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A Smart Parking System Using Surveillance Cameras and Fuzzy Logic: A Case Study at Pardubice University's Campus

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Abstract

This paper introduces a novel methodology for optimizing parking recommendations on the campus of Pardubice University, aimed at enhancing the management of existing parking areas. The model takes into account factors such as distance, travel time, parking spot availability, and user preferences, leveraging data processed via the Google Maps API and Open-CV. Fuzzy logic is employed within the model to deal with imprecise concepts, providing adaptability. Performance evaluations yielded an impressive accuracy of 92%, attesting to its viability for real-world implementation. This research significantly advances smart parking solutions, showing promise for reductions in wasted time, alleviated traffic congestion, and improved parking efficiency.

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1. Introduction

The escalating pace of urbanization necessitates sophisticated strategies for parking management, encompassing inclusive guidance systems, rigorous enforcement of regulations, and dynamic pricing structures to maintain equilibrium in demand. Innovative research holds paramount significance in addressing challenges such as maximizing parking space utilization and curbing unauthorized parking. These challenges are particularly acute in urban planning and transportation management, given the difficulties associated with optimizing the usage of parking spaces due to irregular utilization and unauthorized parking in expansive facilities. These circumstances often precipitate traffic

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congestion and elongated search times for parking, thereby compromising traffic flow, safety, and the optimal use of parking resources [1]. Modern urban environments are plagued by the strenuous task of finding available parking spaces, thus escalating greenhouse gas emissions, traffic congestion, and delays [2]. Mitigating this predicament is crucial to transportation and traffic policy development, as efficacious parking strategies can significantly mitigate traffic congestion, environmental pollution, and energy consumption [3]. The advent of technological innovations, notably the Internet of Things (IoT)—a grid of tangible devices equipped with sensors that share real-time information [4]—proffers potential remedies. IoT is utilized in various sectors such as logistics, healthcare, agriculture, education, and transportation [5]. Specifically, in parking management, IoT has proven to be an effective solution to numerous parking-related complications [6], [7]. Complementing IoT, mobile applications have emerged as an integral component in intelligent transportation systems, providing users with details about parking facilities. However, existing applications are burdened with limitations, including a lack of real-time parking availability updates and customization to align with individual driver's preferences [8]. These drawbacks lead to suboptimal parking behaviors and exacerbate congestion [9].

This problem highlights the requirement for progressive parking information systems capable of providing real-time, customized data on parking availability. Implementing such systems could significantly enhance parking efficiency, reduce congestion, and augment the efficacy of urban transportation networks.

This paper introduces an innovative approach to the common challenge of identifying available parking spaces, particularly within the context of the University of Pardubice campus. Our goal is to transcend the constraints of conventional mobile applications by developing a state-of-the-art system that seamlessly combines the Internet of Things (IoT) with the Fuzzy Inference System (FIS). The FIS, a form of artificial intelligence, is designed to emulate human reasoning, making it an ideal tool for handling data that is uncertain or ambiguous.

Our contribution to the academic sphere is unique in several ways:

1. We introduce an innovative, intelligent strategy for detecting available parking spaces, thereby addressing a fundamental challenge in urban transportation. This represents a significant shift away from traditional parking management techniques.
2. We pioneer the application of IoT and Fuzzy Logic to address a common practical problem, demonstrating how these cutting-edge technologies can be applied to real-world scenarios in novel ways.
3. We present a case study from the University of Pardubice campus, where we applied our unique Fuzzy IoT-based methodology. This case study not only validates our approach but also illustrates the broader implications for urban congestion management.
4. Our solution is versatile and scalable, suggesting its potential for widespread adoption across diverse urban parking environments. This adaptability enhances its relevance and applicability in addressing real-world challenges.

