Design of Energy Charging Nodes for a Shared Economy

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***Abstract* - Consequent of the deficiency in infrastructure for charging Electric Vehicles (EVs), range anxiety continues to be a key obstacle in adoption. This project proposes the creation of an energy charging ecosystem to address this problem and boost EV adoption. To give EV owners easy access to charging stations, our approach concentrates on building a network of interconnected charging nodes that are outfitted with user identification and billing capabilities. Using GPS modules integrated with Raspberry Pi, the charging nodes will be found and localized, guaranteeing precise mapping of EV stations to our users. Secure facial recognition will be used to authenticate users, utilizing Computer Vision and Machine Learning algorithm(s). This eliminates the need for passwords and greatly improves security and user convenience. Billing services will also be seamlessly incorporated into the charging nodes, using Radio Frequency Identification (RFID) technology for simple payment processing. The design process and methodology are further buttressed in the sections contained in this report, along with how it contributes to the reduction of range anxiety, boost EV adoption, encourages EV adoption, and helps solidify electric transportation in our shared economy through charging infrastructure.**

***Keywords:* Electric Vehicles (EVs), GPS, Raspberry pi, Facial Recognition, RFID, Machine Learning.**

I. INTRODUCTION

The transition to electric modes of transportation, including Electric Vehicles (EVs), E-bikes, and E-Scooters, has gained significant momentum due to the increasing demand for greener and more sustainable mobility solutions. However, one of the major concerns that hinder the widespread adoption of EVs is range anxiety, which is the fear of running out of battery charge and being stranded without an option to recharge.

To address this challenge and promote EV adoption in our shared economy, this project aims to develop a comprehensive solution that integrates energy charging nodes with authentication and billing capabilities.

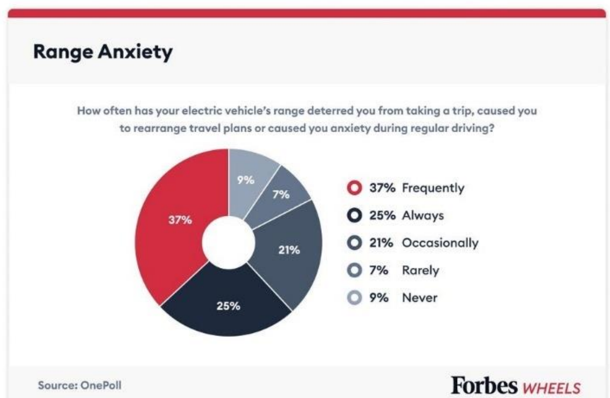

Figure 1: Survey by *Forbes Wheels* and OnePoll on EV drivers' recent experiences with range, charging and operational costs [1].

The motivation behind this project stems from the need to alleviate range anxiety and enhance accessibility to charging infrastructure for electric modes of transportation, specifically EVs. Research indicates that the number of EVs on the road is projected to increase exponentially in the coming years, emphasizing the urgency to establish a reliable network of charging stations.

By implementing energy charging nodes equipped with authentication and billing

mechanisms, EV owners can have access to convenient and secure charging services,
fostering trust and confidence in the shared economy.

The primary goals of this project are as follows:

→ To design and develop a prototype charging node system using Raspberry Pi.
→ To implement robust authentication measures, ensuring only authorized users can access the charging nodes.
→ To integrate a billing system that enables convenient payment processing for charging services based on time and energy consumption.

All of which enhances access to charging infrastructure and helps to minimize range anxiety and support the growing number of electric modes of transportation.

1.1. Contributions

This project offers several contributions to the field of electric transportation and the shared economy:

1. A prototype charging node system that provides real-time information on the availability and proximity of charging stations, improving the accessibility of charging services for EV owners.

2. Implementation of facial recognition as a secure and user-friendly authentication method, ensuring only authorized individuals can access the charging nodes.

3. Integration of Radio Frequency Identification (RFID) technology as a method of billing, enabling easy and seamless payment transactions for EV charging services.

