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An IoT-based Eco-Parking System for Smart Cities

Ibrahim Tamam
Department of Computing and Mathematics
Manchester Metropolitan University
Manchester, UK
ibro.ateya@icloud.com

Shen Wang
School of Computer Science
University College Dublin
Dublin, Ireland
shen.wang@ucd.ie

Soufiene Djahel
Department of Computing and Mathematics
Manchester Metropolitan University
Manchester, UK
s.djahel@mmu.ac.uk

***Abstract*—Advanced Parking Management Systems, representing an essential part of modern transportation systems, are being designed to improve key challenges facing the transportation industry in metropolitan cities. Long commuting times, high congestion levels, and extreme carbon emissions have led researchers to focus on tackling these critical challenges facing our everyday living. This paper aims to design green parking and a truly sustainable solution that reduces CO2 emissions, congestion, and commuting times. This is achieved by developing a proof-of-concept of an original IoT-based and eco-friendly parking system. This system, named Eco-Parking, uses a tag or mobile application for parking id authentication, relies on IR sensors to monitor the real-time parking space availability using MQTT, and allocates the car park space according to vehicular emission class (Equa Index).**

***Index Terms*—Parking, Internet of Things (IoT), Smart Cities, Eco-Parking**

I. Introduction

Fast-paced technological progress within urban development is a key factor in the recent transportation industry growth. This pace developed a reciprocating dependency between the future technological and transportation systems development. Over the last 40 years, the proportion of people having driving licenses in the UK has increased [1], directly affecting the increase in worldwide car production every year since 2010, as highlighted by Statista. Parking, as an evident part of the transportation sector, has evolved into an independent field of innovative research, especially in congested metropolitan cities. However, innovative car park systems are not a recent transportation industry novelty. The first multi-storey car park system dates to 1901 when the City and Suburban Electric Carriage company opened a multi-storey car park system that used lifts over seven floors to carry vehicles [2].

The significant increase of car ownership in recent years and the rise of mega cities around the world led to an urgent need in developing smart and efficient parking management systems to cope with the unprecedented demand on parking spaces. According to the UK's National Travel Survey 2018[1], 42% of commuters reported difficulties driving to work caused by traffic congestion, road works or lack of parking facilities. The challenges and problems of Advanced Parking Management Systems (APMS) differ depending on the location, but they are all focused around commuting time, CO2 emissions and traffic congestion. This is also suggested in a study by C. Shoup [3] which shows that cruising for parking in a small business district in the US creates an excess of 950,000 vehicle mile travel which is equivalent to 720 tons of CO2 emissions. This study suggests as well that 30% of traffic is caused by cruising for parking. Therefore, it is necessary to develop innovative APMSs suitable for the specific needs of metropolitan cities.

In order to solve the challenges presented by the parking industry, many existing solutions rely on the image recognition technologies [4] for authentication and reservation systems [5] to balance the demand. The limitations of such systems include unstable car recognition results under extreme conditions (e.g. evening, rainy days) and lack of adaptation to the real-time supply and demand changes. Smart city solutions integrated with the Internet of Things (IoT) technology play a major role in improving car parks management and traffic control strategies. With the capability to provide real-time monitoring data, such an innovative system can tackle problems with current systems in regard to convenience, congestion, urban mobility, lower costs and the delivery of practical information and intelligence. Therefore, we introduce in this work an innovative concept for car parks management named Eco-Parking which uses IoT technology (i.e. infrared reflective (IR) sensors) to monitor the real-time car park spaces availability using Message Queuing Telemetry Transport (MQTT) [6] and cars' CO2 emissions information as a metric for parking space allocation. A mobile app is also developed and linked to the prototype hardware so that drivers can see their entry and exist time from the car park and the corresponding cost to be paid etc. This Eco-Parking concept is implemented in a small scale prototype (see the demo here [2]).