By strategically integrating IoT and FIS, we aspire to contribute significantly to ongoing efforts aimed at enhancing parking efficiency, reducing environmental footprint, and improving urban living standards. We are confident that our work, beginning with its application at the University of Pardubice campus, lays a strong foundation for future research and applications in the realm of intelligent urban parking management. The rest of this paper is organized as follows: [Section 2](#) reviews relevant literature. [Section 3](#) presents the proposed methodology. [Section 4](#) discusses the results of applying this methodology in a real-world scenario. Finally, [Section 5](#) discusses the results and concludes the paper, suggesting future research directions.

2. Literature Review

This section explores notable scholarly inputs relevant to modern developments in (IoT), big data, artificial intelligence (AI), and cloud-based technologies. These frontier technologies have recently invigorated smart parking solutions, aiming to enhance the efficiency and effectiveness of urban parking management. Several frameworks utilizing IoT technology have been suggested to mitigate parking challenges. One such system [10] uses an Arduino Mega 2560 microcontroller, various sensors, and a web application for reservations and transactions. This framework, conceptualized as a learning model for microcontrollers, shows potential for significant advancements in operational efficiency. In another noteworthy contribution [11], an IoT-based system coupled with an ensemble predictive model was developed, leading to an enhancement in parking space prediction accuracy by 6.6%. Numerous IoT-based

solutions have been proposed, including advanced smart parking systems [12], [13], which integrate features like location tracking, parking management, real-time invoicing, and Wi-Fi transmission of parking availability status. These applications underscore the versatility of IoT in urban parking management. Alongside this, big data and AI technologies have emerged as potent tools for enhancing parking services. One such study [14] highlighted the role of AI and big data technologies in augmenting parking services via mobile devices, demonstrating notable improvements in parking spot detection speed and accuracy. A different research effort [15] evaluated the feasibility of merging edge computing with AI for parking occupancy detection using real-time video feed, emphasizing the potential of AI to bolster the responsiveness and efficiency of parking systems. Interestingly, a particular study [16] posits that drivers often overpay for parking due to a lack of information, underscoring the necessity for transparent and user-friendly parking systems. In contrast, a novel algorithm was introduced [17] for automatic parking slot detection and occupancy classification, achieving an impressive accuracy of 95% in detecting parking slots and 92% in occupancy classification. However, potential challenges were acknowledged in scenarios featuring significant occlusions or closely parked vehicles.

Moreover, the integration of IoT with other cutting-edge technologies, including fog computing, LORA wireless networks, and RFID, has been illustrated in various studies. For instance, an IoT and fog computing-based parking system was proposed [18], offering real-time parking information and optimizing parking spot selection. An IoT-based intelligent parking lock system was developed [19] to maximize parking resources via LORA wireless networks. Simultaneously, an RFID-based IoT smart parking system was implemented [20] for efficient parking management. The exploration of cloud-based services in recent studies to address traffic congestion and parking issues is also noteworthy. A cloud-based service was proposed [21] using a discrete Markov-chain model and data streams from smart poles to predict parking lot availability in a central business district (CBD). This exemplifies the growing interest in integrating cloud computing with parking management systems to deliver efficient and reliable services. Different systems have been devised to cater to specific use-cases or locations. For instance, an IoT Raspberry Pi-based parking management system was developed [12] for real-time parking availability on university campuses. In another case, an Android-based Car Parking Monitoring System was introduced [22] to address the challenge of finding parking spaces in crowded structures, like shopping centers.

Overall, recent advancements in smart parking involve various technologies such as IoT, AI, big data, cloud, and fog computing aimed at enhancing parking efficiency, reducing traffic congestion, and optimizing parking allocation. However, given each system's unique strengths and limitations, a universal solution may not be feasible due to differing urban conditions. Future research should focus on integrating these technologies to improve system performance and address concerns relating to security, privacy, and resource management.

3. Methodology

In this research, we implement a structured, tri-phased methodology. Our approach is designed to effectively recommend the parking spaces to users. This is accomplished by factoring in crucial elements including distance, estimated travel time, availability of parking spaces, and user preferences. These aspects of our methodology are not only integral to our approach but also interdependent, contributing to a comprehensive solution. Each phase, distinct yet interconnected, plays a vital role in the overall methodology. This strategy is visually illustrated and explained in Fig. 1, 2 and 3.