1.2. Overview of the Next Sections

The subsequent sections of this report provide an in-depth analysis of the proposed solution plan. The sections include a detailed explanation of the charging node design, the authentication process utilizing facial recognition, and the integration of the billing system using RFID technology. Additionally, the report presents the methodology employed for the design and implementation, as well as experimental works, including test plans and results, to validate the effectiveness and performance of the proposed solution.

The following sections are covered in this report:
a). Literature Review: This section will provide a concise overview of the existing research, arguments, and established knowledge related to the topic of energy charging nodes for the sharing economy.
b). Requirements: Defines the design requirements for the charging ecosystem, including location-based services, compatibility with various EV models, and authentication and billing capabilities.
c). Solution Plan: Outlines the proposed solution, including the design of charging nodes, the implementation of facial recognition for authentication, and the integration of an RFID-based billing system.
d). Methodology (Design & Implementation): Details the approach taken for designing and implementing the solution, including the use of Raspberry Pi boards, computer vision, and deep learning techniques.
e). Experimental Works (Test Plans and Results): Presents the test plans conducted to validate the functionality and performance of

the proposed solution, along with the corresponding results.

By addressing the range anxiety concerns and enhancing access to charging infrastructure, this project aims to tackle the problem of range anxiety and boost a wider adoption of electric modes of transportation in the shared economy, thus, promoting a greener and more sustainable future.

II. LITERATURE REVIEW

Electric modes of transportation have long been a part of our history since the 1800s, although they were never mainstream or widely adopted.

Today, they are no longer novel and have evolved through time integrating various technologies and innovative approaches to get to what we drive on our roads now. Electric modes of transportation are here to stay and gradually becoming the norm as the push for greener consumption prevails and the move towards a more sustainable future becomes imperative. From E-Scooters to E-Bikes and Electric Vehicles (EVs), there are options to transport people to their destination in our very shared economy. For EVs, just as with any change or emerging technology, there is resistance which poses barriers to its adoption.

Research shows that as of 2023, there are approximately 26 million EVs on the road worldwide and this number is projected to grow over 240 million by 2030 [2]. This data shows that EVs are only 1.8% of the 1.446 billion total vehicles around the world in 2023 [3]; this is partly because vehicle owners are apprehensive about switching from an Internal Combustion Engine (ICE) Vehicle to an EV or purchasing an EV as a prospective vehicle owner.

Vehicle owners expressed concerns with owning an EV with the cost of EVs and range anxiety being the top two major barriers to EV adoption. Range anxiety is a fear that an electric vehicle would not be able to successfully get one to their destination before running out of battery and leaving one stranded. These individuals strongly believe that an EV would not be able to meet the demands of their daily lives. As much as 40% of potential EV owners still express high levels of range anxiety and 43% feel uncertain about being able to charge their vehicles when they need to [2].

This fear is largely due to the infrastructural impediments that plague EVs as the charging infrastructure needed to accommodate the exponential growth of EVs is limited and not keeping pace at this time. Although EV owners can invest in having EV chargers at home, it has been determined that having readily accessible public chargers would be instrumental in supporting EV growth and widespread adoption [2]. Pragmatically, range anxiety is more psychological than it is practical. Nowadays, the available EV offerings from various auto manufacturers are designed to seamlessly integrate into our daily lives and they do the job perfectly, some even outperforming their ICE counterparts.

There are debates that highlight other factors to be considered like the speed of charging, availability of charging stations, and finding the time to charge that comes with owning an EV. All these factors can be considered based on an individual's lifestyle and the human's ability to catastrophize situations. On average, a vehicle spends 96% of its time being parked, which begs the question, how much range is really needed?

III. REQUIREMENTS

The objective of this project is to minimize range anxiety and boost Electric Vehicle (EV)

Adoption by creating a network of connected charging nodes that is easily accessible and readily available for EV owners. To achieve this, there are design requirements that the charging ecosystem should meet to satisfy the needs of EV owners. These requirements include.

→ The location of charging stations *(nodes)* should be made available to the EV driver in real time based on proximity.

