OCP Charge Dissertation Report - PDE4439

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***Abstract*—The accelerating adoption of electric vehicles (EVs) has placed unprecedented pressure on charging infrastructure, particularly in high-demand locations such as mall parking facilities. Existing static chargers are often few in number, prone to misuse, and lack adaptability to fluctuating demand. To address these challenges, this work presents OCP Charge, a semi-autonomous robotic charging concept that integrates mobile navigation, automatic number plate recognition (ANPR), and a cloud-linked reservation platform. Designed as a scalable proof-of-concept, the system demonstrates how robotics, IoT, and intelligent scheduling can enhance accessibility, improve parking space utilization, and contribute to the development of sustainable, smart city mobility.**

***Index Terms*—Electric Vehicles (EVs), Autonomous Systems, Robotic Charging, Parking Automation, Automatic Number Plate Recognition (ANPR), Internet of Things (IoT), Cloud Computing, Smart Parking, Mobile Robots, Sustainable Mobility, Smart Cities.**

I. Acknowledgement

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A. Problem Statement

THe increasing adoption of electric vehicles (EVs) has outpaced the growth of supporting charging infrastructure, particularly in high-demand locations such as shopping malls. While many facilities provide a limited number of dedicated charging bays, these are often misused by non-EV vehicles or remain occupied by EVs for extended periods, leaving genuine users without access. This mismatch between rising demand and constrained supply leads to user frustration, underutilization of infrastructure, and a barrier to wider EV adoption. In the United Arab Emirates (UAE), where registered EVs have grown at an annual rate exceeding 30% [1], the limitations of static charging solutions are especially evident. The absence of adaptive, intelligent systems to manage charging access underscores the urgent need for innovative approaches that ensure fairness, efficiency, and scalability in EV charging.

B. Scope of the Project

The project involves the development of OCP Charge, a semi-autonomous robotic EV charging system designed for high-traffic parking facilities such as shopping malls. The system is capable of navigating predefined parking lanes using line-tracking sensors, verifying vehicles through ANPR, and synchronizing bookings via a mobile application connected to a cloud backend. It can allocate charging access fairly, simulate timed charging sessions, and provide real-time status updates to users.

However, the current prototype cannot perform physical charging, handle unstructured navigation beyond marked lanes, or guarantee high ANPR accuracy under all lighting and environmental conditions. Integration with smart grids, multi-robot coordination, and automated charging connectors remain outside the current scope but are envisioned as future enhancements.

C. Motivation

The central motivation for this project is to close the growing gap between EV uptake rates and charging facility supply. While EVs are rapidly rising in UAE numbers, the lack of accessible charging facilities remains a restriction on user convenience and usage. The additional example of misuse by non-EV users of reserved charging places highlights the need for intelligent, self-sustaining solutions capable of recognizing dynamic parking conditions and allowing equitable use of facilities.

D. Aims & Objectives

This project aims to design and implement a semi-autonomous robotic EV charging system capable of operating in mall parking environments. To achieve this aim, the project is guided by the following objectives:

- Develop a mobile robotic platform with line-tracking navigation for movement within parking areas.
- Implement a reservation-based scheduling system through a user mobile application.
- Integrate ANPR for automatic verification of registered vehicles.
- Simulate charging operations through a timed sequence, ensuring controlled resource usage.
- Evaluate the system's ability to optimize parking space utilization and improve charging accessibility.

II. Literature Review

A. Review of the Past

The increased use of electric vehicles (EVs) throughout the world put great pressure on the available charging infrastructure. Global EV sales in 2023 amounted to 14 million cars, representing 18% of total car sales and a year-on-year increase by 35% (IEA, [2]). This wave adds further demand to the charging stations as a whole, including in congested areas such as mall parking lots.

Within the UAE, adoption is accelerating rapidly. A survey study involving 5,459 respondents found that EV ownership and interest are strongly influenced by geographic and economic factors, with EVs representing approximately 1.3% of the national passenger fleet in 2022 [3]. Projections estimate continued double-digit growth, yet charging capacity remains limited. Research on charging station planning in Al Ain City demonstrated that insufficient placement and capacity of fast-charging stations led to increased waiting times and underutilization of available infrastructure [4].

