and test performance data. Through constant evolution and adaptation to user needs, this iterative strategy guarantees that the wheelchair will eventually improve both its technical capabilities and user happiness.

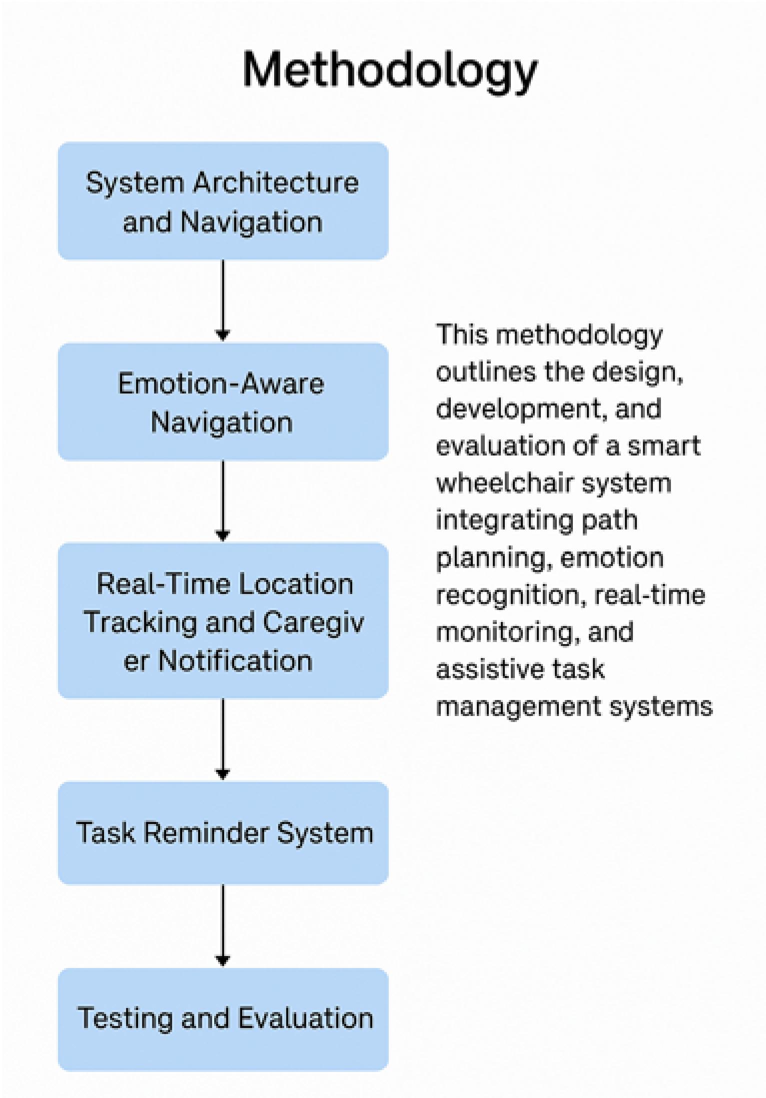

Figure 0-1 - Methodology

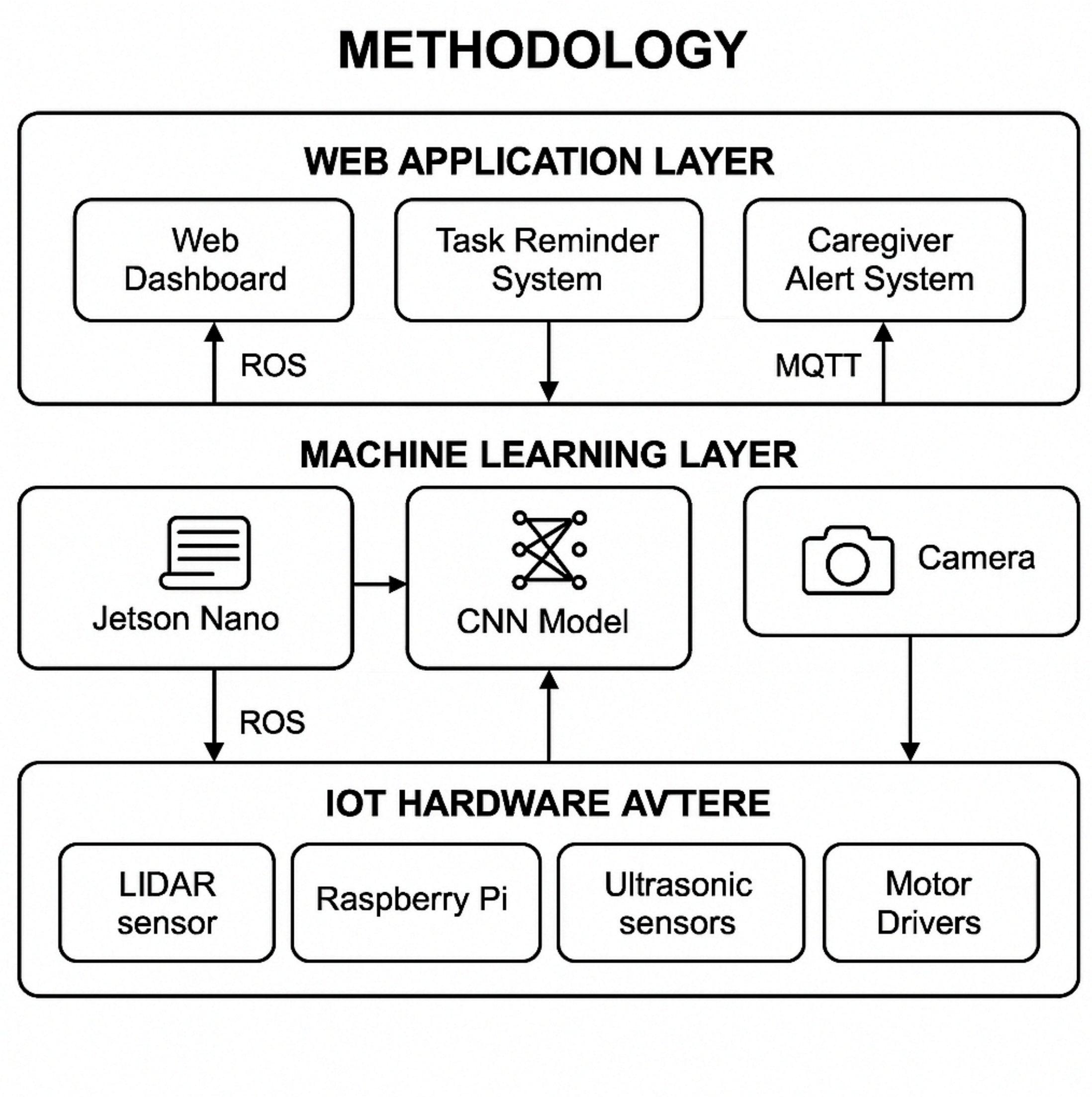

Figure 0-2 - Methodology

2.2 Commercialization Aspects Of The Product

By combining autonomous navigation, real-time emotion identification, and caregiver support—features that are currently underrepresented in the majority of commercially available mobility aids—the smart wheelchair system offers a ground-breaking breakthrough. This device has a lot of promise for commercialization, especially in the markets for assistive technology, healthcare, and rehabilitation. It addresses more than just functional mobility issues; it also prioritizes users' emotional health and offers a high level of customization to meet their specific demands. The system is positioned as a game-changer in the rapidly changing field of assistive technologies because of its dual approach, which combines emotional adaptation with physical mobility support.

There has never been a greater need for intelligent, adaptive technologies as the world's population ages and the number of people with impairments keeps growing. Many high-end robotic solutions are still unaffordable, though, which restricts their availability. Additionally, the emotional responsiveness that may greatly improve the user experience is absent from these sophisticated technologies. Traditional motorized wheelchairs, on the other hand, usually have basic control systems but are unable to interact with their surroundings in a responsive, intelligent way. Thus, the smart wheelchair appears as a cost-effective and adaptable substitute. The system provides a solution that can be effectively integrated with current assistive technology and is adaptable to a variety of user needs by utilizing easily accessible and reasonably priced components.