→ A mobile sensor (GPS) should be used to monitor the current location of the driver and the EV to determine the closest charging nodes available for charging.

→ The user ultimately decides the destination to charge their EVs after the nearest locations have been broadcast.

→ The ecosystem should be equipped with datasets of charging nodes available in the Kitchener-Waterloo-Cambridge regions.

→ EVs and available charging nodes on the network should be compatible. Different EVs on the network have varying charging needs therefore, different types of charging nodes such as level 1 and level 2 nodes should be present.

→ Charging nodes on the network should be equipped with authentication and billing capabilities to ensure adequate security on the network, i.e., only authorized users can access and utilize the ecosystem.

IV. METHODOLOGY

In the ideation phase of the design process, qualitative research was conducted to comprehensively understand existing solutions to the problem of range anxiety. Our approach breaks down implementation into three distinct elements – the charging nodes, user authentication, and a billing mechanism.

A. Charging Nodes

The charging ecosystem's objective is to alleviate range anxiety and drive EV adoption through a user-friendly GPS-based system. GPS, or Global Positioning System, is a satellite-based navigation network that allows users to determine their precise location on Earth. The charging nodes' GPS coordinates are stored in a database accessible to the system, and when an EV owner searches for nearby charging stations, their mobile GPS sensor determines their current location and guides them to the nearest available charging nodes in the Kitchener-Waterloo-Cambridge regions.

GPS modules, small electronic devices in EVs and smartphones, receive signals from GPS satellites. By triangulating signals from at least four satellites, the GPS module accurately calculates the user's position. The system continuously updates the user's location as they move, providing real-time information. Integrating GPS modules into the charging ecosystem enhances accessibility and convenience, easing range anxiety and fostering the widespread adoption of electric vehicles in the region.

B. User Authentication

To ensure the security of charging stations and protect sensitive user information, it is crucial to implement an effective identification solution. This project proposes the use of facial recognition technology as a secure and easily configurable method for authorizing drivers and authenticating transactions at charging stations. Facial recognition offers several advantages over traditional password-based systems, as it eliminates the risk of compromised passwords and provides a convenient and efficient user experience.

To achieve a robust facial recognition system, the proposed approach involves utilizing Computer Vision and Deep Learning techniques. These methods enable accurate and reliable identification even in challenging scenarios such as variations in facial pose and lighting conditions. The system employs a convolutional neural network to extract face encodings, which capture unique features of individuals' faces. These encodings are then compared with the database of authorized users to authenticate their identities.

C. Billing Mechanism

The billing aspect of the infrastructure is a very crucial element that enables EV drivers to successfully utilize the charging nodes after authentication. Without billing, users on the network cannot complete the required process to charge their vehicle(s). Various billing options such as cryptocurrency, tokens, and electronic funds transfer, were considered and each presented limitations either in implementation or for the users.

A billing mechanism that would offer our users topmost security and convenience was paramount in the selection process. These two features were the most important factors of consideration for this element of the network. Radio Frequency Identification (RFID), which relies on radio frequency energy to transmit data and information, was chosen as the preferred billing option; as this method would provide our users with contactless, fast, and very secure payment.

With all three elements of our infrastructure clearly outlined, the next phase involved system integration. Below are the initial concepts developed through iterations which were refined to formulate our final design approach.

Concept 1

The initial concept involved a GPS module integrated as a stationary sensor at charging nodes and continuously broadcasting the location of that node to other nodes on the network. Multiple GPS modules would be used at different node locations and as the driver approaches, these nodes would send their location data to the driver registered on the network. The driver can then select whichever node they would like to use on the network. In this concept, there are no predefined locations, and the vehicle receives real time coordinates from the charging nodes on the network.

Concept 2

In an iteration of concept 1, we developed the following concept that involved acquiring existing location data (longitude and latitude) of charging stations that can be input into our system to create a network of charging nodes. In this implementation, the GPS is used as a mobile sensor node inside the Electric Vehicle that is in motion.