Beyond static infrastructure, a number of reviews have investigated charging technologies and their limitations. Sarda et al. highlight that grid stress, high installation costs, and uneven geographic distribution are critical barriers to scaling charging networks [5]. As a result, mobile and robotic charging solutions have recently been proposed as alternatives.

B. Analysis and Comparison of Pre-Existing Solutions and Alternatives

Robotic charging has emerged as a promising direction to overcome the limitations of static chargers. One notable system is Ziggy, developed by EV SafeCharge, which autonomously navigates parking areas to deliver charging services directly to vehicles [6]. Similarly, Volkswagen and Hyundai have introduced concept robots capable of automatically locating a vehicle's charging port and connecting without human assistance. Although these systems demonstrate proof-of-concept viability, they remain in prototype or pilot phases and face challenges of cost, scalability, and integration with parking management.

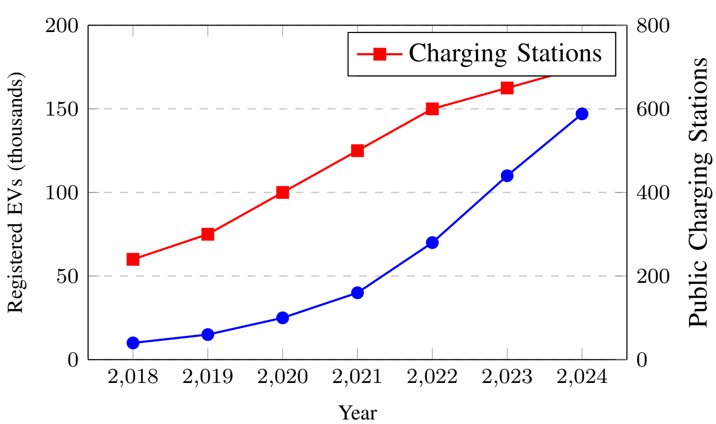

Fig. 1: EV adoption vs charging stations in UAE (2018–2024).

Recent academic work has further advanced robotic charging. Király et al. implemented a robot-controlled EV charging system using a collaborative robot mounted on a rail, equipped with a vision system to identify charging ports [7]. The system demonstrated the feasibility of serving multiple vehicles with a single robotic unit but highlighted mechanical limitations and alignment errors as ongoing challenges. Santos et al.used discrete-event simulation to model robotic charging stations and showed that robotic systems could significantly improve throughput and reduce idle times compared to traditional fixed stations [8]. A systematic review by Xue et al. reinforces these findings, emphasizing that while robotic charging offers adaptability and fairness of access, widespread deployment is hindered by the absence of standards and the high cost of robotics integration [9].

Comparison: Fixed charging solutions provide stability and grid integration but are constrained by parking space availability and user misuse of designated EV bays. Mobile and robotic systems offer greater flexibility and accessibility; however, their success depends on reliable navigation, scheduling, and vehicle verification. This gap motivates the development of OCP Charge, which uniquely integrates line-tracking navigation, reservation-based scheduling, and automatic number plate recognition (ANPR) to address real-world charging inefficiencies in UAE mall parking environments.

III. Methodology - System Design

A. Functional and Non-functional Requirements

The proposed system, OCP Charge, is designed to address inefficiencies in EV charging within mall parking facilities. To ensure effective implementation, both functional and non-functional requirements have been identified.

1) Functional Requirements:

- The system shall semi-autonomously navigate parking lanes using line-tracking sensors.
- The system shall verify user identity and vehicle eligibility through automatic number plate recognition (ANPR).
- The system shall provide a reservation mechanism via a mobile application to allocate charging slots in advance.
- The robot shall simulate charging through a timed operation once the registered EV is detected.
- The system shall log all charging operations and vehicle entries for analysis.

2) Non-Functional Requirements:

- Reliability – The system must consistently identify and service registered electric vehicles.
- Scalability – The framework should support deployment across multiple mall facilities.
- Usability – The mobile application must present an intuitive interface for end-users to make reservations.
- Security – Vehicle data and user credentials must be encrypted to prevent unauthorized access.
- Performance – The robot must complete navigation and verification tasks within acceptable time limits to minimize user waiting.