II. State of the Art

Extensive research has been undoubtedly conducted in the parking systems sector as a key research topic in recent years. Smart Parking systems, autonomous parking algorithms and mobile driven applications have not only revolutionised the driving experience, but also mitigated major issues resulting from this constantly growing industry. However, most of these studies contain a logical gap in real-life scenarios. This leads to a difficulty of proposing these systems to commercial investors. Some studies are so commercial, that

[1]https://www.gov.uk/government/statistics/national-travel-survey-2018

[2]https://www.youtube.com/watch?v=MvhIV8WWiIQ

many crucial environmental challenges are being neglected in favour of profit. This money-driven culture generated a whole bread of drifted research with no middle ground to achieve an efficient solution. There are examples of studies being too theoretical proposing idealistic solutions with no implementation strategy, and others being lucrative enough to conceal their environmental impact. Therefore, it is essential to emphasise the importance of introducing new disruptive systems focusing on balancing all important aspects with a main outlook towards efficiency. With all neglected challenges causing major problems in these systems, the rise of demand for a balanced system is pivotal for any minor progression. Ensuring no consequential factors are neglected creates a feasible representation of an irresistible business model for investors. In this Section, all major assisting technologies and research papers inspiring this project will be analysed to create an understanding of our contribution. Additionally, previous works that aim to solve the issues surrounding car park systems will be critically analysed and compared to the proposed product.

iParker, proposed in [5], focuses on two main concepts in building a car park which aims to improve the parking experience overall; the Real-Time Reservation system (RTR) and Share Time Reservation system (STR). This allows the driver to either reserve a parking space before heading to their destination or directly on time of arrival to the car park. The system's architecture emphasises on some key components like the pricing engine and the smart allocation centre, which make it a unique proposal. The study aims to maximise resource utilisation and still guarantee maximum revenue for owners. A set of formulas is then analysed to produce these results with considerations to some challenges that may face the model. The main challenges are determined to be the constraints to guaranteed allocations when the car park becomes full, and a cost guarantee when circumstances change. Using mathematical modelling with Mixed-Integer Programming (MIP), this system achieves these functionalities with maximum results. Results from multiple simulations have shown various interesting outcomes, such as reducing the cost for parkers, increasing total revenue for car park owners and improving overall efficiency and car park utilisation. The study argues that based on those results, traffic congestion caused by car parking will be eliminated.

In contrast to these results, the study shows some tangible limitations that contradict some of the presented results. For instance, there is no specific implementation of sensors used or communication technology for allocation spaces. The study prefers the usage of a network of sensors connected together with no detailing to any technology used for real-time sensor communication. Additionally, further challenges are recognised when observing the cost guarantee, dynamic cost, and fixed cost models. Despite this, the system presents real-life solutions to some critical challenges facing the car park industry and transportation systems in general.

Another interesting work by Mejri et al. [7], named a Reservation-based multi-Objective Smart Parking (ROSAP), was proposed to tackle some of the main issues facing the car park industry today. The study looks into designing an allocation algorithm that uses Multi-objective Integer Linear programming to assist drivers in finding the nearest parking spaces. This is achieved with considerations to all major issues facing the industry, with an in-depth look at the main constraints that a driver would face. When searching for a parking space, a walking distance to the destination is suggested with an additional flexible option suggesting closer spaces to the destination. The flexible algorithm is called the "greedy approach" and it prioritises walking distance to any other constraint. One of the main advantages of this system is that it directly addresses the parking congestion impact in the allocation algorithm. This is also assisted with approaches to limit drivers walking and travel distance. This achieves convenience for the driver and an overall better experience.

The evaluation of this work has shown promising results such as improvement in occupancy utilisation and a more satisfying driver experience. Taking into consideration the paper's interesting results from short walking distances to the destination, it is notable that it tackles major congestion issues in metropolitan Cities. This paper shows a real suggestion to solve some of the major issues that face the car park industry. On the other hand, the system is reservation based, which can cause it to be unrealistic in some scenarios no matter how much some results can be satisfying. For example, using the greedy approach when navigating to a busy event can cause inconvenience, as it could change the allocation when closer to the destination. But despite all of this, looking at the congestion issue as the bigger picture for the problem can lead to the adaptation of this study in future works. Its real-life scenarios can provide data to tackle the climate and logistic challenges arising within modern car park systems.