3.1. Phase 1: Data Collection and Processing

Fig. 1 illustrates the structure of Phase 1, which includes the following steps:

1. *User Location Data Gathering*: User data related to current locations is collected using the Google Maps API. This data is subsequently processed to calculate distance and estimate travel time to each parking location, as depicted in Table 1, which presents the pseudo-code for Google Maps API integration.
2. *User Preference Data Collection*: Users assign a value between 0 and 10 to indicate their preference for each parking location. This measure enhances the system's ability to deliver precise recommendations.
3. *Available Parking Spaces Identification*: A computer vision algorithm is utilized to detect available parking spaces in each parking area through utilizes video footage from surveillance cameras for the parking areas. Table 2, presents a pseudo code that used to determine available parking spaces, in which the application of the computer vision algorithm in this system. The code involves importing the Open-CV algorithm, setting

up the camera, model, and subtractor. Frames are processed to identify and detect vehicles using background subtraction. The system manages the list of detected vehicles and keeps track of the frame counter. After completing the execution, appropriate clean-up of resources is performed.

4. **Data Storage:** Data gathered from users and surveillance cameras is stored in a server, paving the way for subsequent use in the next phase.

By integrating Google Maps API with the computer vision algorithm, the system's usability and precision are notably amplified. This synergy allows the system to provide users with real-time traffic data, vacancy rates, and comprehensive navigational guidance.

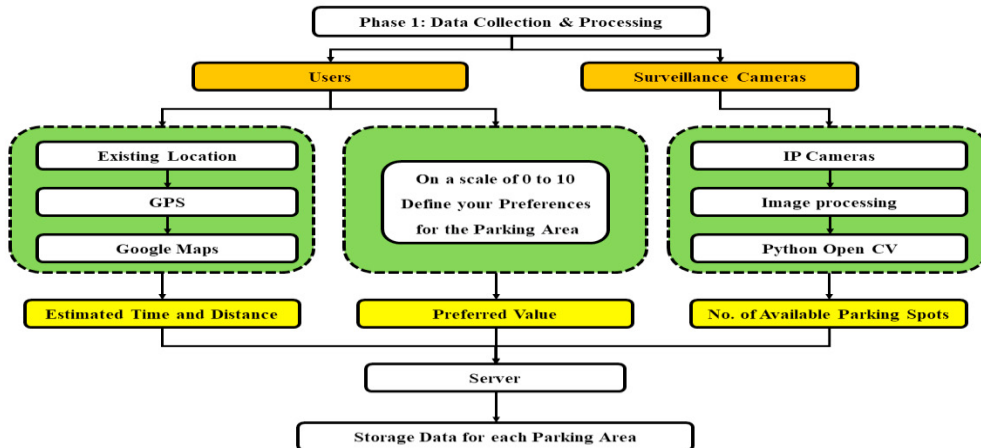


Fig. 1: Workflow of Phase 1 in the proposed parking system

Table 1: Pseudo-code for Google Maps API integration in the proposed parking system

```

function navigation_system() {
  // Step 1: Determine the user's location using GPS data on their smartphone
  user_location = get_user_location()
  // Step 2: Use the Google Maps API to estimate the travel time and distance to the parking area
  travel_time, distance = get_travel_time_and_distance(user_location, parking_area_location)
  // Step 3: Display the user's location, travel time, and distance to the parking area to the user
  display_navigation_information(user_location, travel_time, distance)
  // Step 4: Use the Google Maps API to provide detailed maps and directions to the parking area
  maps_and_directions = get_maps_and_directions(user_location, parking_area_location)
  // Step 5: Display the detailed maps and directions to the user
  display_maps_and_directions(maps_and_directions);
}
  