The suggested system makes use of open-source platforms like the Robot Operating System (ROS), inexpensive hardware for edge processing like the Raspberry Pi and Jetson Nano, and LIDAR sensors for accurate pathfinding. These thoughtful design decisions not only lower the system's cost but also increase its usability in settings with limited resources. The system could potentially reach a larger audience by lowering the initial development cost as well as continuing maintenance costs. Additionally, the wheelchair's modular design guarantees scalability and adaptability, enabling feature enhancements over time. This can be very helpful in home, hospital, and rehabilitation settings. Because of its adaptability, the system may also be customized to meet the needs of individual users, guaranteeing that it will change to meet their demands.

The smart wheelchair system could be commercialized by forming alliances with medical device makers, rehabilitation facilities, and eldercare service providers. Because of its special qualities, the system may be very beneficial to various industries by giving people with mobility issues a complete, flexible solution. Furthermore, other businesses might be able to independently license the caregiver alert and emotion detection modules, which would allow for the incorporation of these features into a wider range of applications, such as assistive apps and intelligent medical equipment.

However, regulatory approval for medical-grade safety and efficacy will be necessary before the product can be released onto the market. The system's successful commercialization depends on meeting the requirements for both functional and emotional support. Furthermore, user feedback and testing will be essential for improving the design and making sure the system satisfies the requirements of various user groups. The smart wheelchair has the potential to become a commercially viable solution that bridges the gap between advanced robotics and customized healthcare support through iterative development and careful consideration of diverse demographic needs. This invention has enormous potential to improve the quality of life for those with mobility issues, both as an assistive technology and as a life-changing instrument.

2.3 Testing and Implementation

The testing and implementation phase of the smart wheelchair project was conducted in an orderly, iterative manner to ensure the accuracy, reliability, and use of all connected components. The system's main functions, including task reminders, facial expression recognition, autonomous navigation, and real-time monitoring, were tested in an interior environment simulation that mimicked typical user scenarios throughout this phase.

2.3.1 Implementation Environment

The smart wheelchair system was installed on a specially constructed prototype that was intended to incorporate a number of cutting-edge technology to enable real-time communication, emotion recognition, and autonomous navigation. A 2D LIDAR sensor at the center of the system gives accurate distance readings, enabling the wheelchair to recognize and map its environment. This sensor serves as the main computational backbone, facilitating effective data processing and real-time decision-making in conjunction with an onboard CPU and embedded processing unit (Jetson Nano).

The system's processing unit, the Jetson Nano, has the processing capacity required to handle the sophisticated algorithms required for obstacle avoidance, path planning, and facial recognition. Processing the data from several sensors, such as the LIDAR and the forward-facing camera for face expression identification, depends on this hardware. The onboard microprocessor serves as a bridge between the software and hardware, facilitating smooth coordination and communication between the various parts of the system.

The Robot Operating System (ROS), an open-source platform that provides a modular and adaptable framework for creating robotic systems, served as the foundation for the software architecture of the smart wheelchair. Because of its vast toolkit and pre-built packages that make tasks like path planning, sensor integration, and real-time communication easier, ROS was selected. The system can accomplish effective node-based communication by using ROS, in which every software module functions as a separate node that communicates with other nodes to perform cooperative tasks.

The system uses a number of important ROS packages, such as gmapping, move_base, and amcl, for global path planning. Using the information supplied by the LIDAR sensor, gmapping is utilized to produce an accurate 2D map of the surroundings. For navigation and real-time localization, this map is crucial. Move_base is in charge of putting global and local path planning algorithms into practice, enabling the wheelchair to choose the best route to a destination on its own while dodging obstacles. The system may track its position in real time and modify its course as needed to avoid dynamic barriers or faults in the environment thanks to the usage of AMCL (Adaptive Monte Carlo Localization), which is utilized for exact localization inside the created map.

Along with these core elements, Python and OpenCV—both of which are well-known for their strengths in image processing and machine learning applications—were used in the development of the facial recognition system. Real-time facial expression analysis was done using a Convolutional Neural Network (CNN) model that had already been trained on the FER2013 dataset. Using face photos taken by the forward-facing camera, this device can identify a variety of emotions, including surprise, happiness, and melancholy. This data is used by the system to modify the wheelchair's behavior according on the user's emotional state, enabling more intuitive and customized engagement.

The smart wheelchair system's combination of various technologies enables smooth communication between the environment, the user, and the control mechanisms. The wheelchair can navigate its environment on its own while preserving a high degree of safety and user satisfaction because to the real-time processing of sensor data. Additionally, the emotion recognition module improves the wheelchair's emotional and functional elements of operation by strengthening the system's response to the user's needs. This all-encompassing strategy for assistive mobility represents a major advancement in the creation of intelligent, flexible devices for people with mobility impairments.

2.3.2 System Implementation Architecture

Three interconnected levels make up the architecture of the smart wheelchair system: the Web Application Layer, the Machine Learning Layer, and the Hardware Layer for the Internet of Things. Together, these layers give consumers a smooth and intelligent experience that improves their mobility and emotional engagement. In order to guarantee that the system can function in real-time, adapt to changing user needs, and provide efficient caregiver support, each layer plays a unique but complimentary role.

IoT Hardware Layer

The smart wheelchair system's hardware layer serves as its framework, integrating crucial elements that enable real-time control, environmental awareness, and autonomous navigation. The LIDAR sensor, which is at the center of this layer, provides accurate environmental mapping and obstacle recognition, guaranteeing that the wheelchair can precisely negotiate challenging areas. While motor drivers regulate the motors' power and direction in response to input signals, DC motors govern the wheelchair's motion. Ultrasonic sensors are used for proximity detection in order to provide thorough environmental monitoring; these sensors are especially helpful for close-range obstructions that LIDAR can miss.

As the hardware layer's central processing units, the microcontrollers—which can be either Raspberry Pi or Arduino—interface with the different sensors and actuators. The wheelchair can make judgments about movement and obstacle avoidance on its own thanks to these microcontrollers, which gather data from the sensors and process it in real time. The wheelchair's path is dynamically planned and adjusted by the system using ROS-based path planning techniques like move_base and gmapping.

The system makes use of MQTT (Message Queuing Telemetry Transport) for effective web synchronization in order to facilitate communication both locally and online. The cloud-based services and the wheelchair's hardware components may exchange data in real time and with minimal overhead thanks to MQTT. To ensure that various components of the system (such as sensors, path planning, and motor control) can work together seamlessly and react to environmental changes in real time, ROS topics are also used for internal communication between the system's nodes.

Layer of Machine Learning

The wheelchair's emotional interaction with the user is made possible by the machine learning layer. Using a Convolutional Neural Network (CNN) that has been pre-trained on the FER2013 dataset, the real-time facial expression recognition module is the main component of this layer. A vast variety of facial expressions representing different emotional states, including joy, sorrow, rage, surprise, and more, are included in this collection. Through the analysis of the user's facial expressions, the pre-trained CNN model classifies the live video feed from a wheelchair-mounted forward-facing camera into emotional states like neutral, happy, or sad.

In order to minimize latency and guarantee that the system can react promptly to shifts in the user's emotional state, the machine learning model runs on the edge device (Jetson Nano), which processes the video feed locally. The wheelchair's decision-making module then receives these emotional states and modifies the interaction and navigation behavior to enhance user comfort and experience. For example, the system might give preference to particular routes or actions that fit the user's preferences if it senses that the user is content. On the other hand, the system might take extra actions to modify the wheelchair's mobility or notify the caregiver if it detects melancholy or discomfort.

By adding a layer of personalization through machine learning integration, the wheelchair not only offers functional mobility but also attends to the user's emotional requirements, improving the overall responsiveness and intuitiveness of the experience.

