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Design And Implementation Of An Autonomous Electric Wheelchair Using Directions-Based Navigation And Smart Mobility Control

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ABSTRACT
This paper presents the development of a smart electric wheelchair system designed to assist individuals with mobility challenges by offering three control methods. The system includes a manual mode that allows users to control speed and direction via Bluetooth, a human-following mode that utilizes a camera for tracking and following a designated person, and an autonomous mode that enables navigation based on directional signboards. Convolutional Neural Networks (CNN) are employed for human detection, while cosine similarity is used to interpret movement commands from signboards. The primary goal is to empower physically disabled individuals by leveraging evolving technologies. The proposed system is cost-effective, easy to construct, and adaptable, and has been implemented and tested in real-time under all operating modes.
Key words: *Electric Wheelchair, Computer Vision, Au- tonomous Navigation, Obstacle Detection, Human Following, Im- age Processing, Smart Mobility, Assistive Technology, Directional Sign Recognition*

INTRODUCTION:

Electric wheelchairs have revolutionized mobility for physi- cally disabled individuals, offering comfort, independence, and ease of movement. Electric wheelchairs use electric motors and run on rechargeable batteries, making them an extremely convenient and efficient mode of movement for individuals who require assistance in daily movement[3],[4],[13]. They are now a necessity for the majority of individuals with limited mobility, offering them better quality of life and greater independence. There are now a wide variety of types and designs of modern electric wheelchairs from which the users may select based on particular needs, body weight, or taste[2],[3],[7],[8]. There are highly adjustable models that feature special provisions like leg lift to raise, gear opera- tion for tilting, and control sticks for smooth turning. Other accessories in the form abilities, offering both speed and high accuracy. YOLO is especially useful for those applications where object classi- fication and localization need to be performed simultaneously in an image.
Conversely, for operations whose goal is to compute sim- ilarity between data features and not necessarily to detect or localize objects, methods such as Cosine Similarity are preferable. Cosine Similarity computes the cosine of the angle between two non-zero n-dimensional space vectors and is popularly used due to its ability to cope with high-dimensional and sparse data. This is extremely suitable in applications like document similarity analysis, face recognition by feature embeddings, and user-item interaction matrix-based recom- mendation systems.

LITERATURE REVIEW

Over the past few years, several methods have been put forward for object detection and similarity quantification in machine learning and image processing domains. Deep learn- ing object detection models like YOLO (You Only Look Once) have become popular with their real-time object detection

In face recognition applications, deep learning models like convolutional neural networks (CNNs) are used most fre- quently to produce feature embeddings, which are used by Cosine Similarity to compute identity similarity. Similarly, in recommendation systems, user tastes and item attributes can be embedded as vectors in a high-dimensional space where Cosine Similarity is utilized to find and recommend similar items. In text processing and text mining, Cosine Similarity is often utilized over term frequency-inverse document frequency (TF-IDF) vectors in document classification and clustering with improved performance in sparse vector spaces than with standard distance measures.

Since the major goal of the present work is to compare the similarity between feature vectors and not object detection or localization, Cosine Similarity is chosen as the preferred approach over object detection models such as YOLO. Stud- ies demonstrate improved safety through real-time environ- ment analysis and enhanced accessibility via adaptive con- trol modes (voice, joystick, autonomous), achieving reliable indoor-outdoor navigation in structured environments. Due to its computational complexity and the fact that it is better suited to the comparison of feature embeddings, it is the best candidate for the desired application.

METHODOLOGY

BLUETOOTH INTEGRATION METHODOLGY: The Bluetooth controller system for the electric wheelchair enables wireless control via a mobile app or dedicated remote. It consists of a Bluetooth communication module (HC-05/HC- 06) that connects the wheelchair to the mobile device, a micro- controller (like Arduino UNO or Raspberry Pi) that processes commands, and a motor controller (e.g., L298N) that directs the wheelchair's movement. Additionally, ultrasonic sensors are used to detect obstacles, and the mobile app provides real- time information such as battery status and connectivity.