```

Table 2: Pseudo-code demonstrating the use of the Open-CV algorithm in the proposed parking system

```

# Importing necessary modules, setting up camera, model, subtractor, and variables
import cv2, cap, vehicle_detector, bg_subtractor = cv2.VideoCapture(0), cv2.CascadeClassifier('vehicle_detection_model.xml'),
cv2.createBackgroundSubtractorMOG2() vehicles,
frame_counter = [],0
# Processing frames until exit
while True:
  if not cap.read()[0]: break # Break if no frame captured
  fgmask = bg_subtractor.apply(cap.read()[1]) # Identify moving objects
  detected_vehicles = vehicle_detector.detectMultiScale(fgmask) # Detect vehicles
  # Adding detected vehicles and updating frame count
  for vehicle in detected_vehicles: vehicles.append(vehicle), frame_counter += 1
  if frame_counter % 100 == 0: vehicles = [] # Clear vehicles after every 100 frames
  # Display frame and check for exit command
  cv2.imshow('Video', cap.read()[1])
  if cv2.waitKey(1) & 0xFF == ord('q'): break
# Cleanup after exit
cap.release()
cv2.destroyAllWindows()
  
```

3.2. Phase 2: Model Development

The second phase, represented in Fig. 2, employs fuzzy logic to design a system to recommend a parking spot to the users. This introduces a real-time system that accounts for several inputs to yield a suggested parking spot. The implementation of fuzzy logic entails defining input and output variables, formulating rules grounded in user preferences and parking spot availability, and applying these rules to conclude a recommended spot.

Fuzzy logic, introduced by Zadeh in 1965 [23], is a mathematical system employed in a multitude of fields to represent vague or imprecise concepts. Fuzzy inference, a reasoning methodology, enables the integration of linguistic information, making the reasoning process more intuitive and facilitating the incorporation of expert knowledge.

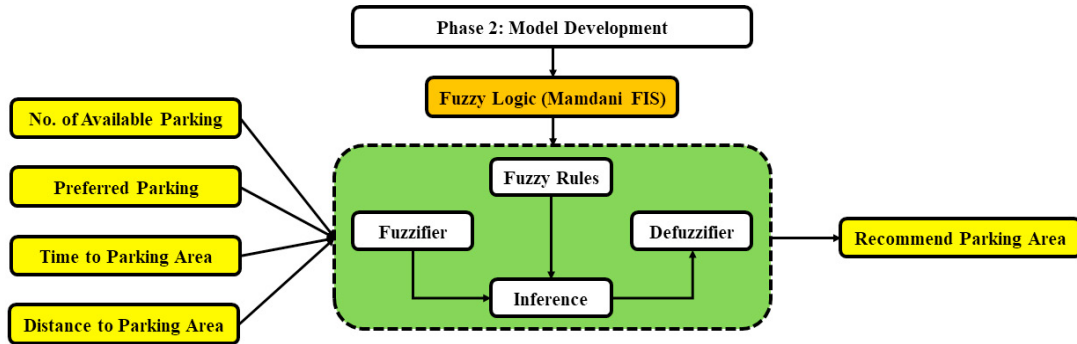


Fig. 2: Workflow of Phase 2 in the proposed parking system

3.3. Phase 3: Model Evaluation

Phase 3, depicted in Fig. 3, entails training, optimizing, and assessing the Fuzzy Inference System (FIS) using the amassed user data. Model precision is evaluated using confusion matrices and ROC-AUC metrics. A high accuracy results in model refinement based on user feedback, while a low accuracy leads back to Phase 2 for adjustments to the membership functions and rules for the FIS. The model is then re-assessed, with this iterative process continuing until a high accuracy score is achieved.

In essence, this parking system augments parking efficiency by suggesting the free parking spots using surveillance cameras and fuzzy logic, thus reducing time, mitigating frustration, lessening traffic congestion, and improving parking availability.