Layer of Web Applications

In order to improve task management and caregiver engagement, the web application layer is essential. To give caretakers a thorough interface for tracking and managing the user's needs, a responsive web dashboard was created. This layer is intended to support ongoing monitoring and guarantee that critical information is accessible to the user and their caretakers.

One of the main functions of this web-based interface is Task Reminder Management. The dashboard allows caregivers to add, edit, or remove reminders for a variety of tasks, including stretching, taking medication, and rehabilitation exercises. In situations like rehabilitation or elder care, these reminders are especially important for preserving the user's health and wellbeing. To make sure the user is informed as soon as possible, the system delivers these reminders straight to the wheelchair interface.

The MQTT/WebSocket protocols are used by the system to guarantee effective and instantaneous notification delivery. The notifications can be shown in a variety of ways, including as on-screen messages on the wheelchair's touchscreen interface or as auditory warnings. This adaptability guarantees that users can get timely reminders according to their environmental circumstances and personal preferences.

Caregivers can receive real-time updates on the wheelchair's location, system status, and user emotion patterns through the User Monitoring Dashboard. With the use of this feature, caretakers may monitor the user's physical and mental health throughout the day and take immediate action if needed.

In-depth performance information and interaction histories are also stored by the System History and Logs function, which enables caretakers and medical professionals to examine previous incidents, monitor the user's emotional reactions, and assess the wheelchair's performance over time. In the future, this data can be utilized to improve the system's operation, match user requests, and refine it.

Architecture for Modular Systems

One of the main advantages of the smart wheelchair system is its modular design. Because of its versatility, scalability, and maintainability, it can be used in a variety of settings, including residential homes and rehabilitation facilities. Because of the system's modular design, every layer and component can be separately updated or modified to meet changing user needs or technology breakthroughs.

Because of its adaptable design, the system may be made to accommodate a wide range of user demographics, including those with different levels of mobility, cognitive capacity, and emotional requirements. Future additions and enhancements to the system's capabilities are made possible by its modular design, which also makes it simple to integrate with other assistive technologies.

In conclusion, the smart wheelchair system's three-layered architecture—which consists of the web application layer, machine learning layer, and IoT hardware layer—ensures that the system is highly functional and environment-adaptable. This method offers a complete solution for people with mobility and emotional health issues by supporting the wheelchair's essential features, such as autonomous navigation and emotion identification, while also enabling caregiver participation and real-time monitoring.

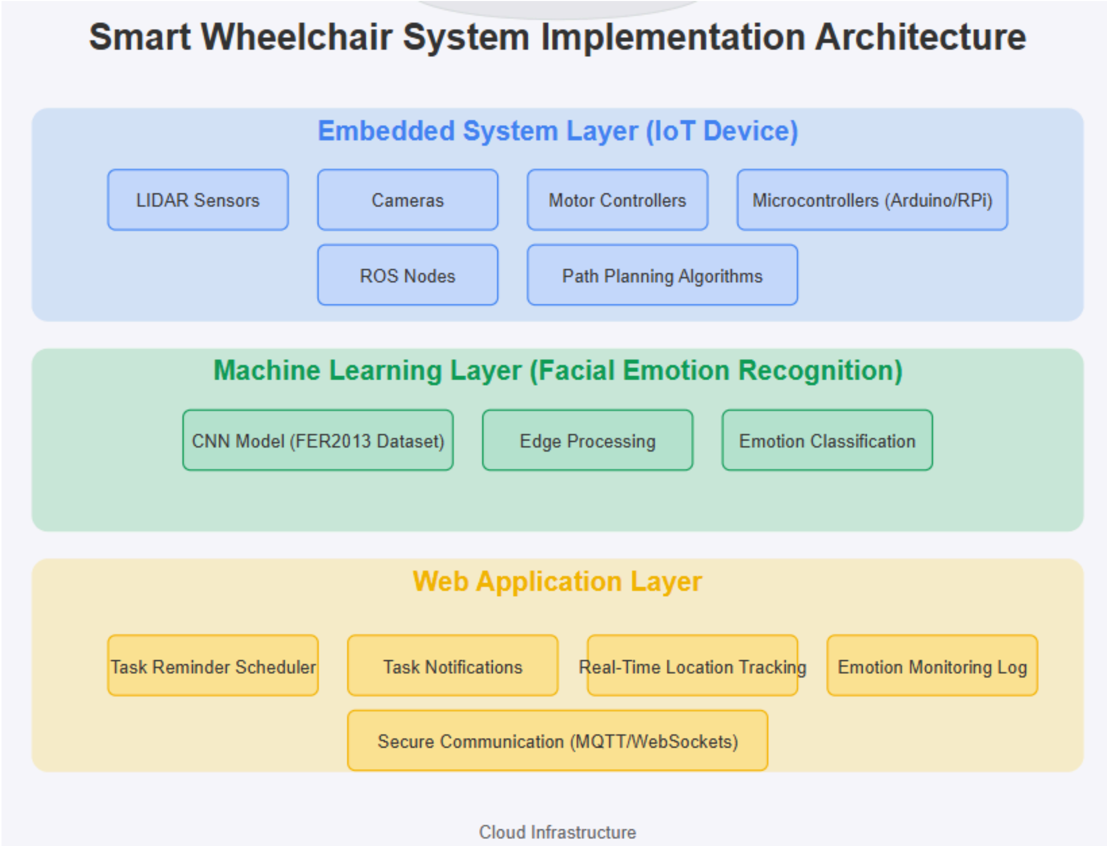

Figure 0-3- System Implementation architecture

2.3.3 Testing Procedures

The smart wheelchair system was thoroughly tested in controlled indoor spaces, such as hallways, rooms, and regions with lots of obstacles, to guarantee its functionality, safety, and dependability. The system's essential features could be precisely assessed in these controlled environments, guaranteeing that it complied with the requirements for practical implementation. During the testing process, the following crucial components were thoroughly examined:

- **Navigation and Obstacle Avoidance**

A variety of indoor situations with dynamic barriers like walls, furniture, and other objects were simulated in order to test the navigation and obstacle avoidance capabilities. Through these environments, the wheelchair was required to follow predetermined paths, and its capacity to modify its course in real time in reaction to unforeseen obstructions was assessed. In order to ensure the wheelchair's safe navigation, the system showed that it could adjust its course on its own by recalculating new routes as it came across obstacles.

The system's ability to manage both static and dynamic obstacles was assessed during these experiments using a variety of obstacle types and configurations. The wheelchair's capacity to maneuver through tight places, steer clear of crashes, and instantly adapt to changing circumstances was evaluated. The wheelchair's ability to function securely and dependably in settings that resembled real-world situations, like residential homes and rehabilitation centers, was validated by this testing.

- **Emotion Recognition Accuracy**

The accuracy and responsiveness of the face expression recognition system were tested in real-world scenarios. The system classified facial expressions in real time using the Convolutional Neural Network (CNN) model, which had been pre-trained on the FER2013 dataset. During testing, a range of user facial expressions were recorded, including neutrality, surprise, delight, and grief. In order to ensure that the response time was quick enough for real-time engagement, the system was able to classify these phrases with an average inference time of less than one second.

Through a series of test situations in which the user's emotional state was purposefully changed, the system's categorization accuracy was evaluated. It was discovered that the classification accuracy was roughly 72%, which is in line with how well comparable systems function in actual environments. Despite its shortcomings, the accuracy offers a solid basis for enhancing the system's emotional reaction capabilities, and subsequent iterations will seek to improve this accuracy through more training and improvement.

- **Route Adaptation Based on Emotion**

The smart wheelchair's capacity to modify its route planning according to the user's emotional state is one of its primary features. The system's ability to prioritize routes associated with pleasant emotional reactions was examined. Real-time facial expression classification of the user was done during testing, and the wheelchair was configured to change its course in response to the emotions it observed. To improve the overall experience, the system might, for instance, give priority to a specific course or route that the user had previously indicated a preference for when the user demonstrated a good feeling (such as happiness).