The hardware setup includes the Bluetooth module, mi- crocontroller, motor driver, obstacle detection sensors, and a power supply. The Bluetooth module allows for commu- nication between the wheelchair and mobile device, while the microcontroller processes Bluetooth commands and con- trols the motors and sensors. The motor driver manages the wheelchair's movement, and the obstacle detection sensors prevent collisions by adjusting the wheelchair's path in real time. The software consists of embedded firmware for the mi- crocontroller and a mobile application. The firmware handles Bluetooth data reception, motor control, and obstacle detec- tion. The mobile app offers easy-to-use movement controls and real-time system feedback. Communication is achieved using Bluetooth's Serial Port Profile (SPP), and the system is designed to operate within the 2.4 GHz ISM band.

The Bluetooth module installed on the wheelchair pro- vides wireless communication between the joystick and the wheelchair [3],[8]. The joystick is equipped with a Bluetooth transmitter, which transmits control signals wirelessly to a Bluetooth receiver in the wheelchair [9],[25],[32]. The receiver decodes these signals and forwards them to the motor con- troller for driving the wheelchair. Cables are not needed, which brings with it enhanced mobility and no entanglement.For implementation reference please look into the Fig.5,Fig.6.

VISION BASED APPROACH: The system utilizes an intelligent, vision-based approach to allow an autonomous wheelchair to track a human subject. The architecture of the design incorporates image sensing, object identification, real-time processing, and motion control to allow for smooth movement without explicit user intervention. The system starts with a camera module on the wheelchair that keeps acquiring live video streams of the surroundings. These frames are analyzed in real-time by applying a human detection algorithm, possibly in the form of deep learning models like YOLO (You Only Look Once), Haar cascades, or any other convolutional neural networks (CNNs). The detection module determines the occurrence of a human and creates a bounding box for the target subject. Furthermore, motion estimation methods are utilized to determine if the individual is moving ahead, which serves as a cue to start the subsequent behavior.

After the individual is identified, positional data is sent to a microcontroller, which acts as the brain of the system. The microcontroller translates the location and direction of movement of the individual through centroid tracking, optical flow, or geometric estimation techniques. Depending on the relative location of the identified person in the camera frame (left, center, or right), the system calculates the necessary motion corrections for the wheelchair.

To provide real-time responsiveness and stability, the micro- controller sends control signals to a motor driver or secondary microcontroller unit that controls the wheelchair's motors. Pulse Width Modulation (PWM) signals are most commonly employed to regulate the speed and direction of the DC or servo motors for smooth forward travel and turning. Feedback mechanisms, including encoders or inertial measurement units (IMUs), can be included for improved motion accuracy and stability.

The whole system works in a closed-loop fashion, always capturing visual information, perceiving human movement, and revising motor commands in response. This enables the wheelchair to maintain a safe, steady following distance and adjust to the user's movement in changing surroundings. The strategy is most helpful for users with mobility disabilities who need to be helped but wish to use a hands-free, responsive mobility device.Refer to Fig.5

JOYSTICK INTEGRATION METHODOLOGY: The wheelchair makes use of a joystick as the main input device, which is positioned on the armrest for convenient access. This placement conforms to ergonomic standards so that the user can control the movement of the wheelchair with ease without exerting undue strain on their hands or arms. The joystick is intuitive in nature to ensure that people with limited mobility can easily navigate around. By controlling the joystick in various directions, i.e., forward, backward, left, and right, the user can regulate the speed and direction of the movement of the wheelchair. The system receives these inputs and controls the motors accordingly, enabling accurate and responsive control over the motion of the wheelchair.

In higher-level systems, the joystick can be used with other features like speed control, where the user has the ability to vary the speed of the wheelchair according to their requirements and situation. For instance, they can speed up for lengthy open routes or slow down while moving through narrow corridors or steering clear of obstacles. There are systems available that provide a variable-speed option that can adjust the speed automatically based on the terrain or slope to provide smoother travel.

In addition, there are some joystick-controlled systems with programmable buttons or switches that can be set for certain purposes. These may include the operation of the lights of the wheelchair, horn operation, or the changing of driving modes. The fact that these features can be programmed makes the wheelchair more tailored to the lifestyle and needs of the user. For those with more extreme motor impairments, there are also adaptive joystick systems available. These might include a variety of different joysticks, including larger, more sensitive handles that are easier to use or even a sip-and-puff type joystick control system for those with very limited hand movement. Some more advanced models have touch-sensitive or tilt-sensitive joysticks, offering even greater control possibilities.