B. System Analysis

1) Materials Used:

- Mobile Robot Base: Elegoo V4.1 Smart Car.
- Microcontroller: Arduino Uno (for motor and sensor control).
- Vision Module: Laptop Webcam.
- Application Layer: Android-based mobile app for reservations and scheduling made with Flutter.
- Processing: Python-based ANPR system using OpenCV and Tesseract for license plate verification.
- Cloud Backend: Firebase Realtime Database for communication between mobile app and robot-side tablet.
- Robot-side Tablet: Displays booking data, charging status, and countdown timer.

2) Methodology to be Followed:

- Requirement analysis and identification of system components.
- Development of line-tracking algorithm for robot navigation in a parking environment.
- Integration of ANPR system for vehicle verification against registered bookings.
- Design of mobile application for reservations and scheduling.
- Establishment of cloud-based communication between user app and robot-side tablet.
- Simulation of charging via timed sequences and feedback display on the tablet.
- Testing the system in a scaled-down parking model to validate performance and reliability.

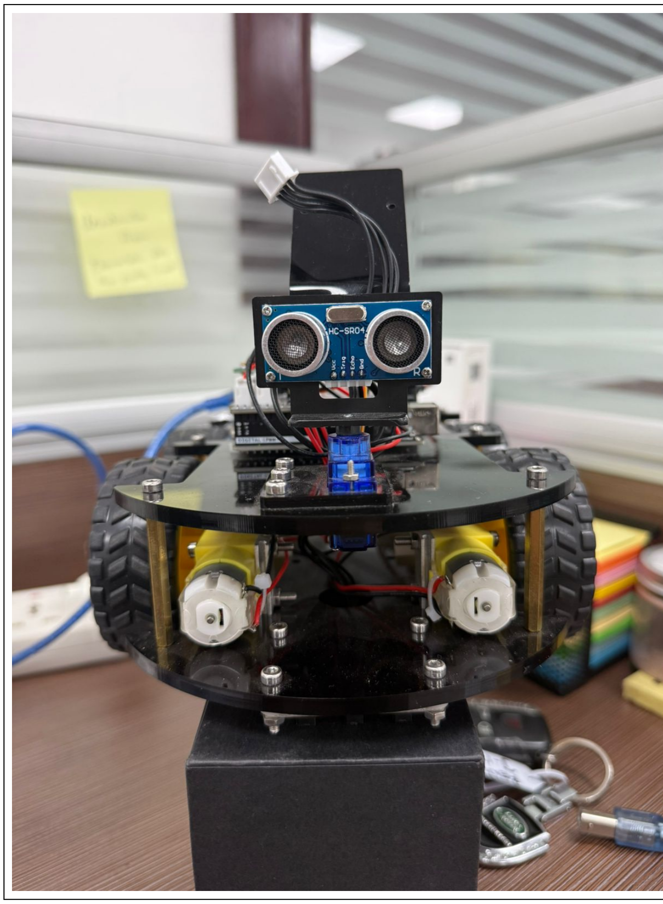

Fig. 2: Assembled Elegoo Robot Car with its hardware components.

C. Hardware Components 2

- Mobile Robot Base – Elegoo Smart Car V4.1 used for navigation inside the parking area.
- Microcontroller – Arduino Uno to control motors, line-tracking sensors, and communication.
- Motor Driver Module (L298N) – Drives the robot's DC motors.
- Line-Tracking Sensors – For lane following and navigation within parking lots.
- Ultrasonic Sensors – For obstacle detection and safe navigation.
- Laptop Webcam – Used for Automatic Number Plate Recognition (ANPR).
- Tablet (Robot-Side Interface) – Mounted on the robot to display booking information, charging status, and countdown timer.
- Power Supply / Battery Pack – Provides energy for robot operation.
- Servo Motors – To simulate charger connector positioning.