In [8], the authors focused on the single failure point of the central subsystem and the end-to-end delay of centralised architectures used in parking management, which limits their practicality and usability. They proposed a new alternative architecture that aims to solve the above problems and improve the overall experience. The main concept of this new system is to decentralise and spread the logic and storage of the architecture over multiple geographical locations. The data is processed in local substations and is stored in the control centre for historic optimisation and improving decision making in such environments.

This architecture is implemented using wireless magnetic sensors that work as individual space detectors. This is shown to be extremely effective, especially when using local gateways. Additionally, the system can be compatible with multi-platform usage which improves its flexibility compared to other models. This architecture is shown to be fully scalable and can be easily implemented in replacement to existing systems with reduced cost. This is achieved mainly through local gateways that make it such a unique architecture. In summary, results show that this system can be used in a real-life environment with minimum setup logistics and cost. It is shown that the system can be used for future works In Smart

City Advanced Parking Management Systems.

III. System Design & Implementation

In this section we present the architecture of Eco-Parking system, its main software and hardware components as well as its main operational steps.

A. Architecture overview

Eco-Parking's system was designed to tackle major transportation and climate issues. Its architecture is inspired from previous solutions proposed in the field of car park management in Smart Cities. This architecture shows the main software and hardware components of Eco-Parking as well as their interactions, as illustrated in Figure 1. The main components of this architecture are described below.

- **Car Park Server**: It acts as the centre piece of Eco Parking's architecture, and it contains four main control components that deal with the main operations of a car park system:
  - **Sensor Control**: It is a vital part of the framework that deals with all communications done between the server and the deployed sensors. The server uses a middle-ware communication protocol (MQTT) to achieve real-time data transactions and boost the overall efficiency. The sensor control system feeds both the allocation and the pricing systems with real-time data, produces allocation and finalises receipts in real-time.
  - **Data Access Object**: It acts as a service layer for all data transactions within the car park system. It deals with all main operations (Create, Retrieve, Update, Delete) and communicates with the pricing and allocation systems to provide operation control in real-time. The layer is directly connected to the cloud database which contains the system's data.
  - **Allocation System**: The allocation system receives data from sensor control and the user. It uses the received data to allocate a parking space using an allocation algorithm.
  - **Pricing System**: It deals with issuing receipts and final pricing for users. That is achieved using a pricing engine that is flexible and can be controlled by the car park owner.
- **MQ Telemetry Transport (MQTT)**: Works as a connection layer between the server and the sensors network. There are many benefits to using this technology as it is low weight, low power and its data packets are compressed. This allows for real-time data transactions which is one of the most important parts of Advanced Parking Management Systems.
- **Sensors Network**: It consists of a set of sensors that work together to create an efficient car park system. The sensors network provides the data needed for many operations such as allocation, authorisation and pricing.
- **Cloud Database (MYSQL)**: This is the main database that contains all the system's data.
- **Admin Web Control**: A system provided for the car park owner to control the car park and define some key permissions and constraints depending on the owner's preference.
- **Mobile Application**: An essential part of the parking system. It works as the main user interface tool, designed to maximise utility and usability.
- **User**: The user benefits from the system by interacting with the user interface (Mobile Application) to reserve a parking space or have a spot assigned upon arrival.

B. Software components

The main user interface for Eco-Parking is the Android mobile application designed to provide key operations for reservation, allocation and a payment system. Focusing on usability and user experience, the app is designed with a simple layout and a set of steps that are easy to follow when reserving a parking space or checking reservation history. The logo is designed to indicate the sustainable approach of the app in lowering CO2 emissions. As shown in Figure 3, the user firstly enters the car park ID to login to the system if not using a tag. When successfully login, the user receives the allocation result along with the entry time. Lastly, when the user exits the car park, the mobile application also shows the summary of receipt. All wireframing for the application layout is done using an industry standard wireframing and user experience software -Adobe XD-.

The allocation system for Eco-Parking was implemented using an European standard known as Equa index as a metric for parking space allocation. Equa index uses a vehicle rating system that is based on lower and upper bound gram per kilometre of CO2 emissions. This classifies each parking space as shown in Table I.