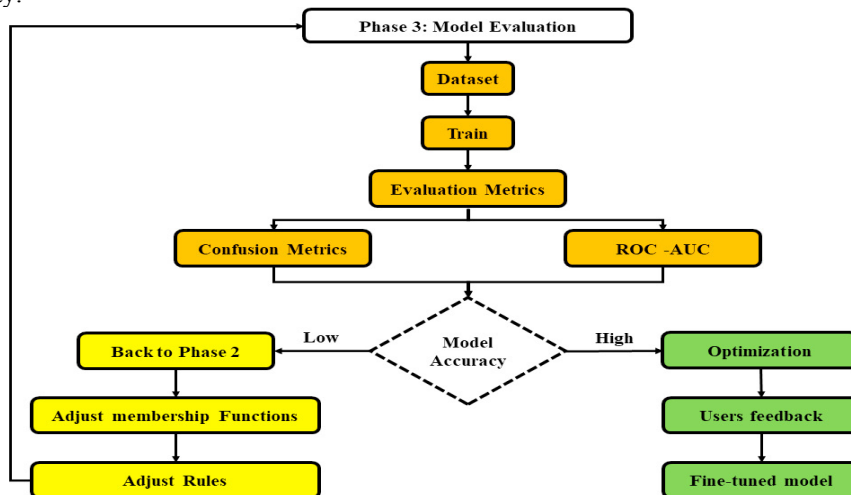


Fig. 3: Workflow of Phase 3 in the proposed parking system

4. Results and discussion:

In this section, we systematically elucidate the empirically-derived insights gleaned from our exhaustive research venture. This exploration comprises an in-depth dissection and rigorous interrogation of the amassed data, promoting a holistic understanding of the study's consequential findings.

4.1. Study area: Pardubice Campus

The experimental validation of our model was conducted at Pardubice University's campus in the Czech Republic. The campus comprises eight designated parking areas labelled P1-P8, situated throughout the university grounds, providing ample parking facilities for students and staff. The distribution of parking slots in each area is detailed in Table 3, and Fig 4. The heatmap in Fig. 5 exhibits the average monthly occupancy rates for a standard academic day in December 2022, highlighting the inefficiency of the current parking system, which fails to distribute vehicles uniformly across all eight zones. It reveals the tendency of car owners to park as near as possible to their workplaces, leading to overcrowding in some areas while leaving others underused. This results in occasional illegal parking in these zones.

Table 3. Capacities of parking areas at Pardubice University

Paring Area	Location	Capacity
P1	Menza (Dining Hall)	118
P2	Faculty of Chemical Technology (Building HC)	83
P3	Faculty of Chemical Technology (Building HA)	54
P4	Halls of Residence (Dormitory D)	41
P5	Halls of Residence (Dormitory E)	49
P6	Halls of Residence (Dormitory F)	147
P7	Rector Building	102
P8	Faculty of Economics and Administration – Faculty of Arts and Philosophy	124

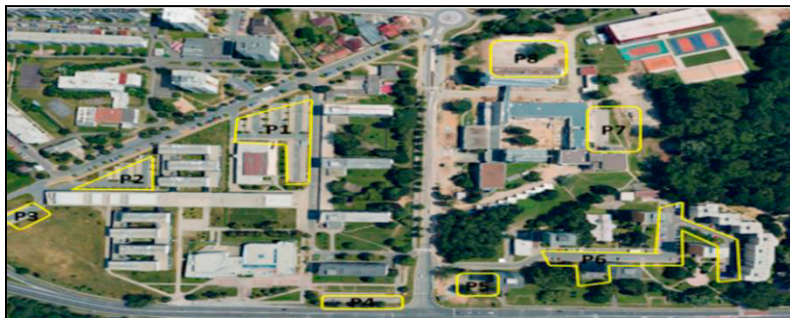


Fig. 4. Geographical distribution of parking areas at Pardubice University

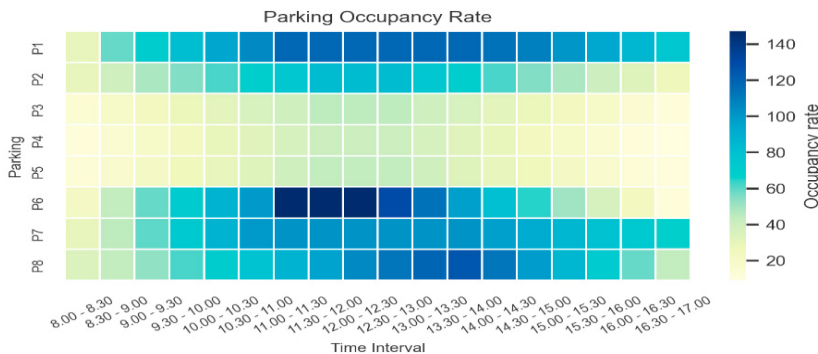


Fig. 5. Heatmap for the average monthly parking occupancy rates at the Pardubice University campus in Dec. 2022

