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Automatic Valet Parking Robot

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***Abstract*—This study details the design and execution of an automated vehicle parking and retrieval system, which employs robotic movement to enhance space efficiency and user satisfaction within restricted settings. Central to the system's functionality is an intelligent detection mechanism that autonomously locates and assigns available parking spaces, thereby substantially decreasing the time and manual labour required for parking searches. Moreover, a streamlined retrieval procedure is facilitated through the incorporation of Radio-Frequency Identification (RFID) technology, wherein vehicle retrieval is activated by a straightforward user command associated with the stored vehicle. The principal aim is to validate the practicality of secure and space-efficient parking solutions, enabling a greater concentration of vehicles within a confined physical space when contrasted with traditional systems. By providing an effective, automated, and safe substitute for controlling vehicle storage and access, this work advances intelligent transportation systems.**

***Index Terms*—Automated Parking System, Valet Robot, RFID Technology, Smart Parking, Autonomous Vehicle Retrieval, Intelligent Transportation System, Space Optimization, Robotics, Vehicle Management, Automation.**

I. INTRODUCTION

The primary driving force behind the development of an Automatic Valet Parking (AVP) robot project is the severe and growing parking crisis in major cities. The demand for parking spaces far outweighs the infrastructure available, which is further limited by the prohibitively high cost of urban land. This leads to deeply ingrained issues, the first of which is a disastrous level of traffic congestion, with up to 30% of urban traffic in core areas attributed to drivers" cruising" for a parking spot, wasting valuable time and fuel and significantly increasing localized air and noise pollution. Second, conventional parking structures are an unsustainable use of prime urban real estate because they devote enormous amounts of space—up to 40% of the built area—to ramps and maneuvering aisles for human drivers. Chaotic and disorganized on street parking, which encroaches on public roads and sidewalks, further impedes traffic flow and poses serious safety and security risks to vehicles, exacerbates this widespread inadequacy. In order to overcome these constraints, the AVP robot project is suggested as a necessary, high-tech solution. It uses robotic shuttles and autonomous navigation to remove ramps, maximize vertical and horizontal density, and instantly manage parking space, turning a significant cause of urban dysfunction into a model of automated efficiency.

A. Objectives of Work

The creation of an advanced, fully automated, and space efficient parking system is the main goal of the project. In order to increase speed and safety, the project intends to use robotic movement to automate vehicle parking and retrieval. This means that vehicles will be moved and positioned by machinery instead of human drivers. The necessity to find and assign empty slots using smart detection which entails using sensors and clever algorithms to monitor the facility in Realtime, quickly locate available spaces, and strategically assign them to incoming vehicles, guides this robotic movement. Vehicle owners will be able to safely and promptly ask the robot to transport their particular vehicle to an exit bay using an RFID card or signal thanks to the system's implementation of RFID based retrieval based on user input. In the end, the integration of these technologies is intended to facilitate safe and compact parking in confined spaces, maximizing the number of cars that can be kept in a small physical area while guaranteeing that the entire process is extremely accurate and reduces the possibility of damage.

B. Motivation for this Work

Pursuing these objectives is motivated by the pressing need to address the problems caused by increasing urbanization and space limitations in metropolitan areas. Because they require large ramps and wide lanes, which take up valuable space and worsen traffic jams and driver annoyance, traditional multi-level parking lots are often inefficient. The goal is to develop an Automated Vehicle Parking and Retrieval System that transforms parking from a labour-intensive, manual procedure into a highly effective robotic one. By efficiently identifying and allocating spaces through robotic movement and intelligent detection, the system significantly increases parking density, providing a practical solution to the land shortage. Additionally, RFID-based retrieval enhances the user experience by providing quick, secure, and hassle-free access to vehicles. The ultimate motivation behind the entire endeavour is to enable safe and compact parking in cramped areas, creating a model for more sustainable, safe, and intelligent urban infrastructure that can handle the growing demands of modern traffic.

II. LITERATURE REVIEW

The potential of autonomous valet parking (AVP) systems to increase user convenience, decrease traffic, and improve parking efficiency has drawn more attention. Reliable AVP solutions have been developed thanks to significant developments in robotics, sensor technology, and intelligent control systems.