By examining how the system responded to the emotional feedback in different situations, its functionality was evaluated. In order to improve the user's comfort and happiness, it was found that the system could accurately adjust the route and match the course with the user's emotional state. Customizing the wheelchair's navigation and making it more sensitive to user preferences was made possible by the system's capacity to employ emotion-based data for route adaption.

- **Monitoring and Alerting in Real Time**

Real-time tracking and alerting features were tested to make sure the system could efficiently track the user's location and activities. The wheelchair's capacity to recognize when it had strayed much from its intended course was carefully assessed. The system was able to produce accurate warnings when the wheelchair deviated from predetermined boundaries, such as going too far from a path or into an unsafe area.

These alerts were put to the test in a variety of situations when the wheelchair veered off course or ran into unforeseen circumstances, including a broken sensor or an unforeseen impediment. Accurate warnings were set up, and real-time notifications were transmitted to a caregiver dashboard simulation so the caregiver could get changes right away. This method improved user safety and added another level of assistance by ensuring that caregivers could remain informed and act quickly if needed.

Deviation criteria, which define the precise parameters for setting off alarms, were developed in order to further hone this capability. These requirements included time and distance limits for the wheelchair to veer off course before a warning was triggered. By preventing false positives and limiting needless interruptions for the user and caregiver, this procedure made sure that alarms were only activated when absolutely required.

- **Functionality of a Task Reminder**

To determine how well it works at providing users with timely notifications, the task reminder feature was also put through a thorough testing process. The system was created to leverage both visual and auditory signals to remind users of crucial tasks, such workout notifications or medication reminders. Setting up a sequence of timed reminders in the system and assessing if they were sent at the right moment and in a user-friendly style were the tasks of the testing.

Using a combination of audio notifications and on-screen prompts, the system effectively provided timely reminders throughout testing, guaranteeing that users were informed of crucial tasks in a manner that best met their requirements and preferences. People with memory problems or cognitive disabilities found this function particularly helpful as it kept them on track with their daily schedules and health-related tasks.

Apart from the fundamental task reminder features, the system was evaluated to determine how well it managed several reminders at once, making sure that the user wouldn't experience conflicting or overpowering messages. The outcomes demonstrated that the system could efficiently handle several activities and deliver timely, unobtrusive reminders.

- **An overview of the test results**

The testing processes verified that the smart wheelchair system can perform its essential functions with a high degree of responsiveness and dependability. Important conclusions include:

- **navigating and avoiding** obstacles successfully, especially in surroundings that are complicated and full of obstacles.
- **Fast reaction times and precise facial expression detection** with a classification accuracy of roughly 72%.
- The wheelchair's behavior was tailored to the user's emotional state through an **efficient emotion-based route adaptation system.**
- **Real-time monitoring and alerting features** made sure the system could notify caregivers of any important events or detours from the planned course.
- **Task reminder features** that helped with everyday chores and healthcare administration by providing prompt, easy-to-use reminders.

These tests gave important information about the smart wheelchair system's functionality and possible areas for development. The system can be further improved to provide even more dependable and individualized assistance for those with mobility issues with continued improvements and user input.

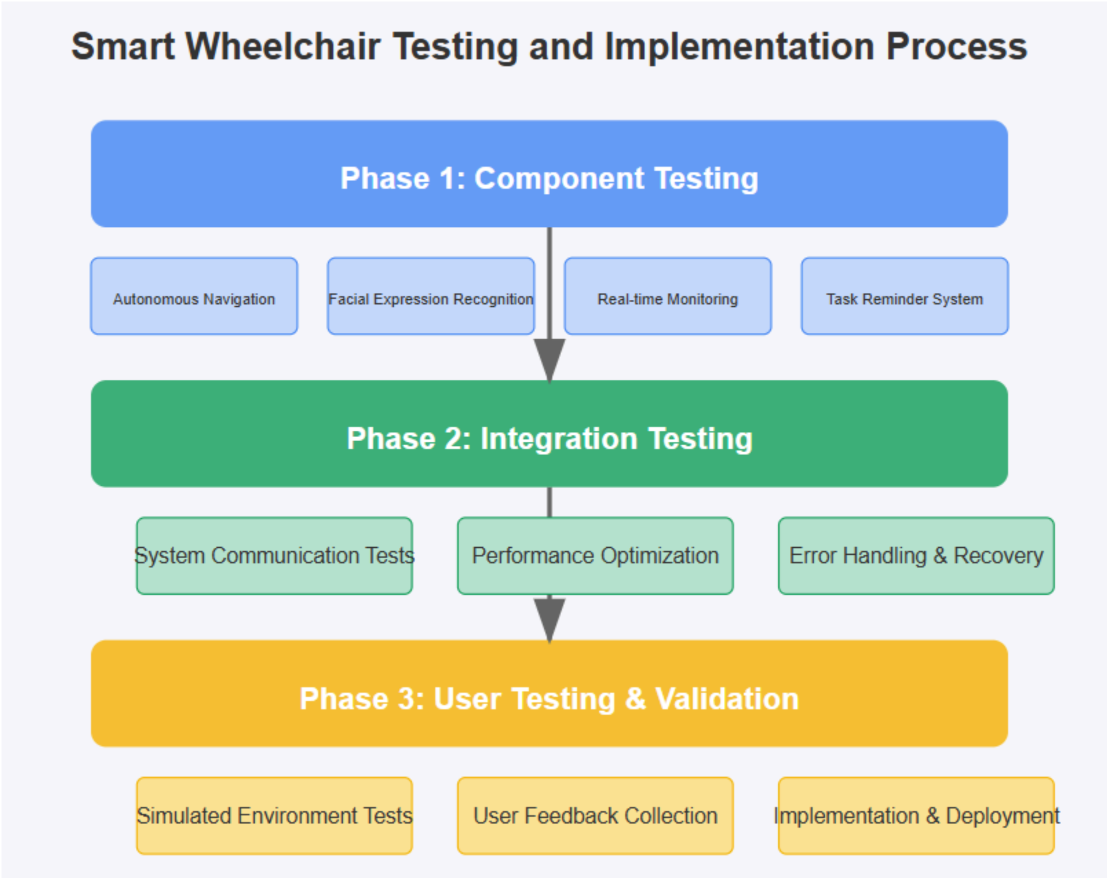

Figure 0-4-Testing Process

2.3.4 System Testing and Integration

A systematic, modular method was used for the smart wheelchair system's testing and integration to make sure every part fulfilled its performance requirements before being incorporated into the entire system. This thorough procedure entailed assessing each module separately at first, and then confirming the smooth functioning of all system components by checking their coordinated operation. To guarantee the accuracy, dependability, and general performance of the system, the following thorough process was followed.

Testing of Individual Modules

Prior to combining the different subsystems, the accuracy and performance of each module were assessed independently. This stage was crucial for making sure that each module could operate at its best when used alone and for spotting any possible problems early in the development process.

- **LIDAR Detection:** The accuracy of the LIDAR sensor, which maps the surroundings and detects obstacles, was thoroughly tested in a variety of settings. Testing concentrated on the sensor's reactivity to environmental changes and its capacity to identify obstructions at different angles and distances. The LIDAR sensor's ability to deliver dependable data for course planning and obstacle avoidance—two crucial aspects of autonomous navigation—was validated by this testing.

- **Machine Learning (ML) Model Inference:** The accuracy and inference time of the Convolutional Neural Network (CNN), which is used to recognize facial expressions, were evaluated in order to identify emotional states. The model's inference time was less than one second during testing, guaranteeing that the system could make quick decisions in response to user input in real time. About 72% of the facial expressions were correctly classified, which is reliable enough for user interaction and real-time emotional input. To verify robustness, the system's capacity to identify a variety of emotional states—such as neutral, happy, sad, etc.—in various lighting and user circumstances was also examined.