In general, the joystick control system of an electric wheelchair is an essential interface that enables users to control the wheelchair effectively, safely, and comfortably. Its simplicity, along with the versatility of sophisticated features, guarantees that it can accommodate the varied needs of a broad spectrum of users.

Autonomous EV: The Autonomous EV Wheelchair is built on a rechargeable Lithium-ion (Li-ion) battery-powered motorized wheelchair platform. The core of the system is a Microcontroller Unit (MCU) like Arduino or Raspberry Pi with the ability to process sensor data, motor control, and decision-making logic. DC motors through a motor driver drive the wheelchair, with Pulse Width Modulation (PWM) signals being used to control the wheelchair to enable smooth speed control, as well as direction control[6],[18],[19]. The system includes navigation modules Fig. 6. This image represents the front-facing view of a road divided into a 3x3 grid, serving as the input for autonomous navigation. The segmentation helps detect directional edges and paths using image processing techniques, aiding the wheelchair in determining forward movement and turning angles. like GPS and IMU to determine position and orientation, while LIDAR or camera modules are used for obstacle detection and mapping. Ultrasonic and Infrared (IR) sensors provide addi- tional safety features through near-range obstacle detection. For user interface and remote operation, the setup includes a Wi-Fi or Bluetooth module to connect to a smartphone or computer using a Graphical User Interface designed and developed internally. The entire hardware is energized and governed by a master power distribution board. All hardware components are attached to the wheelchair securely with wires, shielding, and calibration. The software integrates navigation algorithms, safety mechanisms, and real-time feedback sys- tems that form a closed-loop system to provide autonomous as well as userassisted mobility [20],[29],[32]. This lab setup forms a solid platform to test and validate intelligent mobility technologies for the differently-abled.

Fig. 7. This figure displays the output of a grid-based path recognition system for an autonomous wheelchair. The visual interface, divided into multiple blocks, identifies directional movement based on detected features. The text" FORWARD" suggests the wheelchair's decision to move ahead based on the processed road grid.

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IMPLEMENTAION: The Autonomous EV Wheelchair system integrates multiple control modes to provide smart mobility support to differently- abled people. The system is developed on a typical motorized wheelchair platform that is designed around a direct DC power supply or non-rechargeable batteries. A Microcontroller Unit (MCU), such as an Arduino or Raspberry Pi, acts as the processing unit, communicating with sensors, communication modules, and motor drivers to control operations.
In Joystick Mode and Bluetooth, the user controls the wheelchair manually via a joystick that is attached to the armrest. The joystick is linked to a Bluetooth transmitter, which wirelessly transmits control signals to a receiver module that is fixed to the wheelchair. The signals are decoded and transmitted to the DC motor driver, where Pulse Width Modulation (PWM) is applied to manage speed and direction. The wireless interface eliminates physical wiring between the base and joystick, providing more mobility and convenience to the user.
The Human Following Mode is implemented with a Rasp- berry Pi interfaced to a webcam installed at the back. The camera continues to take video frames and subject them to real-time processing with object detection techniques like Haar cascades or deep learning-based pose estimation. After the system has detected a target person, it determines their relative motion and transmits motor control commands to synchronize their walking speed and direction. When the target person stops or leaves, the wheelchair stops automatically to ensure safety.
In Autonomous Mode, GPS is utilized for position measurement and an IMU for orientation estimation. Ultra-sonic and Infrared (IR) sensors are utilized for the detection of near-obstacles. Feedback from the sensors is given to the MCU, which interprets the data and drives the movement of the wheelchair accordingly through PWM signals. Remote control or monitoring is provided through a Bluetooth or Wi- Fi module, and a Graphical User Interface (GUI) is envisaged for ease of use. Power supply to all the parts is controlled using a simple power distribution circuit for stability and safe operation.
This configuration offers a practical and flexible solution that blends manual control with smart autonomous capabilities, appropriate for indoor or controlled testing without depending on high-end LIDAR sensors or rechargeable power.