In AVP, path planning and tracking continue to be major obstacles. Accurate motion control within indoor parking spaces has been made possible by the application of techniques like trajectory generation and tracking based on Kalman filters [11]. In order to create smooth trajectories appropriate for tight parking maneuvers, colthood-based path planning has been investigated [6]. Additionally, adaptive path guidance strategies for long-range valet parking in smart city settings have been proposed using reinforcement learning techniques
[7].

Semantic mapping and reservation-based mechanisms are becoming popular ways to maximize space utilization and enhance system responsiveness. Reservation-enhanced AVP systems allow for more intelligent space allocation by taking user demands and practical limitations into account [8]. By combining contextual cues with camera data, semantic visual mapping and localization techniques specifically designed for parking environments have also been proposed, improving perception [9].

Additionally, to support long-range AVP scenarios with improved efficiency, cyber-physical system architectures that combine reservation and cost optimization have been introduced [10]. Traffic behaviour and vehicle scheduling in AVP systems have been examined via simulation models which employ spatiotemporal grid reservation techniques [3]. To lessen reliance on pre-defined maps and allow for more flexible navigation, autonomous exploration techniques based on road structure detection have also been applied [12].

All things considered, earlier research has established a solid basis for sensor integration, motion planning, vehicle coordination, and environment comprehension. Nevertheless, there are still issues with robust performance in dynamic urban environments, low- cost implementation, and real-time obstacle avoidance. The need for integrated AVP systems that are dependable, scalable, and environment-adaptive is highlighted by these gaps

III. METHODOLOGIES ADOPTED

The automated parking system's methodology is predicated on a clear system architecture and a particular block diagram that shows the components and control flow.

A. System Architecture and Key Components

The system architecture is fundamentally built around four key components that enable the automation and smart detection features:

Robotic Platform (AGV – Automated Guided Vehicle): The physical mechanism in charge of the" Robotic Movement" goal is the Robotic Platform (AGV, Automated Guided Vehicle). The car is physically moved to and from its parking space by the AGV, which removes the need for human drivers inside the building.

Ultrasonic Sensors:

These are an essential component of the" Smart Detection"; goal. To measure distances, detect the presence of vehicles, and determine the boundaries of vacant parking spaces, they are either placed in the parking slots or utilized by the AGV. They supply the input required for compact positioning and safe navigation.

RFID Reader and Tags:

The” RFID based Retrieval” goal is addressed by this component. RFID tags are used to safely identify the user or the vehicle. In order to start the process of retrieving the appropriate vehicle, the RFID Reader receives the signal from the tag (based on user input).

Parking Slot Management Algorithm:

The” Allocation of Empty Slots” is managed by this clever software. It tracks the status (occupied/empty) of each slot in real-time and analyses the data from the sensors and reader to determine the best place to park a carjack the status (occupied/empty) of every slot in real-time

B. Parallel Parking

Backing into a gap between two parked cars while keeping your car parallel to the curb is known as parallel parking. To properly position the car, you must find a space that is roughly 1.5 times the length of your car and then make a number of reverse turns. To finish the park, you must pull up parallel to the car in front of you, reverse and turn towards the curb, straighten the wheel, and then turn away from the curb. Finding an appropriate spot that is at least 1.5 times the length of the car to ensure sufficient maneuvering room is the first step in the precise, multi-step process needed to execute parallel parking successfully. After positioning the car parallel to the car in front of the space while keeping a tiny lateral gap of roughly two feet, the driver must critically assess the area for safety. Turning and going into reverse are the first steps in the core maneuver.The steering wheel all the way to the curb while backing up gradually. Straightening the wheels and continuing to reverse until the car’s front edge clears the rear bumper of the vehicle in front of it instantly corrects this angle. Lastly, the driver must keep reversing until the car is parallel to the curb after turning the steering wheel completely away from it. The final step of the maneuver is to center the car in