With a predefined data set, these nodes serve as anchor nodes with known locations that can be used to estimate the location of the mobile node. As the EV driver approaches, using the known location of the anchors and location data from the mobile sensor (GPS), the distance from the driver to the three closest charging nodes would be calculated using trilateration and the final distance would be displayed to the driver to select a desired charging node destination.

Concept 3 (Proposed Framework)

A. Charging Node

To implement the proposed framework for the charging ecosystem, we utilize a GPS-based system along with Blynk and gmplot libraries to enhance user experience and accessibility. The objective is to provide real-time information to drivers on the network about nearby charging nodes and displaying the locations on a map.

The core functionalities of the proposed framework are as follows:

I. *GPS Data Collection*

The system uses a GPS module connected to a serial port to collect GPS data, including latitude, longitude, and altitude. The collected data is parsed using the pynmea2 library, ensuring accurate and reliable location information.

II. *Map Visualization*

To display the charging nodes and the user's current location, the gmplot library is used. The system generates a Google Map plotter and adds pre-defined charging node markers with their respective names. Additionally, it adds a dynamic marker representing the user's current location.

III. *Blynk Integration*

The Blynk library facilitates the integration of the charging ecosystem with the Blynk platform. The user's latitude and longitude are updated on Blynk's virtual pins, enabling remote access to location information through the Blynk app or dashboard.

IV. *User Interface*

The charging ecosystem creates an HTML file displaying the map with charging node markers and the user's location marker. This file is automatically opened in the web browser for easy access.

V. *Real-time Update*

As the user moves, the GPS data is continuously collected and updated, providing real-time information about the nearest charging nodes.

The proposed framework's seamless integration of GPS technology, Blynk, and gmplot allows EV owners to access the nearest charging nodes efficiently, reducing range anxiety and fostering the widespread adoption of electric vehicles in the Kitchener-Waterloo-Cambridge regions. Additionally, the Blynk integration offers remote monitoring and access to location information, enhancing the overall user experience and convenience.

B. Authentication

This section outlines the methodology employed to develop the proposed facial recognition-based authentication system for charging stations. It describes the approaches, methods, processes, and procedures used to design and implement the framework.

I. Research Conducted

The research involved exploring existing facial recognition systems and leveraging computer vision and deep learning techniques. The objective was to identify the most effective and secure approach to implement facial recognition-based authentication for charging stations.

II. Framework Development

a. Dataset Collection: A dataset of facial images as of now was prepared with the images of the team members. These images were captured using a video stream from a webcam and stored in the "dataset" folder.
b. Face Detection and Encoding: The OpenCV library and the haarcascade_frontalface_default.xml model were used to detect faces in the collected images. For each detected face, facial encodings were computed using the face_recognition library.
c. Model Training: The collected face encodings, along with their corresponding

names, were used to train the facial recognition model. The train_model.py script processed the dataset, extracted facial embeddings, and associated them with the names of the authorized individuals.

d. Model Serialization: The trained facial recognition model, including the encodings and associated names, was serialized, and saved in the "encodings.pickle" file. This file served as the database for the authentication system.

III. System Implementation

a. Real-time Face Recognition: The facial_req.py script was developed to implement the authentication system. It utilized the serialized encodings from the "encodings.pickle" file.

b. Video Stream Processing: The system utilized the VideoStream class from the imutils library to capture video frames from a webcam in real-time. The frames were resized to a suitable resolution to improve processing speed.

c. Face Detection and Comparison: The system employed the face_recognition library to detect faces in each video frame. The detected faces were then compared against the stored face encodings from the "encodings.pickle" file to determine the individuals' identities.

d. Authentication Status Display: The system displayed the authentication status on the screen by overlaying the recognized person's name and an appropriate message indicating whether authentication was successful or unsuccessful.

C. *Billing*

This project utilizes Radio Frequency Identification (RFID) system as a method of payment for the charging ecosystem.

The charging nodes would be equipped with RFID readers that would enable users on the network with integrated RFID tag(s) on their payment cards to complete payment in an efficient and easy manner. After successful authentication, users will be directed to a secure billing gateway that provides universal payment options to complete their payment. Depending on the duration of charge and the cost per charge at a node location, the final payment amount will be calculated and deducted from the user's payment account after the card is tapped and data is read and transferred.