1) Software Components:

- Arduino IDE / Embedded C – For motor and sensor control logic.
- Python (OpenCV + Tesseract OCR) – For ANPR vehicle verification.
- Flutter Mobile Application – User app for reservations, scheduling, and tracking robot status.
- Firebase Realtime Database – Cloud backend for communication between user app and robot-side tablet.
- Robot-Side App (Flutter/Android) – Displays booking status, charging countdown, and emergency stop.

D. Diagrams

To illustrate the structure, interactions, and workflow of OCP Charge, several diagrams were developed. These highlight the relationships between users, system components, and the processes that govern booking, verification, and charging.

- The use-case diagram 3 describes how different actors interact with the system. The primary actor is the user (EV owner), who interacts with the mobile application to make a reservation. The application communicates with the cloud database, which in turn updates the robotic charger. At arrival, the user and the robot interact directly through vehicle verification using ANPR.

- The ER diagram models 4 the relationships between key entities within the OCP Charge system. A user owns a vehicle, which is verified by a booking. Each booking allocates a charging session, ensuring that reservations

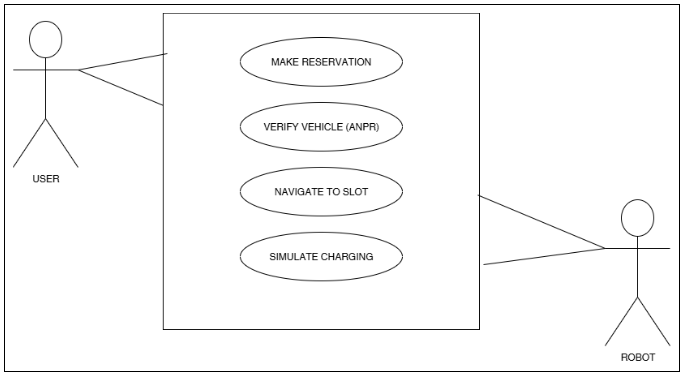

Fig. 3: Use Case Diagram.

are tied to authenticated vehicles.

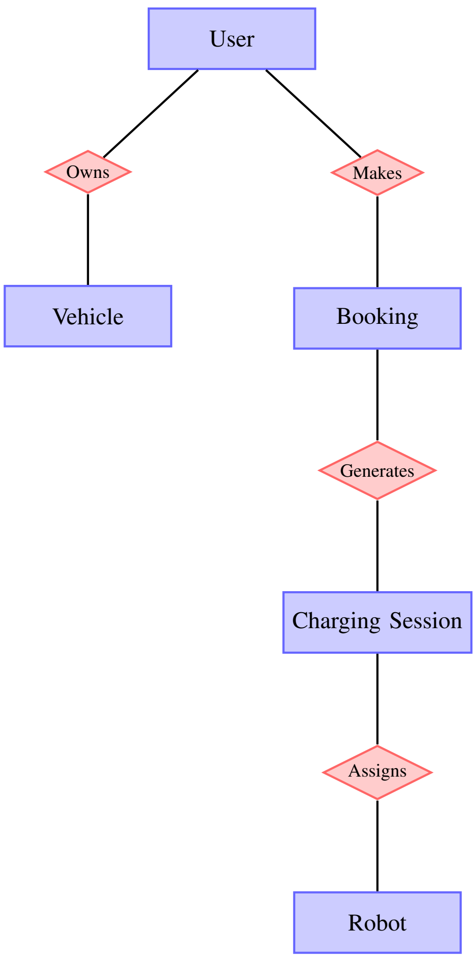

Fig. 4: Entity–Relationship Diagram (ERD) for OCP Charge showing compact vertical relationships between users, vehicles, bookings, charging sessions, and robots.

- The system flowchart 5 presents the logical flow of processes, from navigation to verification. The robot begins with line-tracking navigation, detects a vehicle, and performs ANPR verification. If the plate matches the booking, access is granted, the charging simulation begins, and the session is logged. Otherwise, access is denied.