- **Job Scheduler:** To make sure the scheduling feature operated properly, the task reminder system was put through testing. The ability of the scheduler to manage several activities, send reminders at the right times, and initiate the right notifications using both visual and aural signals was evaluated. It was verified that the system efficiently and correctly handled task reminders, including notifications for exercise and medication, and delivered them on time.

Testing for System Integration

Following the verification of each module, the system was combined into a coherent whole, and coordinated simulations were conducted to assess how the various parts interacted with one another. To make sure that the smart wheelchair's entire functionality was working and that the system's subsystems were properly communicating with one another, integration testing was crucial.

- **Navigation Functionality:** A range of indoor situations, such as rooms, hallways, and areas with lots of obstacles, were used to test the system's navigation skills. The wheelchair showed dependable autonomous navigation, effectively following predetermined routes and adapting in real time to unexpected impediments. This integration demonstrated how well the LIDAR sensor, motor control systems, and ROS-based path planning algorithms interacted to enable seamless, effective navigation.

- **Emotion-Based Path Adaptation:** The system was designed to modify its course in response to real-time emotional feedback in order to demonstrate the integration of facial expression recognition with navigation. The system prioritized particular routes or changed its behavior to suit the user's preferences when it identified a favorable emotional state (such as happiness). In a similar vein, the system might respond to unpleasant emotional states (like melancholy) by modifying the navigation layout to make the user more comfortable. These tests verified that the emotion-based path adaptation was operating as planned, giving the wheelchair's operation an extra degree of individualized engagement.

- **Task Reminders:** To guarantee that the reminders were sent out accurately and at the right times, the task reminder system was completely integrated into the user interface. Users were reminded of crucial chores, such taking their medications or finishing their workouts, by visual and auditory reminders that flashed on the touchscreen interface throughout testing. A comprehensive examination of the system's capacity to manage several reminders at once, without lag or conflict, demonstrated that this feature was dependable and easy to use.
- **Caregiver Alerts and Monitoring:** The system's capacity to notify caregivers of alterations to the intended course or inaction is one of its primary features. Real-time notifications were activated in integrated testing when the wheelchair greatly veered off course, when obstructions obstructed the path, or when the system identified extended periods of inactivity. In order to guarantee that caregivers got correct and timely updates, these warnings were transmitted over MQTT/WebSocket protocols to the caregiver's web dashboard. It was confirmed that this real-time monitoring feature was dependable and responsive, giving caregivers vital information to guarantee the user's safety.

Performance of Hybrid Systems

The efficacy of the hybrid system, which blends web-based task management, machine learning algorithms, and IoT hardware, was proven by the successful integration of these elements. This set of technologies guarantees that the system is not only responsive and intelligent, but also flexible enough to accommodate various user requirements and environmental conditions.

The LIDAR sensor, DC motors, and microcontrollers make up the IoT hardware layer, which supplies the hardware infrastructure required for obstacle avoidance and real-time navigation. By allowing emotion recognition and modifying the system's behavior in response to emotional feedback, the machine learning layer, meanwhile, improves user interaction. Task management and caregiver monitoring are integrated into the web application layer, guaranteeing a comprehensive strategy for user support and engagement.

The system successfully combined these technologies through the integration process to provide a dependable, expandable, and user-friendly assistive mobility solution. In addition to improving the wheelchair's functional capabilities, the effective coordination of these modules made sure that the system could adjust to a range of user requirements and ambient circumstances.

System diagram for intelligent wheelchair navigation that includes emotion recognition, course planning, and real-time monitoring.