RESULTS

The wheelchair system's three modes of opera- tion—autonomous, human following, and joystick and Bluetooth—were assessed in a controlled indoor setting.
The system demonstrated smooth control and low latency in both the joystick and Bluetooth modes. The joystick made it simple for users to control speed and direction, and Bluetooth modes appropriate for various testing situations and user requirements.
wireless transmission was efficient up to ten meters away. The user's convenience and mobility were improved by the removal of wired connections. The Raspberry Pi camera setup used Haar cascade classifiers to successfully track a target individual in normal lighting conditions during Human Following Mode tests. When the target stopped or disappeared from view, the wheelchair automatically came to a stop. It was able to keep a steady distance and pace from the target. Even though performance somewhat suffered in dimly lit environments or for general use cases, the system remained dependable even with rapid movements.
Basic obstacle avoidance using infrared and ultrasonic sen- sors worked in Autonomous Mode, enabling safe mobility in simple indoor settings. Because GPS is inaccurate indoors, it was not used. Rather, the IMU supplied orientation data that aided in basic turning and path planning. The wheelchair maneuvered through hallways

with ease and steered clear of stationary obstacles. Bluetooth or Wi-Fi could be used to wirelessly monitor the system with a simple graphical user interface.
These findings demonstrate the potential of a modular, reasonably priced EV wheelchair system with several control

Conclusion

In this paper, a smart EV wheelchair system that combines basic autonomous features, human-following capabilities, and joystick control is presented. Flexible and dependable mobility support for people with disabilities is made possible by the system, which was constructed with affordable parts like an Arduino, Raspberry Pi, Bluetooth modules, and ultrasonic and infrared sensors. Each mode's efficacy was tested in controlled settings, proving that manual and semi-autonomous navigation is possible without the need for sophisticated hardware like GPS or LiDAR.
The system functions as a practical and reasonably priced platform for research into intelligent assistive technologies and personal mobility assistance.

Future Work

Using lightweight machine learning models (like Mo- bileNet) to integrate more precise vision-based tracking is one potential future improvement.
The camera-based human following system has better light- ing adaptation. Improved graphical user interface features like gesture recognition, voice command support, and route planning. Simple power-saving circuits are used for battery management and power optimization. To ensure robustness and collect performance feedback, real-world field testing is conducted in a variety of environments.
These enhancements will contribute to the system becoming more useful, intuitive, and flexible for various user situations.

Acknowledgement

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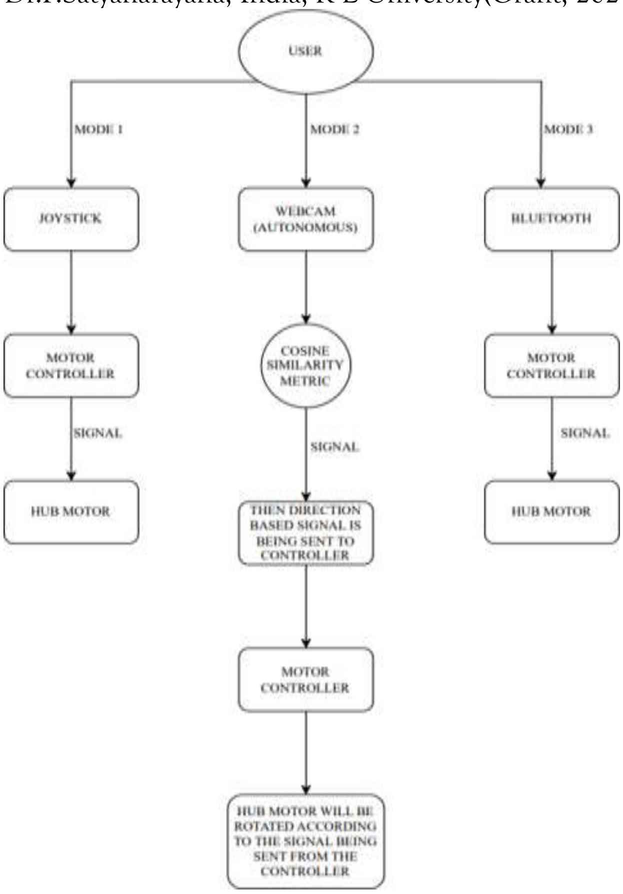