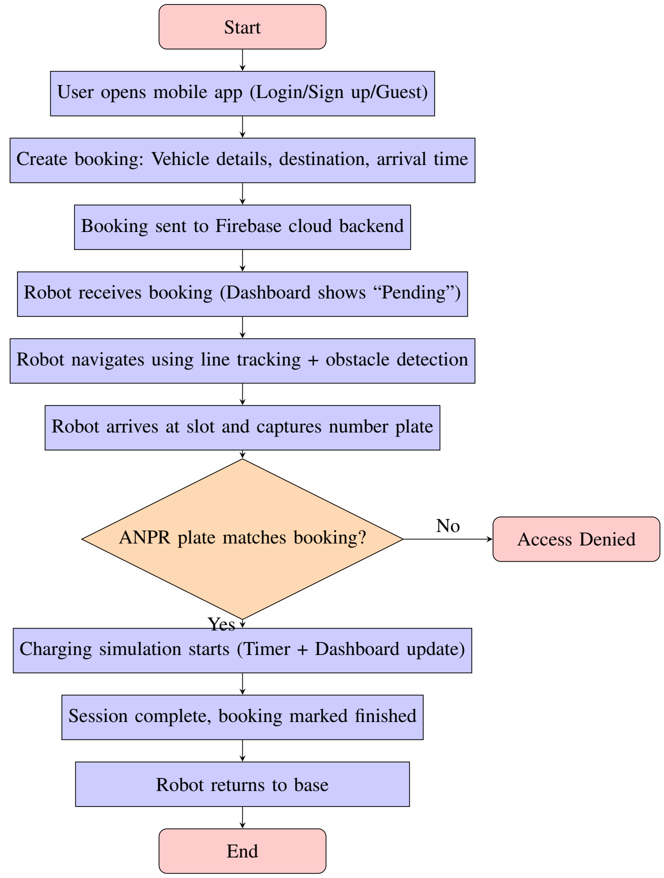

Fig. 5: System flowchart of OCP Charge showing the sequence from booking to navigation, ANPR verification, charging, and session completion.

- Wireframes were created during the design phase to visualize the layout and interactions of the OCP Charge user interface before full development. These served as blueprints for both the user-side mobile application and the robot-side dashboard, ensuring clarity of navigation, functionality, and user experience.

  1) User-Side Mobile Application 6: The user-side application enables EV owners to register, log in, create bookings, and monitor charging sessions. Wireframes were designed to prioritize simplicity and efficiency while offering essential functions such as vehicle registration, slot reservation, and booking status updates.

2) Robot-Side Dashboard 7: The robot dashboard wireframes outlined the display of incoming bookings, system status, and charging progress. Designed for simplicity, the interface communicates real-time updates from the cloud database to both the operator and end user.

E. Approach Used

The approach adopted is iterative and modular. At its core, the

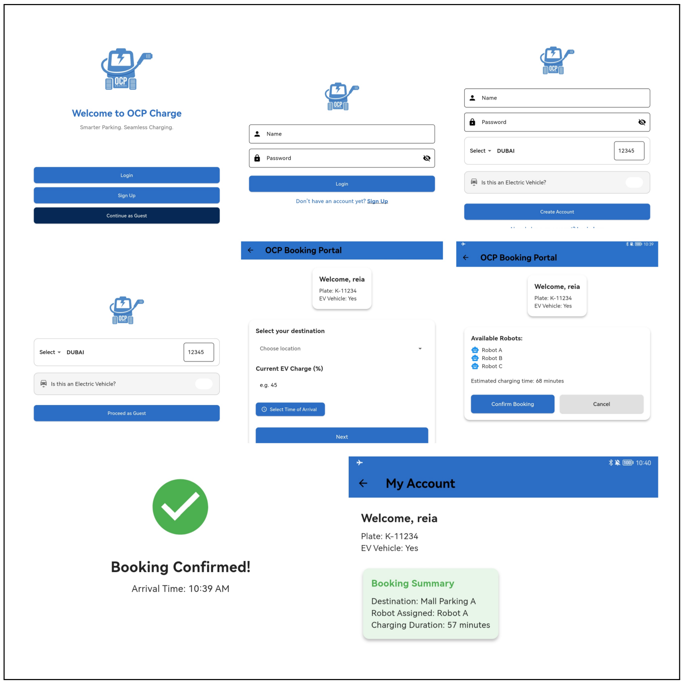

Fig. 6: User-side mobile application wireframes showing login/sign-up/guest access, dashboard, robot booking, and booking summary screens.