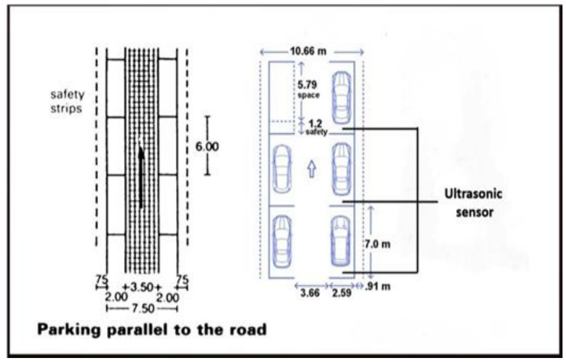

Fig. 1. Parallel parking

the space, no more than one foot away from the curb. Consistent practice is essential for success, as is keeping a slow, controlled speed and continuously using all of the mirrors to keep an eye on the vehicle’s position in relation to its surroundings. must turn the steering wheel fully away from the curb and continue reversing until the vehicle is parallel to the curb. The maneuver concludes by adjusting the position to center the vehicle in the space, leaving no more than one foot from the curb. For success, consistent practice is key, alongside maintaining slow, controlled speed and constantly utilizing all mirrors to monitor the vehicle’s position relative to the surrounding environment. When it comes to parallel parking, the biggest benefit of incorporating omnidirectional wheels, like Omni wheels, into an automatic car parking valet system is the total removal of the nonholonomic constraint present in traditional car steering. Conventional parallel parking necessitates a complicated, multi-step process that takes a lot of time and requires a lot of lateral clearance. It involves reversing, turning the steering wheel fully towards the curb, straightening the wheels, and then turning fully away (see the provided guide). By enabling the car to move laterally, or” crab” straight into the parking spot from the adjacent traffic lane, omnidirectional wheels eliminate this requirement. In comparison to any system based on traditional wheel technology, this not only makes parking instantaneous and single-motion, but it also significantly reduces the necessary maneuvering space, resulting in maximum packing density and far greater efficiency in high demand parking garages.

C. Block diagram

The block diagram of the Automatic Valet Parking Robot provides a clear graphical representation of how each component will work together to achieve automated, precise and collision-free operation. Navigating in a parking garage can be difficult because of many obstacles, but this system was designed to make it easy. The main controlling and processing

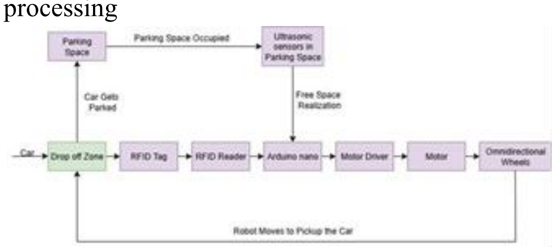

Fig. 2. Block Diagram of Automatic Valet Parking Robot

by dropping it off at its designated location. The drop-off

Figure 2. Block Diagram of Automatic Valet Parking Robot

unit of the system is the Arduino Nano, which receives information from both RFID readers and sensors and uses programmed logic to interpret that information. The Arduino then sends control commands to the motor driver module (L298N), which connects the low-power control signals produced by the Arduino with the high-current requirements of the motors. The motor driver also regulates the speed and direction of the DC geared motors attached to the robot via a mechanical connection to the omni-directional wheels. In addition to being able to drive straight or in reverse, the robot can move sideways and at any angle to avoid colliding with obstacles when it is in a tight parking space. The operation of the vehicle parking system can be broken down into individual components. These components include Power Distribution, Input Detection, Signal Processing and Motion Execution.

During the initial stage of the automated parking system, the driver parks their car on to the automated parking system location contains an RFID reader which acts as the portal for user/system communication and the start of the automatic parking system. To communicate with the RFID reader, the driver holds an RFID tag, which has a unique identification number programmed into it, and brings it close enough for the RFID reader to wirelessly scan the tag using 13.56 MHz frequency. Once the RFID tag is detected by the RFID reader, the RFID reader sends the data for the tag to the Arduino Nano through SPI (serial peripheral interface). After receiving the RFID tag data, the Arduino Nano checks whether the tag is an authorized user and performs the slot assignment for that driver's vehicle. The Arduino Nano also saves the relevant information for the system, including the RFID tag's identification number, the status of the assigned parking slot, and the location within the parking structure. In order to operate the moving parts of the robot, the Arduino Nano also provides the necessary data to control the DC geared motors through PWM (pulse-width modulation) signals via the L298N motor controller. Using these motors, the robot's movement is controlled very precisely by providing the required torque, and this is accomplished at very low speeds. Ultrasonic sensors allow the robot to navigate (i.e., detect obstacles and avoid crashes) and monitor its parking spots (i.e., whether the spot is occupied or empty). Together with the use of omnidirectional wheels, these capabilities give the robot the ability to move freely in many directions (i.e., up, down, left and right, in an arc or circularly) without having to turn the robot around. These features enhance the robot's manoeuvrability in confined spaces.