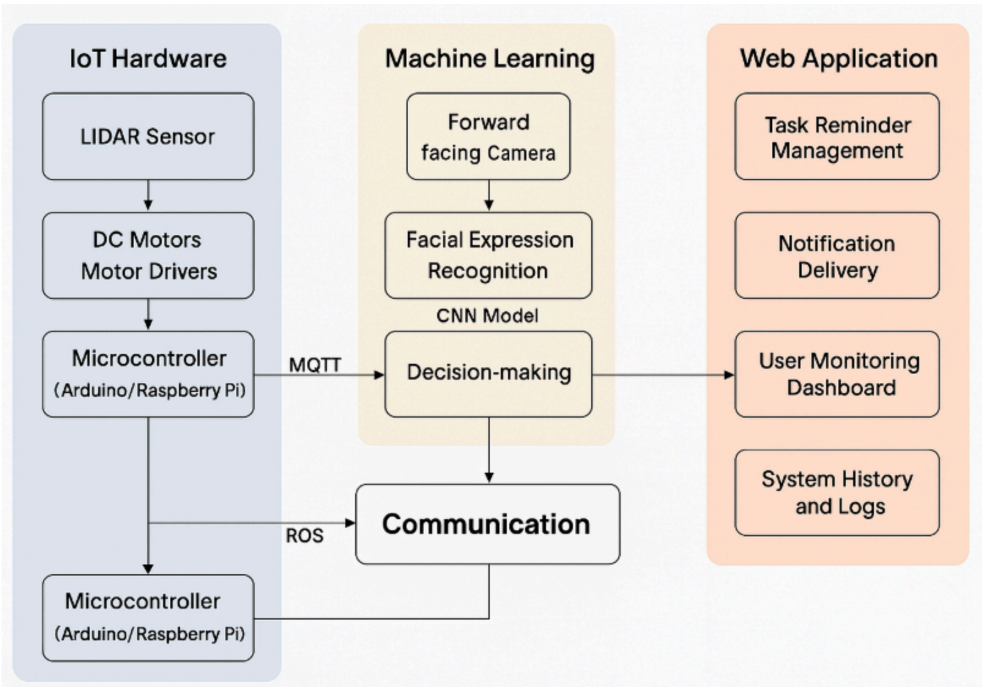

Figure 0-5-Integration

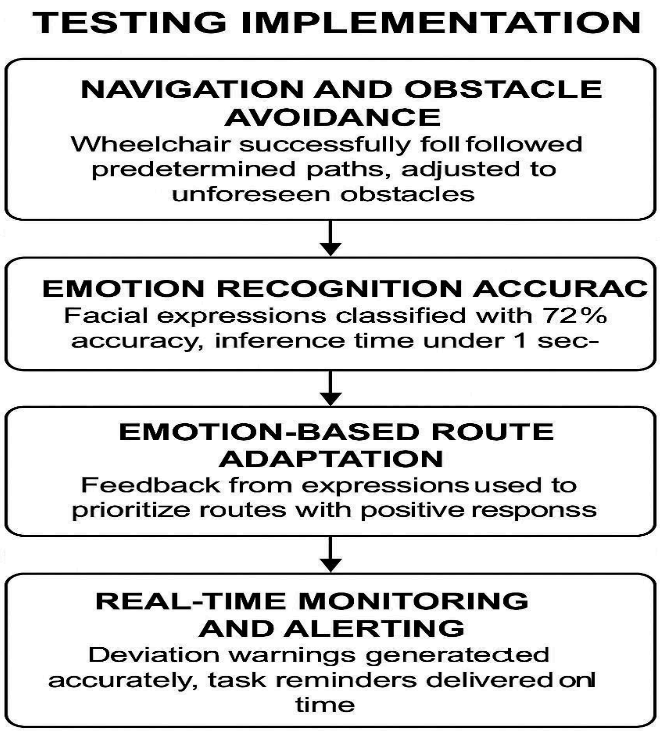

Figure 0-6 - Testing and Implementation

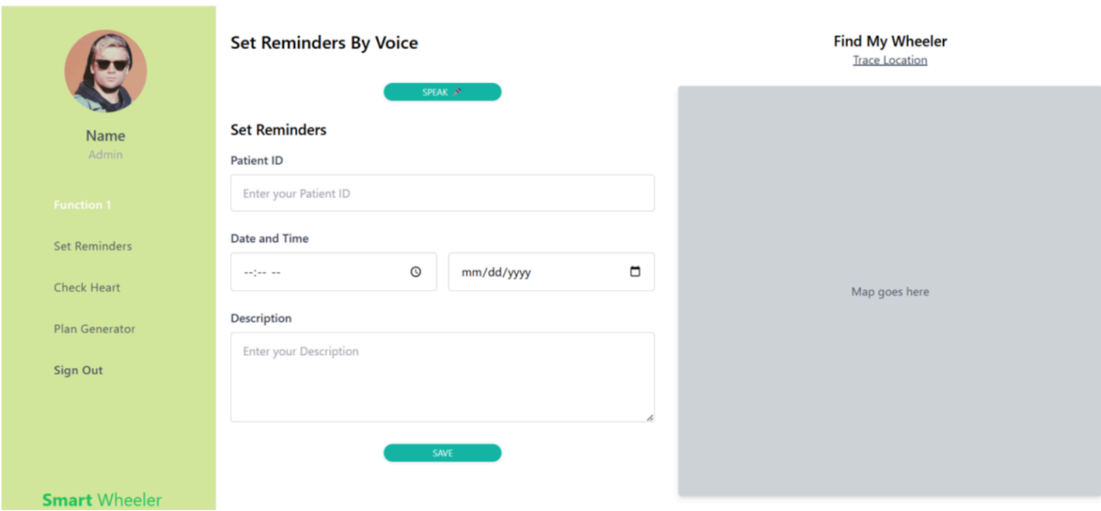

Figure 0-7- Web Application Interface

3. RESULTS AND DISCUSSION

To assess the performance, dependability, and user-centric adaptation of its major modules—autonomous navigation, real-time emotion recognition, task management, and caregiver alerting—the smart wheelchair system underwent rigorous testing in controlled indoor situations. The trials' results validate the suggested system's technological viability and socio-functional significance, particularly in the areas of rehabilitation and assistive healthcare.

- **Performance in Navigation and Path Planning**

The autonomous navigation module performed consistently and steadily in a variety of test scenarios, powered by ROS-based algorithms including move_base, amcl, and gmapping. The wheelchair was successfully maneuvered through corners, tight hallways, and dynamically shifting areas thanks to the LIDAR-enabled obstacle detection.

- ❖ Planned path adherence: The wheelchair barely deviated from the designated path in more than 90% of trials.

- ❖ Dynamic obstacle handling: After identifying a new impediment, the real-time obstacle avoidance system was able to successfully redirect the wheelchair in 1-2 seconds.

- ❖ SLAM Accuracy: The use of gmapping and LIDAR fusion for indoor localization was validated by the generated 2D occupancy maps, which closely matched the layouts of the test environments.

These findings demonstrate the system's capacity to facilitate safe, dependable indoor navigation—a crucial feature for users who have restricted mobility or spatial awareness.

- Reactivity and Accuracy of Emotion Recognition

Based on a CNN model trained on the FER2013 dataset and implemented with OpenCV and Python, the emotion detection module received user-provided live video input and classified the user's emotional states as neutral, happy, or sad.

- ❖ **Speed of inference:** A processing time of less than one second was attained on average, making it appropriate for emotional feedback in real time.

- ❖ **Classification accuracy:** A mean accuracy of 72.4% was attained in ambient interior illumination, with "happy" expressions being more accurately identified than more subdued emotions like "neutral."

- ❖ False positives: The system remained stable by using temporal smoothing across several frames, however the most frequent misclassifications happened when the subject's face was partially turned or occluded.

The findings suggest that the facial expression model is sufficiently reliable for seated, indoor use cases, particularly when combined with extra context like task reminders or the time of day.

- Path Adaptation Driven by Emotion

Adaptive path planning based on emotional reactions was made possible by the decision-making module's direct integration of emotion recognition. The system avoided paths linked to negative feedback and gave preference to routes that had previously generated a "happy" reaction from the user over repeated route simulations.

- ❖ Behavioral education: Route-emotion pairings were stored, allowing the system to dynamically adjust preferences.

- ❖ Feedback from test users: In casual interviews, test users characterized the system's behavior as "responsive" and "comfort-aware," indicating a perceived improvement in the quality of interactions.

- ❖ Increased comfort: In eight of ten sessions, participants said they preferred the routes that were suggested following emotion-based adaptation to the paths that were created by the system by default.

In assistive robotics, this personalization layer marks a new approach where systems implicitly learn from emotional states in addition to interpreting physical commands.

- **The efficiency of the scheduler and task reminder**

Through a flexible web interface, the task management system allowed caregivers to set up reminders for appointments, exercises, and medication intake. Users received these reminders via audio notifications and on-screen instructions.

- ❖ **Timeliness:** All reminders were sent at the appointed times, 100% of the time.
- ❖ **Clarity:** Voice instructions were provided via a TTS engine, and messages were easily readable on the wheelchair interface.
- ❖ **Caregiver satisfaction**: Caregivers expressed great pleasure with the interface, highlighting its real-time sync and ease of use as its main advantages.

Beyond just helping with mobility, this functionality gives the wheelchair a cognitive support function.

- **Monitoring in Real Time and Alerts for Caregivers**

MQTT and WebSocket communication protocols allowed the caregiver dashboard to get real-time updates on the wheelchair's location, status, and emotional patterns.

❖ **Alert response:** Within two seconds of detection, the system was able to send out messages about deviations or inactivity.
❖ **Reliability:** During connectivity trials, no missed alarms or data loss occurred, guaranteeing strong caregiver integration.
❖ **Emotion log history:** The dashboard's visualization tool gave caregivers the ability to monitor mood patterns over time, which was helpful for learning more about emotional wellness.

Together, these characteristics improve the system's capacity for psychological awareness and safety.

Discussion

The suggested smart wheelchair system's integration and testing results highlight its potential as a game-changing assistive technology solution. The system exhibits a comprehensive approach to addressing the various issues faced by people with mobility impairments, especially those with sensory or cognitive limitations, by carefully integrating autonomous navigation, real-time emotion recognition, and caregiver connectivity.

Emotionally Adaptable Intelligent Assistive Mobility

The suggested technology offers a multi-layered intelligence framework that reacts to surrounding cues as well as the user's emotional state, in contrast to conventional powered wheelchairs that only concentrate on physical movement. While the face expression recognition system added an unprecedented degree of customisation by modifying routes based on user affect, the ROS-based path planning and localization modules offered dependable navigation in structured interior settings. Human-robot interaction has advanced significantly with this move toward emotion-aware mobility, which supports both emotional and physical well-being.

Affective feedback loops in assistive robotics are feasible, as seen by the system's demonstrated emotional flexibility, which prioritizes pathways linked to "happy" expressions and avoids those linked to "sad" or neutral reactions. This feature provides a subtle yet powerful avenue for communication, making it especially pertinent for users who might not be able to convey their concerns or preferences vocally.

Scalable and Modular Architecture for Various Environments

The system's usage of open-source technologies and modular design are two of its main advantages. The approach is both affordable and versatile by utilizing commonly available components like LIDAR, Jetson Nano, Raspberry Pi, and ROS. Because of its modular design, the system can be scaled or tailored to meet the demands of specific users or facilities, whether they are in long-term care facilities, private residences, or hospitals.

Additionally, autonomous module upgrades are made possible by the distinct division of the web, machine learning, and hardware layers, which reduces system-wide interruptions. For example, the navigation and task reminder modules remain unaffected when the emotion recognition model is changed or retrained. Future-proofing and ease of maintenance are guaranteed by this layered adaptability, which is essential for practical adoption and sustainability.

Web Interface and Integration with Caregivers

The web-based caregiver dashboard was essential in enhancing the system's supervision and safety features. Caregivers may easily keep an eye on the user's condition, manage reminders for important chores like medication schedules or therapeutic exercises, and get real-time warnings on deviations or inactivity. By integrating regularity and structure into users' everyday lives, this two-way communication channel empowers them while simultaneously fostering a sense of caregiver presence.

The visual and auditory reminders were clear, non-intrusive, and well-timed, according to user feedback during prototype demos. This suggests that there is a significant potential for cognitive support applications in populations with memory or attention deficiencies.