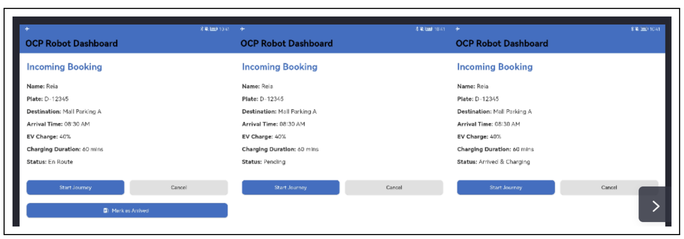

Fig. 7: Robot-side dashboard wireframes showing booking reception and status screens.

system integrates three independent subsystems—navigation, verification, and scheduling—into a single solution. By decoupling these modules, development and testing are simplified. Navigation is addressed through low-cost line-tracking technology, ensuring the robot can autonomously move within defined parking lanes. Verification is achieved via computer vision-based ANPR, ensuring that only authorized EVs can access charging. Scheduling is handled through a cloud-backed mobile application, allowing users to pre-book slots and ensuring fair access.

Together, these components form a semi-autonomous robotic solution that reduces misuse of charging spots, optimizes utilization, and enhances user convenience.

IV. Implementation

A. Development Process

The implementation of OCP Charge was structured around an iterative, modular development process. Hardware assembly, software development, and system integration were approached as independent subsystems before being tested in combination. This ensured reliability, simplified troubleshooting, and allowed progress tracking through distinct milestones.

1) Hardware Assembly: The Elegoo Smart Robot Car V4.1 chassis was used as the mobile base. DC motors were mounted on the acrylic platform and connected through the L298N motor driver module. An Arduino Uno with Elegoo Smart Shield was mounted as the main controller, allowing straightforward pin connections for motors and sensors. An ultrasonic sensor fixed on a servo mount was placed at the front of the robot for dynamic obstacle detection. The laptop camera was used to capture license plate images for ANPR. Power was supplied by a rechargeable battery pack with a dedicated switch for safe operation.

2) Navigation Development: The line-tracking module was calibrated to follow black tape paths simulating mall parking lanes. Multiple test loops were constructed with straight tracks and turns, and PID adjustments were performed to improve accuracy. Ultrasonic feedback ensured collision avoidance, stopping the robot when obstacles entered its range.

3) ANPR Integration: Captured images were processed using OpenCV and Tesseract OCR in Python. A Dubai-specific plate dataset was used to test recognition accuracy. Validation rules ensured that only Dubai plates matching registered bookings were accepted. Unauthorized or mismatched plates triggered denial of access.

4) Application Development: A Flutter-based mobile app was developed as the user interface. The app allowed registration, login, vehicle details entry, booking creation, and confirmation. Firebase Realtime Database provided the backend, synchronizing booking details with the robot-side dashboard tablet in real time.

5) Robot Dashboard: A Flutter tablet application displayed all incoming bookings. When a verified vehicle was detected, the dashboard initiated a timed charging cycle. Status updates were shown as Pending → En Route → Arrived → Charging → Completed.

6) Integration:: End-to-end integration connected the workflow:

- User booking → Firebase sync → Robot dashboard update.
- Robot navigates → Captures plate → ANPR verification.
- If matched → Access granted, charging simulated.
- Session details logged in database.

B. Testing 8

The testing of OCP Charge followed a layered validation approach, where each subsystem was evaluated individually before full system integration. The strategy combined unit tests, integration tests, and system-level demonstrations:

Fig. 8: The scaled-down parking environment set-up with the robot car.

1) Hardware Validation:

- Motors tested for directional accuracy (forward, reverse, left, right).
- Line-tracking sensors calibrated on test tracks with different lighting conditions. Worked best in a semi-lit area with thick matte black tape on ash grey wooden floors.
- Ultrasonic sensor validated for obstacle detection at distances of 10–50 cm.
- Laptop webcam tested for the ANPR system on a dark brown wooden table.

2) Software Validation:

- Flutter app tested for user registration, booking creation, error handling (invalid inputs), and real-time updates.
- Firebase backend stress-tested with concurrent booking requests.