TABLE I
Equa Index

Classification	Lower Bounce (g/km)	Upper Bound (g/km)
AA	0.0	0.0
A	0.0	0.08
B	0.08	0.12
C	0.12	0.18
D	0.18	0.25
E	0.25	0.50
F	0.50	0.75
G	0.75	1.00
H	1.00	None

After validating the vehicle on the server, a JSON (JavaScript Object Notation) data request of a vehicle, as shown in Figure 2, is sent to the cloud using the Data Access Object to retrieve all emission related data. When the data is received, the server runs the allocation function and classifies the parking spot. Once this is achieved, a parking space is reserved depending on the classification category. If there are not enough spaces, the user is notified that the car park is full. This is all done in real-time through server-cloud communication. Since all sensor data is constantly updated using MQTT communication between the sensors and the

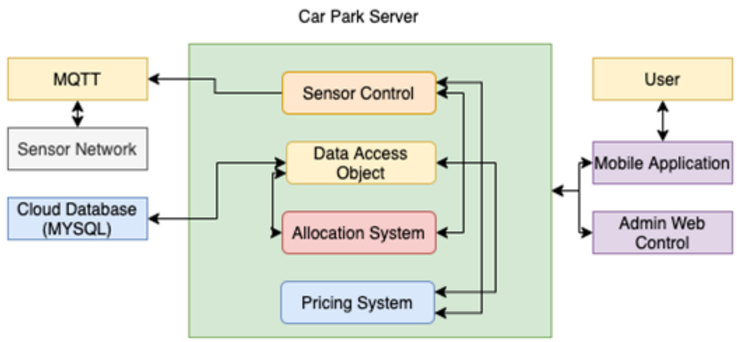

Fig. 1. Eco-Parking system architecture


```
{
    "make":"TESLA",
    "model":"MODEL X",
    "dateOfFirstRegistration":"28 MARCH 2017",
    "yearOfManufacture":"2017",
    "cylinderCapacity":"0cc",
    "co2Emissions":"0 g/km",
    "fuelType":"ELECTRICITY",
    "transmission":"AUTOMATIC",
    "taxStatus":"Taxed",
    "colour":"BLACK",
    "typeApproval":"M1",
    "wheelPlan":"2 AXLE RIGID BODY",
    "revenueWeight":"Not available",
    "taxDetails":"1 MARCH 2021",
    "motDetails":"27 MARCH 2020",
    "vin":"5YJXDCE47HF029363",
    "taxed":true,
    "mot":true
}
```


Fig. 2. An example of a vehicle JSON Data

server, all transactions are completed in high speed and great efficiency. The idea behind this allocation system is mainly inspired by reducing cruising time and travel distance. The goal is to allocate parking spaces directly so that the user is aware of the parking space before entering the car park. By allocating the closest parking spaces to the car park entrance to vehicles with higher emission levels, Eco-Parking promises reduction in travel distance, especially in large multi-storey car parks, and total emissions.

C. Hardware components

The main hardware component of Eco-Parking is the sensor network, the hardware part Eco-Parking implementation was aided with extensive research in the field of electronics and the IoT technology used in car park systems. The design phase included network connections and an understanding of sensors needed for the implementation phase, the main parts of Eco-Parking's sensor network are:

- **VINT Hub Phidget**: Used as a hub for the IR reflective sensors around the car park.
- **Infra-Red Reflective Sensors**: Each parking space includes one sensor to detect the occupancy status.
- **Servo Motors**: Entry and exit gates are controlled by servo motors that move upwards and downwards using program controls.
- **RFID Readers**: An alternative authentication method to using the mobile application, reads pre-programmed tags to authenticate the user.
- **Ultra-Sonic Distance Sensors**: In the same way they are widely used in modern car park and built in vehicles for object detection, they are used as vehicle detectors on entrance and exit.

This was implemented by creating an approximate layout of a modern car park. Each parking space was numbered and categorised using the Equa Index classification feature to ensure the prototype product meets the concept of the project. Figure 4 shows this layout in detail, which was used as a cardboard base for the sensor network.