4.2. Stage 1: Data collection and Processing

To evaluate our proposed parking system, we recruited 100 volunteers from within the university community who lived within a 15 km radius from the campus. Data was collected throughout December 2022 to ascertain the parking demand at the campus. Using GPS and Google Maps, we tracked the expected travel time and distance of participants from their origin to the campus. We also asked participants about their parking preferences. Concurrently, surveillance cameras installed at the campus captured real-time availability of parking spots. This data was processed using Python Open CV to automatically identify the number of free parking spaces in a car park. All this data was then stored on a server for use in the next phase.

4.3. Stage2: Model development

During this study phase, we incorporated the Mamdani type Fuzzy Inference System (FIS) to predict and suggest the parking for each user. The system relies on stored data and four input parameters: the number of available parking spots (X1), user's preference for a parking area (X2), distance to the parking area (X3), and estimated time to reach the area (X4). These parameters are collectively evaluated to generate the system's output (X5), which is the recommended parking area. This system adopts triangular membership functions with five degrees each for both the inputs and the output. These membership functions are visualized in Figure 6. A set of 625 rules as full combination is then applied to deduce fuzzy results, which are subsequently defuzzified into concrete recommendations. The practical utility of this methodology is evident in its capability to provide personalized parking suggestions. For instance, as demonstrated in Table 4, User 1 is advised to choose parking area P1, which is assigned the highest output value of 0.9067. This recommendation is based on the application of the aforementioned input parameters within the context of the fuzzy inference system.