Fig. 1. Flow chart representation of multi-purpose utilization

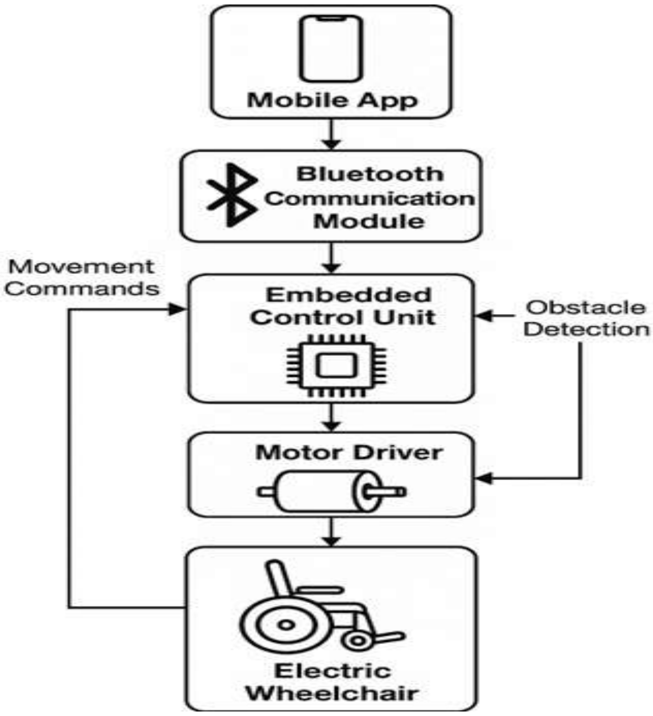

Fig. 2. Bluetooth Implementation Flow chart

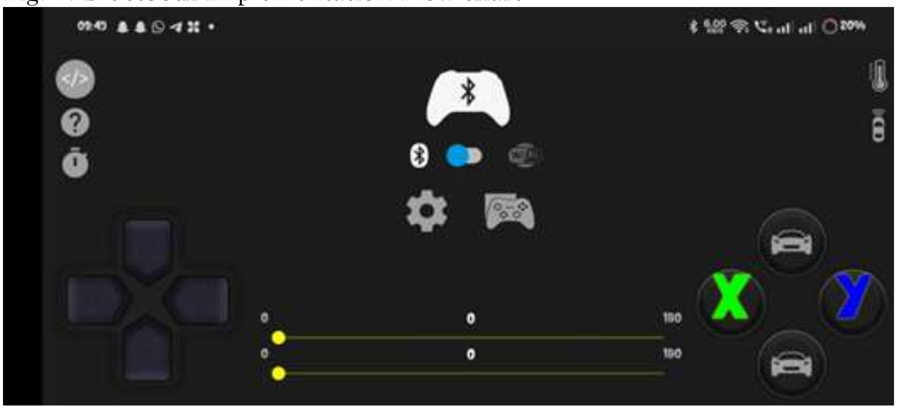

Fig. 3. Utilization through bluetooth implementation and this is the interface on which we are being using it for the controlling the wheel chair .