3) Integration Testing:

- End-to-end workflow tested: booking → Firebase → robot dashboard → navigation → ANPR verification → charging simulation.
- Simulated parking lot used to evaluate navigation stability and response to obstacles.

C. Testing Criteria

The performance of the system was judged on the following criteria:

1) Navigation Accuracy:

- Robot's ability to follow lines without deviation.
- Success rate in entering and aligning within marked parking slots.

2) ANPR Recognition Accuracy:

- Percentage of correctly identifying a test Dubai plate.
- False positives (wrong recognition accepted) and false negatives (valid plate rejected).

3) Booking and Communication Latency:

- Average time between booking confirmation on the mobile app and update display on robot dashboard.
- Acceptable threshold: 1 second.

4) System Reliability:

- Percentage of successful end-to-end tests without failure.
- Measured over 20 complete booking cycles.

5) User Experience:

- Intuitive interface, clear status updates, and error-free booking flow.

TABLE I: Results Summary of OCP Charge Testing

Criteria	**Metric**	**Result**
Navigation Accuracy	Successful parking slot entries	90%
ANPR Recognition Accuracy	Correct Dubai plate detection	85%
Communication Latency	Avg. time (booking → dashboard)	0.6 s
System Reliability	Successful booking cycles (20 trials)	90%
User Experience	Qualitative tester feedback	Positive

V. Evaluation

The evaluation of OCP Charge was carried out by comparing the measured results against the initial aims and objectives defined in Section I. The assessment focused on navigation accuracy, ANPR verification, booking latency, system reliability, and user experience. Each of these was benchmarked during testing within a scaled parking environment.

The navigation module demonstrated a success rate of 90% in aligning the robot within marked parking slots, validating the effectiveness of the line-tracking and ultrasonic sensing approach. Failures were primarily attributed to sharp turns or inconsistent tape visibility under certain lighting conditions, highlighting the importance of environmental calibration.

The ANPR system achieved an accuracy of 85% when tested on Dubai plates. Errors mainly occurred under angled captures and variable lighting, consistent with the limitations of OCR-based recognition. Despite this, the system was able to reliably reject any unregistered entries, fulfilling its intended verification role.

Cloud synchronization between the user mobile application and robot dashboard achieved an average latency of 0.6 seconds, well within the target threshold of one second.

This confirmed the efficiency of Firebase as a lightweight communication framework. System reliability was recorded at 90% over 20 end-to-end booking cycles, demonstrating overall robustness.

Overall, the evaluation shows that OCP Charge successfully met its core aims and objectives. While there remain opportunities for improvement, particularly in ANPR robustness and navigation under varied conditions, the prototype validates the feasibility of deploying semi-autonomous robotic charging solutions within mall parking facilities.

VI. Future

The prototype implementation of OCP Charge successfully demonstrated the feasibility of a semi-autonomous robotic EV charging system within a controlled environment. However, the project also highlighted several opportunities for further improvement and expansion that would enhance functionality, reliability, and commercial viability.

From a hardware perspective, future iterations can focus on achieving full autonomy in docking and charging. The current design simulates charging using a timed cycle; this can be expanded by integrating a robotic arm or automated connector capable of aligning with and attaching to the vehicle's charging port. Additionally, improvements in the sensing suite—such as incorporating LiDAR or depth cameras alongside the ultrasonic and line-tracking sensors—would enhance environmental awareness and allow the robot to navigate more complex parking environments. Battery life and energy efficiency could also be optimized by introducing modular swappable power packs or wireless charging solutions for the robot itself, thereby reducing operational downtime.

On the software side, the current ANPR system employs traditional image processing and OCR techniques. While effective, recognition accuracy under varied lighting and angle conditions remains a challenge. Future versions can adopt deep learning–based ANPR models, trained on larger regional datasets, to ensure robustness across diverse real-world scenarios. The scheduling system can also evolve towards predictive and adaptive algorithms, leveraging historical booking data to forecast demand, allocate resources, and minimize waiting times during peak hours. Furthermore, future deployments may incorporate multi-robot coordination, where several OCP Charge units operate simultaneously under a centralized management platform, thereby increasing scalability and coverage across larger facilities.