This way of prototyping hardware was mainly used to test and refine how well the design functions as an entity. Additionally, it is used to evaluate the overall product performance which can result in attracting investors with positive performance results. After constructing the base for the sensors, the sensors are connected together and tested using the Phidget Control Panel software. This is done to ensure all sensor communication is ready for the software implementation phase. Figure 5 shows how the final hardware prototype looks after the implementation process.

D. Operational details

As illustrated in Figure 6, there are two main paths to getting a parking space. The first path is taken when a car drives into the car park with no prior reservation, and the second when a slot is reserved using the dedicated mobile application. The system will then analyse the user information by checking if they have a blue badge. All blue badge users get allocated the disabled reserved spaces automatically, while other users go through a registration number check to get assigned a space depending on fuel type. After running the registration number through the allocation algorithm, the user will get allocated a

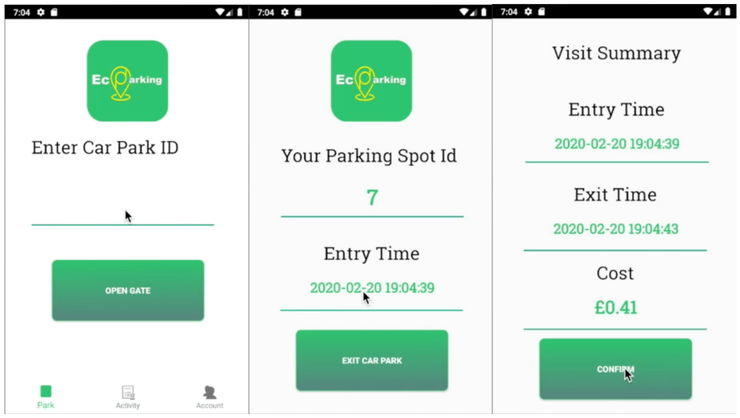

Fig. 3. User interfaces of Eco-Parking mobile application indicating system login (left), displaying parking allocation results (center), and receipts (right)

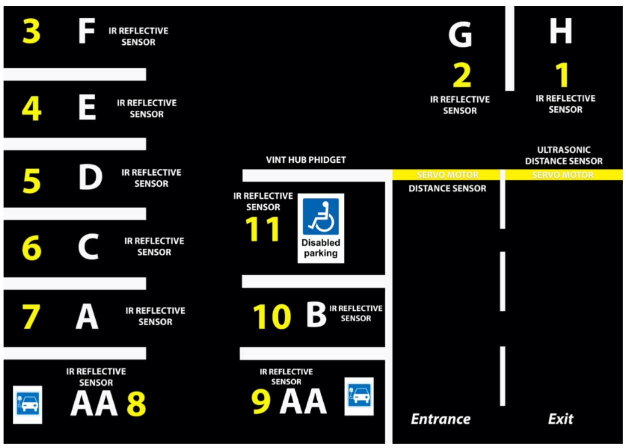

Fig. 4. Hardware floor design used in Eco-parking's proof of concept

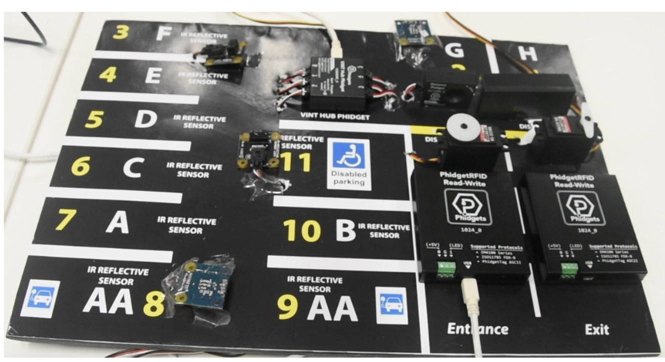

Fig. 5. Implemented hardware

parking space. The allocation algorithm uses a classification system called Equa index to categorise cars depending on CO2 emissions.

After allocating the parking space, the system will wait for the car to arrive. If the car fails to arrive on time the parking space will automatically become available and the booking will be cancelled. In the same way, the driver can cancel their reserved space at any point if they cannot arrive on time. A charge is added to cancelled reservations to improve utilisation and avoid void bookings. The car is then set to occupy the spot on arrival.