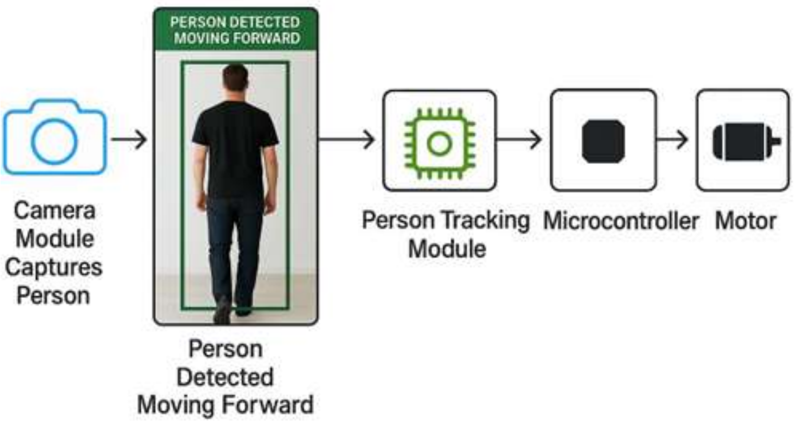

Fig. 4. Human Follower implementation

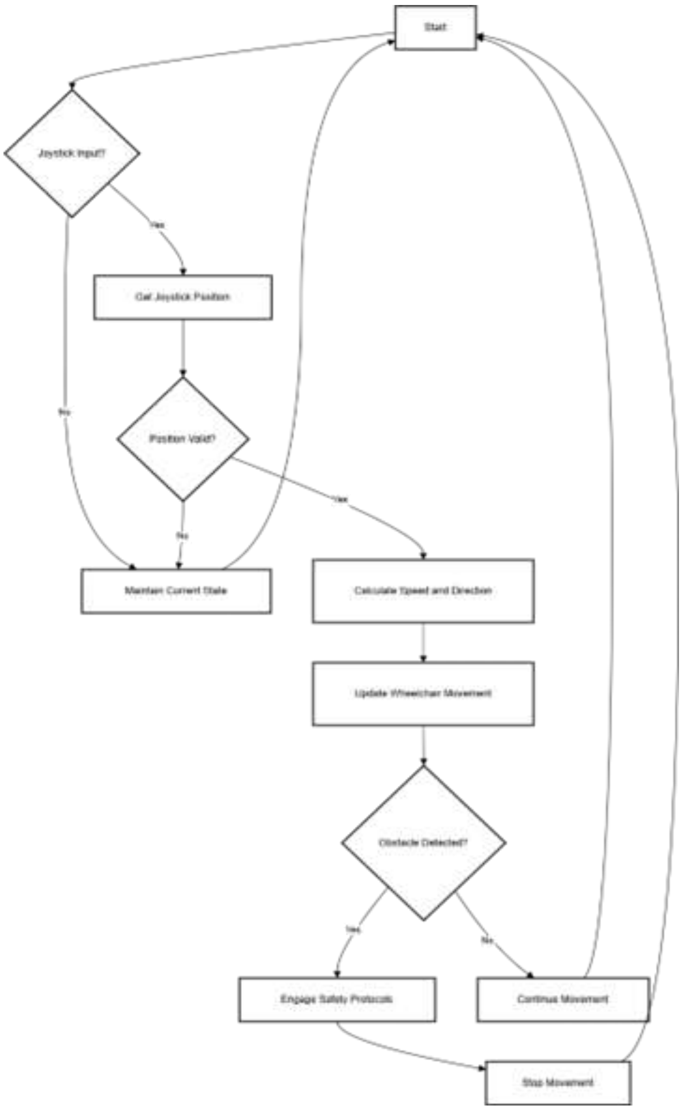

Fig. 5. Flow chart for the joystick based control mechanism.

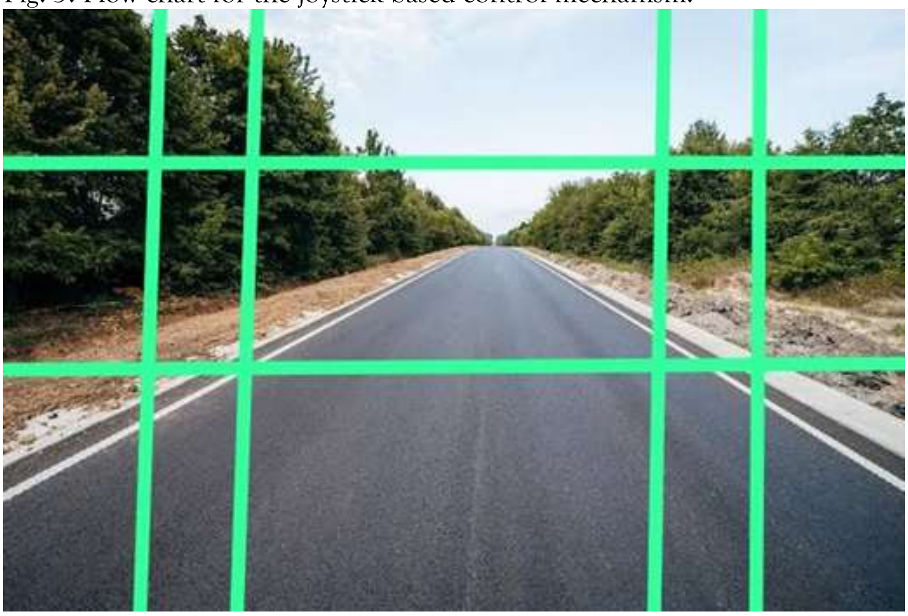
Fig. 6. Front-facing view of a road divided