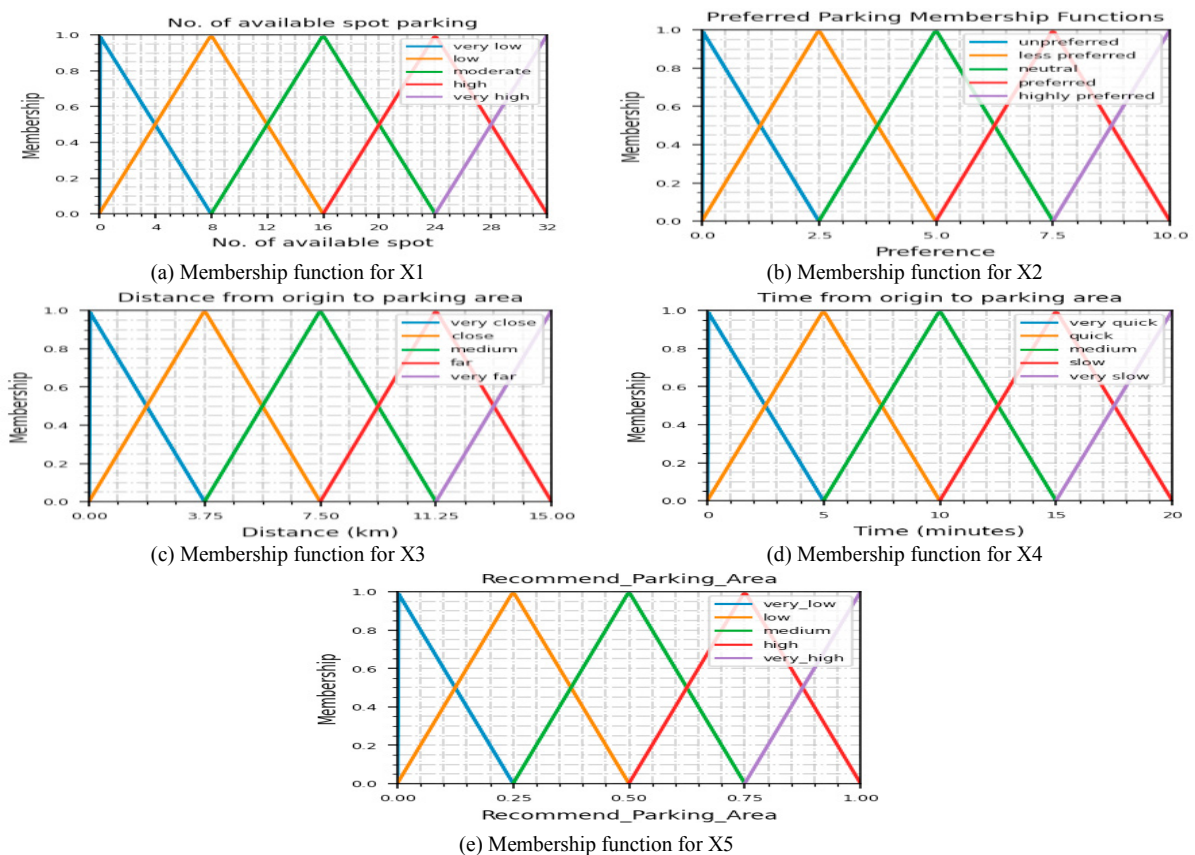


Fig.6. Illustration of the membership functions for inputs and output in FIS

Table 4. Fuzzy inference system’s inputs and resulting output recommendations for user 1

User	Parking area	X1	X2	X3	X4	Output	Recommended Parking Area	
1	P1	32	9	6.9	5.7	0.9067	0.9067	P1
	P2	4	6	4.4	3.6	0.4344		
	P3	26	1	8.4	7.0	0.5000		
	P4	5	6	5.5	4.6	0.3928		
	P5	2	4	8.7	7.2	0.3209		
	P6	10	7	7.9	6.6	0.4192		
	P7	28	8	15.8	13.2	0.6375		
	P8	1	4	9.6	8.0	0.2795		

4.4. Stage3: Model Evaluation

In this phase, we initiated the evaluation of our model with a confusion matrix, shown in Table 5. The matrix comprises four critical metrics: True Positives (TP), False Positives (FP), False Negatives (FN), and True Negatives (TN) for each class. These metrics hold significant importance: TP and TN indicate accurate predictions of the presence and absence of an outcome respectively, highlighting the model's precision. Conversely, FP and FN, representing false alarms and missed detections respectively, help identify areas where the model falters [24]. The robust performance of our proposed model is highlighted by the confusion matrix, which demonstrates a high number of (TN) and a low count of (FN) across all predicted parking classes. Following this initial evaluation, for a more holistic understanding, we computed other metrics, including precision (Eq. 1), recall (Eq. 2), F1-score (Eq. 3), and accuracy (Eq. 4), the detailed explanation of these metrics can be found in this article [24].

Table 5. Confusion matrix of parking classes.

	P1	P2	P3	P4	P5	P6	P7	P8	TP	FP	FN	TN
P1	9	1	0	0	0	0	0	0	9	0	1	90
P2	0	10	1	0	0	1	0	0	10	1	2	87
P3	0	0	17	0	0	0	0	0	17	2	0	81
P4	0	0	0	9	0	0	0	1	9	0	1	90
P5	0	0	0	0	21	0	0	0	21	0	0	79
P6	0	0	0	0	0	9	1	1	9	1	2	88
P7	0	0	1	0	0	0	9	0	9	2	1	88
P8	0	0	0	0	0	0	1	8	8	2	1	89

$$\text{Precision of class}(i) = \frac{TP_i}{TP_i + FP_i} \tag{1}$$

$$\text{Recall of class}(i) = \frac{TP_i}{TP_i + FN_i} \tag{2}$$

Here, TP_i , FP_i , and FN_i represent true positive, false positive, and false negative values for each class, respectively.