In addition to increasing the effectiveness and speed of the robot's operations, this coordinated approach allows for safe, highly efficient and touchless automated parking service

IV. WORKING MECHANISM

A. Working of Lifting Mechanism

The battery is what powers this robot's lifting mechanism. Both the robot's motor controller and DC-Lifting Motor receive support from a consistent amount of electric current and voltage that is produced by the battery. The battery allows the robot to achieve autonomous functionality (independent operation from an external power supply), while maintaining

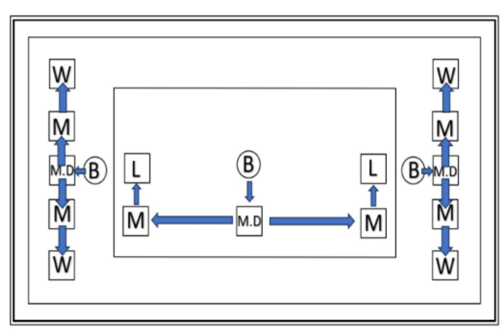

Fig. 3. 2D Model of the project

performance consistency when performing lifting tasks. A Motor Controller acts as an intermediary between low-power control signals produced by the microcontroller (in this case, an Arduino Nano) and the high-current demands placed on the lifting motor. The Arduino sends logic-level commands to the motor controller. The motor controller then regulates the flow of both voltage and current to the lifting motor so it can be controlled accurately with respect to the speed, direction, and torque required for lifting. The bi-directional functionality of the motor controller allows for the safe and accurate raising and lowering of the vehicle. The lifting motor will convert the electrical energy supplied by the motor controller to mechanical energy for the operation of the lifting mechanism. The lifting motor's torque will help create sufficient force to move the vehicle off or onto the lift.

B. Working of Wheel Motion

The electrical energy required for the valet parking robot to move is supplied by the 12V rechargeable battery. It ensures that the motors run smoothly under a range of load conditions by providing a steady voltage and enough current to power the motor driver. The Arduino Nano's low power control signals and the drive motors' high-current needs are interfaced by the motor driver (L298N). It gets PWM signals from the controller to control speed and direction, allowing the wheels to move forward, backward, and in all directions. During operation, the driver makes sure that the motors are precisely controlled and protected. The motor driver provides regulated voltage and current to the DC motors, which transform electrical energy into mechanical rotational motion. The omni-directional wheels receive this rotation and convert the motor motion into multidirectional movement. The robot has excellent manoeuvrability in confined parking spaces thanks to its omnidirectional wheels, which enable it to move forward, backward, sideways, or diagonally. The valet parking robot is able to navigate precisely and carry out automated parking tasks safely because of the coordinated flow from battery to wheels, which guarantees dependable, effective, and responsive motion control.

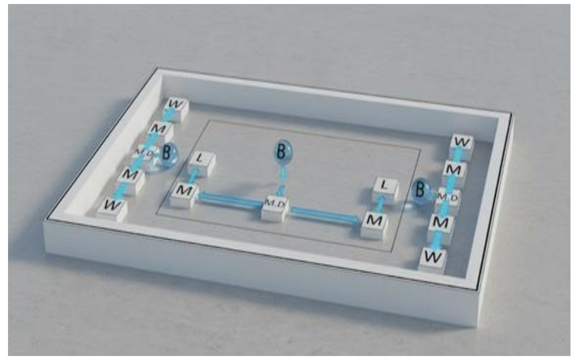

Fig. 4. 3D Model of the project

V. SUMMARY

In order to improve parking automation and user convenience, this paper describes the thorough design and development of an autonomous robotic valet parking system. The Arduino Nano microcontroller at the core of the system architecture controls a number of subsystems, such as RFID based user authentication and ultrasonic sensors for real-time obstacle detection. detection, as well as omnidirectional wheels for accurate and adaptable parking space manoeuvrability. The robot can now lift and move small objects thanks to a specialized lifting mechanism, expanding its capabilities beyond simple navigation. Compatibility, dependability, and affordability were given top priority when choosing components to guarantee an effective and scalable system design. In order to facilitate future integration, implementation, and performance assessment in real-world parking situations, this work creates a strong framework for autonomous valet operations. Compatibility, dependability, and affordability were given top priority when choosing components to guarantee an effective and scalable system design. In order to facilitate future integration, implementation, and performance evaluation in real-world parking scenarios, this work creates a solid framework for autonomous valet operations.

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