Fig. 7. This figure displays the output of a grid-based path recognition system for an autonomous wheelchair

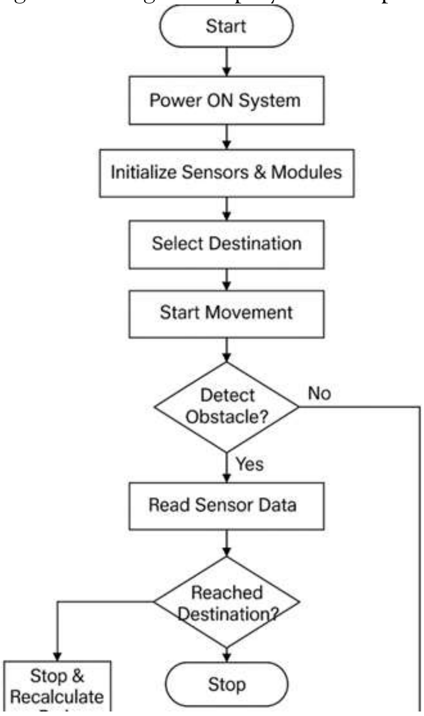

Fig. 8. Flow chart for the Autonomous direction mechanism .

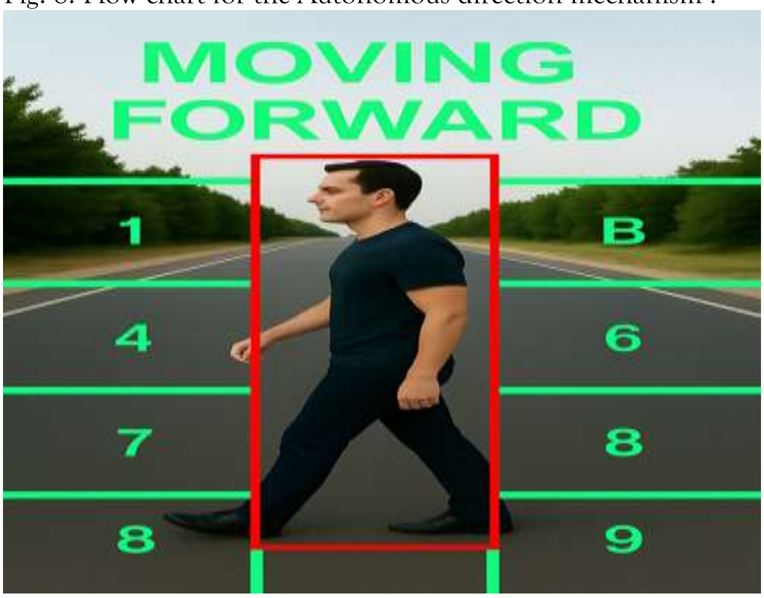

Fig. 9. Forward implementation in the grid view

Fig. 10. Forward direction being detected and will move forward accordingly based on the direction showed in the cam feed.

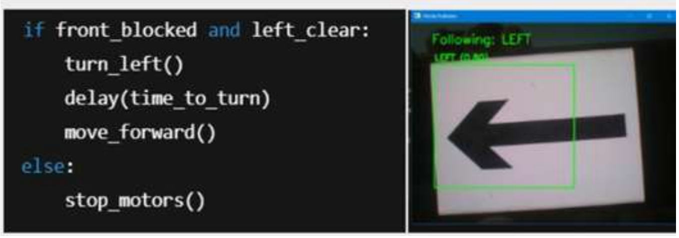

Fig. 11. Left direction being detected and will move forward accordingly based on the direction showed in the cam feed.

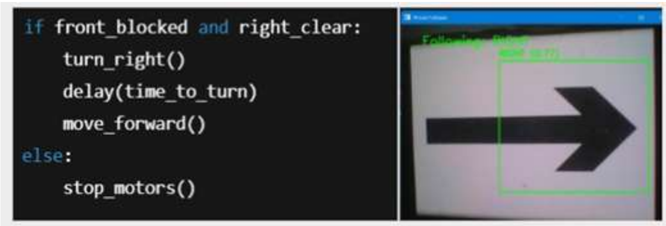

Fig. 12. Right direction being detected and will move forward accordingly based on the direction showed in the cam feed.

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