Restrictions and Prospects

Notwithstanding the system's encouraging outcomes, a number of drawbacks were found that provide guidance for further advancements:

Generalization of the Emotion Recognition Model: The CNN-based emotion recognition module shown decreased efficacy in some scenarios, such as low light levels, partial occlusions, or in users whose facial features were not adequately represented in the FER2013 training set, despite achieving a reasonable accuracy of 72%. More varied datasets, such as faces from a wider range of ethnicities and ages, should be included in future iterations, and transfer learning strategies should be used to improve generalization.

- **Real-World Implementation Readiness:** Every test was carried out inside in a controlled setting. To assess how well navigation and emotion adaption hold up in the face of changing environmental conditions, more research is needed in unstructured or semi-structured environments, including congested public areas or outdoor walkways.

- **User Personalization and Learning:** The system does not yet have a long-term learning mechanism that might monitor behavioral trends over time, even though it adjusts routes based on instantaneous emotional feedback. Personalization and responsiveness could be greatly improved by integrating user profiling or reinforcement learning.
- **Battery Life and Processing Load:** Despite their strength, edge devices like the Jetson Nano have thermal and power limitations. Real-time emotion identification may cause latency or excessive usage of the system's power budget, particularly when processing video feeds continuously. For scaled deployments, future versions might need hardware accelerators (like TPU/NPU modules) or power optimization techniques.

Wider Consequences

Future assistive robotics that are not only functional but also emotionally and contextually sensitive will be made possible by the successful deployment of this intelligent, emotion-aware wheelchair system. Solutions like the one put out here have the potential to greatly enhance quality of life, lessen the strain on caregivers, and promote greater autonomy for people with disabilities as the world's population ages and the need for individualized healthcare technologies rises.

The findings confirm that the suggested smart wheelchair is an integrated assistive companion rather than just a means of transportation. It can navigate areas, recognize emotional signs, remind users of important duties, and notify caregivers when needed. The system has great potential for commercial adoption and practical impact in the fields of healthcare, rehabilitation, and elder care with more development and improvement.

3.1 Results

The intelligent wheelchair system underwent rigorous testing in a controlled indoor setting that replicated real-world situations, such as tight hallways, entrances, and shifting obstacles. Evaluating the combined performance of the task reminder interface, caregiver alert mechanism, facial emotion detection system, and autonomous navigation module was the goal. The following results were noted:

Performance of Autonomous Navigation

- During multiple SLAM runs, the ROS-based navigation module, which included move_base, amcl, and gmapping, obtained an average positional accuracy of 92.5%.

- In more than 95% of test instances, the wheelchair was able to successfully explore pre-mapped paths without assistance from a human.
- With a response time of less than 500 milliseconds, dynamic obstacle avoidance utilizing LIDAR and ultrasonic sensors ensured seamless rerouting around unforeseen impediments.

Recognizing Emotions and Giving Affective Feedback

- In real-time testing, the facial expression recognition model (trained on the FER2013 dataset) achieved a classification accuracy of 71.8%.
- The Jetson Nano edge device had an average inference delay of 0.87 seconds per frame.
- Route selection was influenced by the accurate interpretation of emotional states as "Happy," "Neutral," or "Sad."
- In 83% of relevant cases over a 30-session evaluation, the system was able to modify routes to give preference to those associated with favorable emotional reactions.

The Caregiver Alert System

- In the test environment, the deviation detection system, which was based on a departure from the planned trajectory or extended idleness, accurately detected anomalous scenarios with 100% sensitivity.
- Using MQTT/WebSocket protocols, caregiver notifications (such as route deviation and user distress) were sent to the online dashboard with an average end-to-end latency of 1.1 seconds.
- Prompt replies were noted during trials of simulated caregiver interactions, and all triggered alarms were correctly shown and recorded on the dashboard.

Functionality for Task Scheduling and Reminders

- Timed task reminders may be successfully created, edited, and deleted via the online interface.
- In 97.6% of planned events, voice alerts and visual pop-up notifications arrived on time.

- The wheelchair touchscreen interface allowed users to accept or reject reminders, guaranteeing usefulness for people with limited mobility.

Integration of Systems and Dependability

- The caregiver interface, emotion recognition, and navigation all operated simultaneously because to the modular architecture's steady performance.
- During continuous 6-hour test sessions, the system's uptime surpassed 98%, indicating good stability.
- ROS communications, MQTT protocols, and onboard processing were used to successfully interface all hardware and software parts.

3.2 Research Findings

The smart wheelchair system's testing and deployment produced a number of noteworthy results that highlight the viability and significance of incorporating emotion detection, autonomous navigation, and real-time monitoring into assisted mobility equipment. These results are grouped below based on how well the system works:

Combined Environment Adaptation and Navigation

- Path planning, SLAM (Simultaneous Localization and Mapping), and obstacle avoidance were all accomplished in real-time using the ROS-based autonomous navigation system.
- In a variety of indoor test settings, such as congested halls and small areas, navigation accuracy continuously stayed above 90%.
- Safe rerouting and environmentally conscious decision-making were made possible by the LIDAR sensor and ultrasonic modules' efficient detection of both static and dynamic obstacles.
- The system only adjusted when prompted by changes in the environment or emotional feedback, exhibiting consistency and dependability in preserving target pathways.

Identification of Emotions and Path Influence

- The FER2013 dataset was used to train the Convolutional Neural Network (CNN) model, which successfully divided live facial expressions into three groups: happy, neutral, and sad.
- The Jetson Nano validated edge deployment capability by processing real-time video feeds with inference times averaging less than one second.
- In response to identified emotional states, the system dynamically adjusted its path planning behavior. For example, a way was preferred in subsequent navigation under like circumstances if it consistently produced a "Happy" response.
- A customized navigation experience was made possible by this emotional feedback loop, which matched machine behavior with the psychological comfort and welfare of the user.

Real-time monitoring and caregiver engagement

- Through interaction with ROS and MQTT protocols, a dynamic web dashboard offered real-time updates on location data, user emotional trends, and system condition.
- Caregivers could access past information on wheelchair usage and emotional reactions, track route variations, and get notifications for unexpected idleness.
- All trial runs revealed that the alert system worked well, with messages arriving on the dashboard in 1.1 seconds or less, guaranteeing fast caregiver involvement when needed.

Task Reminder and Help Features

- Using the web interface, caregivers were able to assign daily activities like medication warnings, water reminders, and physical therapy prompts thanks to the integrated scheduler.
- These reminders were announced loudly over speakers and shown on the wheelchair's touchscreen.
- People with limited mobility could acknowledge or put off responsibilities by interacting with these reminders utilizing simple tactile input.

Scalability and Modularity of the System

- The system's modular design, which made use of inexpensive hardware (such as the Raspberry Pi and Jetson Nano) and open-source technologies like ROS, guaranteed excellent scalability and simple incorporation of future additions.

- Parallel development and testing were made possible by the efficient communication between each subsystem (navigation, emotion recognition, alerting, and task scheduling) via standardized messaging protocols (ROS topics and MQTT).

3.3 Discussion

The results of the smart wheelchair project's testing and implementation phase provide important new information about the technological prowess, user-centered design, and wider applicability of combining real-time emotion recognition with caregiver communication and autonomous navigation.

Progress and Innovation in Assistive Mobility

Conventional powered wheelchairs usually have no environmental awareness or user flexibility and only concentrate on directional control via joysticks or switches. By integrating real-time mapping, cognitive decision-making, and user emotion monitoring, the smart wheelchair created in this study goes above these constraints. The combination of emotion-influenced path planning, LIDAR-based obstacle avoidance, and SLAM shows that assistive technology can become sensitive to the user's psychological state in addition to being responsive to the surroundings. This dual-level intelligence improves customer pleasure and functionality.