Data stored on RFID tags can be changed, updated, and locked. This is important because it provides an extra layer of security for our users on the network. For example, when a registered driver on the network misplaces their payment card or the card gets stolen, the driver can lock their card to ensure no unauthorized payments go through. Overpayments can also be refunded as needed.

Each RFID tag contains a unique identifier in the tag's memory and this unique information is used to verify the identity of a user during payment.

Data flow of a payment transaction is as follows:

- → User is directed to billing gateway after authentication.
- → The charge amount is displayed for user confirmation.
- → Upon confirmation, the user taps card on reader which transmits this amount to be deducted from the tag.
- → On tap, the unique identifier stored on the tag's memory is checked to verify that the authenticated user is the right owner of the payment card.

→ Once verification is complete, the charge amount is transmitted and deducted from the user's payment account.

V. EXPERIMENTAL WORKS

With predefined location data stored on the network, the EV driver can visualize charging nodes within a 5km range distance from their current location. This was tested by localizing the driver on Google Maps and varying the range distance by kilometers to observe how responsive the system is. The results from testing demonstrated that nodes within the tested ranges 5km – 10km are displayed to the driver once they are connected and logged into the system.

In our authentication experiment, three methods were tested:

A). Password-based authentication:

→ Commonly used but vulnerable to password leaks and weak password choices.

B). Biometric authentication using fingerprint recognition:

→ Secure, but hardware compatibility issues were observed in some situations.

C). Biometric authentication using face encodings:

→ Highly effective and user-friendly.

→ Utilized existing user pictures for readily available face encodings.

→ Real-time face detection through a camera and accurate matching.

→ Users instructed to face the camera with straight eyes and a forward-facing posture.

→ Provided a smooth and accurate user experience.

Results - The two-factor authentication system, consisting of credential-based login followed by facial recognition, successfully combines security and user convenience. The implementation showed enhanced protection against unauthorized access and proved to be an effective and reliable means of authentication.

To facilitate billing, cryptocurrency and other forms of digital currencies were tested and these options posed certain limitations. These forms of payment run on blockchain technology which demands a level of technical complexity that was not accessible for the duration of this project. There is also not a mass adoption of this form of payment which would greatly limit the number of users we can have on the network.

To ensure a simplified solution while maintaining a secure and trustworthy method of payment, an RFID System was employed. Multiple tests were run on the system to ensure that only authenticated users with a valid method of payment can successfully utilize the charging nodes on the network to charge their EVs.

VI. CONCLUSION

Great progress was made with prototyping and testing the charging node ecosystem. With time and resources made available, the system can be further refined to enhance user experience and expand to local areas and regions across Canada.

Electric Vehicle transportation is here to stay and cultivating an environment to boost its adoption is a step on the right track for a more sustainable future.

A. *Future Work*

1. *Expansion to More Areas*

To increase accessibility and promote the adoption of electric vehicles, it is crucial to expand the charging node network. Identifying strategic locations for setting up new charging nodes based on demand, population density, and transportation infrastructure will be vital. By gradually expanding to more areas in Ontario and subsequently across Canada, we can cater to a wider user base.

2. *Compatibility with Different Charging Types*

Different types of vehicles utilize various charging standards, such as CHAdeMO, CCS, or Tesla Superchargers. To accommodate this diversity and provide convenience to users, charging nodes should be compatible with multiple charging standards. This can be achieved by installing different connectors or providing adapters, ensuring that all types of electric vehicles, e-bikes, and e-scooters can be charged seamlessly.

3. *Integration with Mobile Apps and Navigation Systems*

Developing a dedicated mobile application will enable users to easily locate nearby charging nodes, check availability, and reserve charging spots. Integration with popular navigation systems like Google Maps or Apple Maps will provide real-time information on charging station availability and directions to the nearest charging point. This seamless integration enhances user experience and encourages wider adoption.

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