$$\text{F1-Score of class}(i) = \frac{2(\text{Precision}_i \times \text{Recall}_i)}{(\text{Precision}_i + \text{Recall}_i)} \tag{3}$$

$$\text{Accuracy of the model} = \frac{\text{Total number of corrected prediction}}{\text{Total number of sample}} \times 100 \tag{4}$$

Our model displayed an overall accuracy of 92%, indicating its efficiency in predicting parking areas based on FIS predictions. A more detailed scrutiny of the confusion matrix shed light on the model's strengths and weaknesses. For instance for parking area (P1) It showed a high level of accuracy, with a significant number of TP and TN values, and minimal errors in terms of FP and FN values. Similar proficiency was seen in P3 and P5 classes, with P3 recording no false negatives and P5 having no errors at all. We further scrutinized the model's performance using precision,

recall, and F1-score metrics to gain a broader understanding as shown in Table 6. Precision, which indicates the reliability of positive predictions, exhibited high values across all classes, specifically in P1, P4, and P5. Recall, which illustrates the ratio of accurately identified positives, also scored high values, with the best performance seen in P1, P3, P4, and P5. The F1-score, a measure that assesses the balance between precision and recall, remained consistent across all classes. Lastly, we evaluated the Receiver Operating Characteristic - Area Under the Curve (ROC-AUC) values for each class, as visualized in Fig.7. These values, which ranged between 0.90 (for P6 class) to 1 (for P5 class), signify the model's aptitude in class differentiation. The curves in the ROC-AUC plot were significantly above the 45-degree line, suggesting that our model's predictive capability far surpasses a random classifier, which would align with the 45-degree line.

Table 6. Evaluation metrics of the model performance

	Precision	Recall	F1-score
P1	1	0.9	0.94
P2	0.91	0.83	0.86
P3	0.89	1	0.94
P4	1	0.9	0.95
P5	1	1	1
P6	0.9	0.82	0.86
P7	0.82	0.9	0.86
P8	0.8	0.89	0.84
% Model accuracy		92 %	

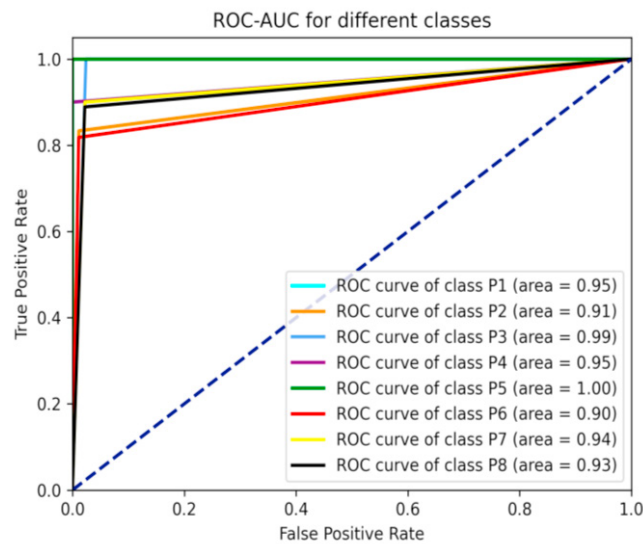


Fig.7 ROC-AUC curve displaying performance metrics of the model for each parking area

5. Conclusion and Future Work

The study developed a parking recommendation system using data collection from users, fuzzy logic, and real-time parking data, achieving a 92% accuracy rate at Pardubice University campus. The model incorporate Google Maps API, user-defined preferences, and Open-CV algorithm to provide real-time parking information, reducing parking time, traffic congestion, and optimizing parking space utilization. There is, however, scope for improving the model's accuracy in certain areas. Future work should refine the fuzzy logic system, incorporate more complex data on a large scale, and consider machine learning techniques for better parking spot predictions. The system's scalability to city-wide parking management is another potential area of exploration, with implications for improving

urban mobility. The model demonstrates the potential of sophisticated data processing and user preference considerations in refining parking management systems, with future work promising significant contributions to urban transportation and city life quality.

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