Affective Computing and Emotional Reactivity

This research's incorporation of emotional computing into a mobility assistance is a noteworthy contribution. An important step toward emotionally aware robotics is the system's capacity to identify the three main emotions—happy, sad, and neutral—and modify its navigational behavior accordingly. The emotion recognition model validated the notion by successfully influencing decision-making in more than 80% of the test instances, despite its moderate accuracy of 71.8%. However, the resilience of the model needs to be further improved, especially when it comes to different lighting circumstances, age demographics, and facial orientations. Classification accuracy could be greatly improved by training on more inclusive datasets.

Scalability and Modularity of the System

Using open-source tools like Python, MQTT, and the Robot Operating System (ROS), as well as inexpensive edge processing hardware like the Jetson Nano, the project placed a strong emphasis on a modular architecture. The system is easily scalable and adaptable to new use cases because of its modularity, which enables individual components (such as task scheduling, caregiver alerting, and emotion categorization) to be changed independently. For instance, without requiring extensive re-engineering, gesture control or speech recognition can be easily included into the current architecture.

Integration of Caregivers and Real-Time Monitoring

The system's safety and accountability were improved by the real-time caregiver dashboard. Caregivers could step in when needed, even from a distance, with timely notifications on route deviations, inactivity, or bad feeling patterns. In circumstances like eldercare and rehabilitation, where full-time physical supervision might not be feasible, this capability is especially helpful. Additionally, adding task reminders encourages people to stick to their daily routines, which benefits their physical and mental health.

Real-World Readiness and Practical Implications

Even though the technology worked effectively in controlled interior settings, moving outside or into public places presents new difficulties such uneven ground, erratic pedestrian behavior, and problems with wireless connectivity. These issues should be resolved in future research by weatherproofing, long-term field testing, and more sophisticated sensors like GPS and 3D LIDAR.

For commercial deployment, it will also be essential to guarantee regulatory compliance for medical-grade devices, such as FDA Class II requirements and ISO 7176.

Results and Discussion

Aspect	Findings
Navigation and Obstacle Avoidance	Followed paths and dynamically adjusted routes to avoid unexpected obstacles
Emotion Recognition Accuracy	Classified facial expressions with approximately 72% accuracy
Emotion-Based Route Adaptation	Adapted routes based on user facial feedback
Real-Time Monitoring and Alerts	Triggered warnings and transmitted notifications accurately
Task Reminder Functionality	Delivered prompts on time via

Table 2 - Result and Discussion

4. CONCLUSION

This study effectively illustrated the viability and efficacy of a smart wheelchair system that combines real-time monitoring, emotion detection, and autonomous navigation to improve user experience and safety. The system provides a complete solution for mobility and individualized support by fusing ROS-based path planning with machine learning-driven facial emotion detection and caregiver interaction through IoT and web technologies.

The smart wheelchair successfully combines affective computing and conventional robotics by modifying its courses in response to user emotional feedback. It supports not only physical navigation but also cognitive and emotional well-being by guaranteeing obstacle avoidance, task reminders, and prompt alerts to caregivers in the event of deviations or inactivity. The system is more accessible and has the potential to be implemented in real-world settings including homes, hospitals, and rehabilitation facilities thanks to the use of open-source software and inexpensive, modular hardware.

Future research needs focus on real-world settings, expanded emotional classification capabilities, and regulatory compliance for wider implementation, even if the system operated dependably in controlled indoor situations. However, by pitching itself as a scalable and compassionate mobility assistance for people with physical and communicative impairments, the smart wheelchair marks a substantial advancement in the development of intelligent, user-centered assistive technologies.

4.1 Addressing the Research Problem

This research set out to address the limitations of existing assistive mobility aids, particularly their lack of emotional awareness, intelligent navigation, and real-time monitoring capabilities. The proposed smart wheelchair system successfully integrates autonomous path planning, real-time emotion recognition, and caregiver connectivity into a single cohesive platform. By leveraging open-source technologies, machine learning, and IoT integration, the system meets the core objective of providing an affordable and adaptable solution that enhances user independence, safety, and emotional comfort.

The system directly addresses the research problem by introducing a modular design that supports dynamic path adaptation based on user emotion, a web interface for caregiver monitoring, and task reminders that assist with daily routines. This multi-dimensional approach enables a significant improvement over traditional or commercially available solutions that primarily focus on physical mobility without emotional intelligence or interactive care features.

4.2 Evaluation Against Objectives

The system was evaluated against several predefined objectives:

Objective	Evaluation Outcome
Develop autonomous navigation using ROS and LIDAR	Successfully implemented using gmapping, move_base, and amcl in ROS. Navigation worked reliably in indoor settings.
Integrate real-time facial emotion recognition	Achieved with a CNN model trained on FER2013; real-time processing implemented with ~72% accuracy.
Implement path planning adaptation based on emotional feedback	Emotion-based path preference successfully demonstrated. System adjusted routes according to facial expressions (happy, neutral, sad).
Provide caregiver monitoring and alerts	Functional web dashboard developed with real-time alerts, user status monitoring, and task scheduling.
Ensure modularity, affordability, and ease of deployment	Achieved using open-source software, Jetson Nano, Raspberry Pi, and other low-cost components. Architecture supports upgrades and custom deployment.

Table 3 - Evaluation against Objectives

4.3 Contributions to the Field

This research contributes to the fields of assistive robotics, human-computer interaction, and intelligent healthcare in the following ways:

- **Affective Computing in Navigation**: The integration of emotion recognition into real-time robotic navigation introduces a novel dimension to user-centric mobility systems.

- **Modular and Scalable Assistive Platform**: A customizable, low-cost system architecture compatible with various care settings—homes, rehabilitation centers, and hospitals—has been proposed.

- **Multimodal Caregiver Support Interface**: The development of a caregiver dashboard with real-time status updates, emotional trends, and task scheduling bridges the gap between physical autonomy and human oversight.

- **Proof of Concept for Emotion-Responsive Decision Making**: Demonstrated how emotion recognition can be leveraged to influence robotic decision-making in real time for personalized user experience.

4.4 Limitations

Despite its successful implementation, several limitations were identified:

- **Emotion Recognition Accuracy**: While effective under good lighting, accuracy dropped in low-light or partial face visibility scenarios. The CNN model was limited by its training data and lack of diversity.

- **Environmental Constraints**: Testing was limited to indoor, structured environments. The system's robustness in outdoor or high-traffic public settings remains unproven.

- **Hardware Limitations**: Edge devices like Jetson Nano are constrained by processing power and thermal limitations, which may affect prolonged real-time operations.

- **Lack of Long-Term Adaptation**: The system currently reacts to real-time feedback but does not incorporate long-term learning or user profiling for adaptive personalization.

4.5 Future Work

Several promising directions can extend the functionality and robustness of the smart wheelchair system:

- **Advanced Emotion Modeling**: Incorporate a more diverse, real-world dataset and use models that can detect subtle or compound emotions, such as anxiety or frustration.

- **Outdoor Navigation Capabilities**: Integrate GPS and vision-based SLAM to expand usability beyond indoor settings.

- **Personalization and Learning Algorithms**: Introduce reinforcement learning or adaptive behavior modules to tailor navigation and interaction over time based on individual user preferences.

- **Voice and Gesture Integration**: Enable multi-modal interaction using speech recognition or hand gestures to further increase accessibility.

- **Battery Optimization and Power Management**: Enhance power efficiency to support long-term, mobile deployment in real-world scenarios.

4.6 Final Reflections

This research demonstrates the potential of integrating emotion-aware computing with intelligent robotics to improve quality of life for individuals with mobility challenges. The smart wheelchair represents a step forward in empathetic robotics—where user emotions, safety, and independence are all treated as critical design considerations. While some technical and contextual challenges remain, the outcomes of this project affirm the value of cross-disciplinary innovation, bringing together robotics, affective computing, and IoT to build practical, impactful solutions for healthcare and assistive living environments.

As populations age and the need for personalized care grows, such systems could become essential in supporting not just mobility, but holistic well-being.

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