IV. Conclusion

This paper presented Eco-Parking system that represents an original green parking solution that uses IoT sensors along with a CO2 emissions based parking space allocation algorithm to minimise the cruising time of more pollutant vehicles inside large multi-storey car parks. The proof of concept demo developed in this work has proven the potential of the concept behind Eco-Parking. Future work includes large-scale simulation studies with more vehicles being tested and improvement of the current allocation algorithm. In addition, an interesting idea worth exploring is to coordinate the management of Eco-Parking with traffic prediction solutions run by traffic authorities to achieve better control of traffic congestion and avoidance of potential bottlenecks in key cities roads.

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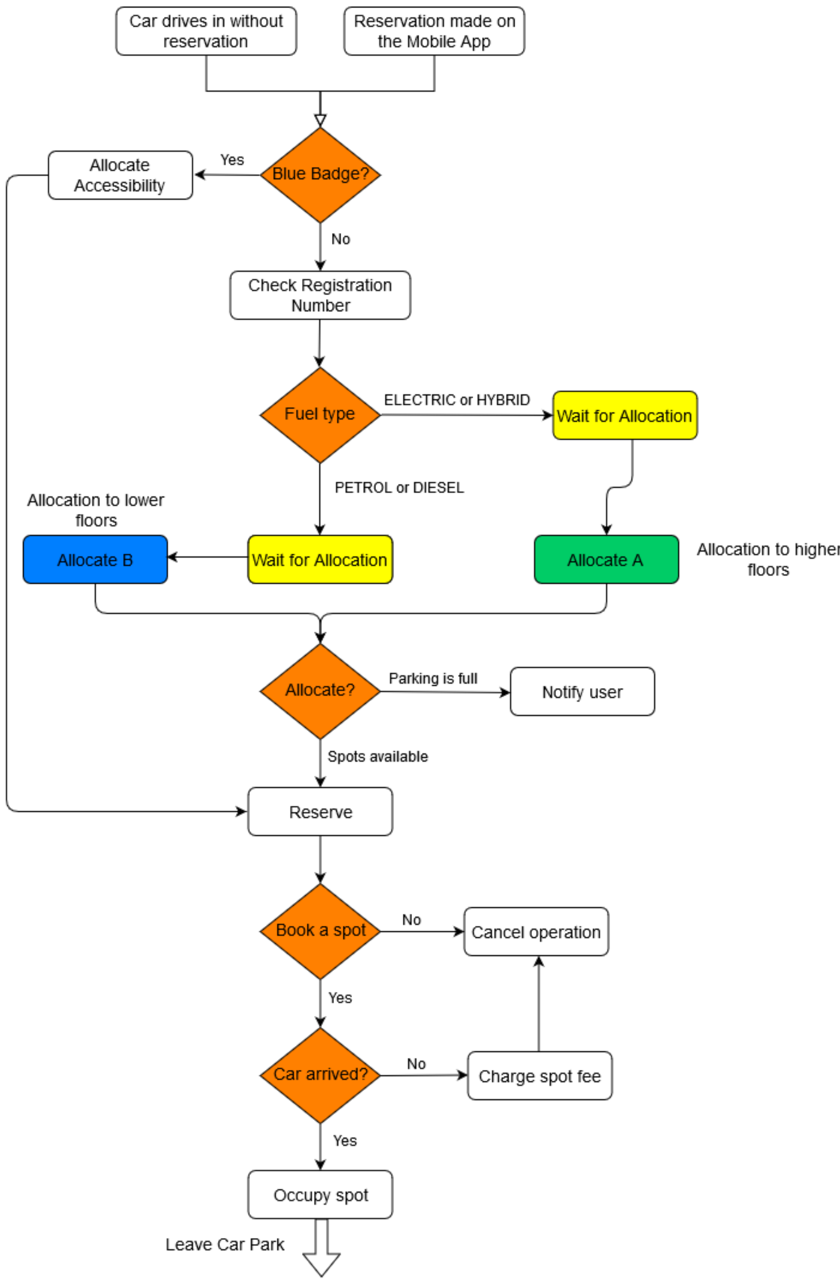

Fig. 6. Eco-Parking main operational steps