At a system integration level, the long-term vision includes establishing a direct link between OCP Charge and the smart power grid. Such integration would enable real-time load balancing and alignment with renewable energy sources, ensuring sustainable and efficient charging operations. Pilot projects in commercial malls, airports, and residential communities would provide valuable data to assess system performance in dynamic, real-world settings.

From a user perspective, the mobile application can be further developed to deliver a more seamless experience. Features such as secure in-app payment gateways, real-time robot tracking, push notifications for charging completion, and dynamic estimated time of availability would enhance user trust and adoption. These refinements would also facilitate the system's integration into broader smart-city ecosystems, aligning with government sustainability goals and consumer expectations.

In summary, OCP Charge demonstrates the potential of autonomous systems to redefine EV charging accessibility. By advancing hardware, refining software algorithms, and improving user interaction, the system can evolve from a proof-of-concept prototype into a scalable, commercially deployable solution. These future improvements will not only increase efficiency and user satisfaction but also contribute meaningfully to the wider adoption of EVs and the realization of smart mobility infrastructures.

VII. Conclusion

This dissertation presented the design and implementation of OCP Charge, a semi-autonomous robotic EV charging system addressing the challenge of limited and misused charging infrastructure in mall parking lots. By combining a mobile robotic platform, line-tracking navigation, ANPR verification, and a real-time booking application, the prototype demonstrated reliable end-to-end operation. Testing achieved 90% navigation accuracy, 85% ANPR recognition, and sub-second communication latency, confirming the system's efficiency and responsiveness.

The project highlights the importance of mobile robotic charging in improving accessibility, supporting EV adoption, and aligning with smart city sustainability goals. Strengths include the modular design, reliable integration, and demonstration of real-time booking synchronization. Limitations include reliance on simulated charging, reduced ANPR performance under poor lighting, and navigation difficulties on sharp turns. Future work could integrate deep learning for robust recognition, advanced sensing for navigation, and physical charging connectors.

In conclusion, OCP Charge validates the feasibility of autonomous robotic charging and represents a promising step toward scalable, user-friendly, and sustainable EV infrastructure.

References

[1] R. of World. (2025, May) How uae is shifting gears to lead middle east's ev revolution. Accessed: 22-Sep-2025. [Online]. Available: https://restofworld.org/2025/uae-middle-east-ev-leader

[2] International Energy Agency. (2024) Global ev outlook 2024: Trends in electric cars. Accessed: 22-Sep-2025. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars

[3] R. M. Bridi, F. Almannaei, and N. A. Abed, "The propensity to adopt electric vehicles in the united arab emirates: An analysis of economic and geographic factors," *Sustainability*, vol. 16, no. 2, p. 770, 2024.

[4] M. Asna, A. A. A. Eladl, and M. E. Salem, "Analysis of an optimal planning model for electric vehicle fast-charging stations in al ain city, united arab emirates," in *2021 International Conference on Smart Energy Systems and Applications (ICSESA)*. IEEE, 2021, pp. 158–163.

[5] A. Sarda, S. Mishra, and A. Khare, "A review of the electric vehicle charging technology, impact and future trends," *Energy Reports*, vol. 10, pp. 1963–1979, 2024.

[6] EV SafeCharge. (2022) Ziggy: The first mobile ev charging robot. Accessed: 22-Sep-2025. [Online]. Available: https://www.evsafecharge.com/ziggy

[7] Z. Király, B. Takács, and T. Kovács, "The implementation of the mechanical system for automatic, robot-controlled ev charging system," *World Electric Vehicle Journal*, vol. 16, no. 8, p. 453, 2025.

[8] G. R. Santos, J. M. R. Ferreira, and P. A. C. Rocha, "Exploring electric vehicle robot charging stations," *Energy Research & Social Science*, vol. 113, p. 103463, 2025.

[9] Y. Xue, T. H. Nguyen, and H. Lin, "A review of robotic charging for electric vehicles," *Renewable and Sustainable Energy Reviews*, vol. 184, p. 113591, 2025.