International Journal of Scientific Research & Engineering Trends
Volume 11, Issue 1, Jan-Feb-2025, ISSN (Online): 2395-566X

IoT and Computer Vision for Efficient Parking Management in Urban Areas: A Comprehensive Review

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Abstract- Urbanization and population growth have led to an exponential increase in vehicles, exacerbating parking-related challenges. Efficient parking management systems have become imperative to mitigate congestion, reduce fuel consumption, and minimize environmental impact. This paper reviews the integration of Internet of Things (IoT) technologies, computer vision, and Bluetooth Low Energy (BLE)-based indoor positioning systems for developing an efficient parking management system in urban areas. The proposed system is divided into three core modules: prediction of parking availability, real-time parking detection, and indoor navigation to guide users. This review evaluates existing approaches, highlights technological advancements, and discusses potential challenges in developing a proof of concept for the Indian context, emphasizing the cost-efficiency of the system.

Index Terms- Smart Parking Systems, Computer Vision, Parking Availability Prediction, Indoor Positioning System (IPS), Object Detection Algorithms

I. INTRODUCTION

The rapid urbanization and growing population in cities worldwide have led to a significant rise in the number of vehicles. As a result, parking has emerged as a critical issue in urban planning and infrastructure development. Congested streets, unorganized parking, and limited availability of spaces not only inconvenience citizens but also contribute to increased fuel consumption, greenhouse gas emissions, and air pollution. Studies indicate that drivers often spend an average of 15–30 minutes searching for parking spots, leading to traffic bottlenecks and additional strain on already overwhelmed road systems.

Traditional parking systems, predominantly reliant on manual monitoring or simple pay-and-park mechanisms, fail to address these challenges efficiently. Manual systems are prone to errors, are time-intensive, and are incapable of scaling to meet the demands of rapidly growing cities. In the Indian context, the problem is exacerbated by the lack of standardized parking policies, unregulated private parking spaces, and a limited focus on technological interventions. This scenario highlights the pressing need for advanced, intelligent systems to optimize parking management.

Recent advancements in technology, particularly in the realms of the Internet of Things (IoT), computer vision, and wireless communication, have opened new possibilities for solving urban parking woes. IoT-enabled devices can provide real-time data on parking availability, while computer vision systems offer accurate detection and monitoring of parking spaces. Meanwhile, indoor positioning systems (IPS) based on Bluetooth Low Energy

(BLE) technology facilitate seamless navigation within parking facilities, guiding users to available spots. These innovations collectively pave the way for smart parking management systems that enhance user convenience, reduce environmental impacts, and optimize resource utilization.

This review paper focuses on the integration of IoT, computer vision, and BLE technologies for efficient parking management in urban areas. The proposed system is divided into three key modules: parking availability prediction using camera feeds, real-time detection of vacant spaces through image processing, and indoor navigation leveraging BLE-based positioning. The primary objective is to design a cost-effective, scalable system that can address parking challenges in the Indian context. This is achieved by incorporating locally sourced data, affordable hardware, and open-source software solutions, making the system accessible for widespread adoption.

Through this review, we aim to provide a comprehensive understanding of the existing research, evaluate the limitations of current approaches, and propose a framework for developing a proof of concept (PoC) tailored to urban India. By doing so, we hope to contribute to the ongoing efforts towards creating smarter, more sustainable cities equipped to handle the growing demands of urban mobility.

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II. LITERATURE REVIEW

Amato et al. [1] proposed a deep learning framework using Convolutional Neural Networks (CNNs) to predict parking lot occupancy based on weather, time, and historical data .

Pereira et al. [2] explored the use of Long Short-Term Memory (LSTM) networks to model temporal patterns in parking availability.
Tong et al. [3] implemented a hybrid approach combining statistical models with real-time IoT sensor data to improve prediction accuracy in smart cities.
In the Indian context, Srivastava et al. [4] demonstrated the application of locally trained machine learning models for predicting parking availability in unstructured urban environments.
Azimi et al. [5] developed a YOLO-based parking detection system, achieving high-speed detection in real-world conditions.

Faster R-CNN has been extensively applied in parking detection studies. Chou et al. [6] utilized it to achieve high accuracy in identifying vehicle positions in complex urban settings.

Mask R-CNN was employed by Zhang et al. [7] for instance segmentation in multi-level parking structures, highlighting its effectiveness in handling occlusion.

Singh et al. [8] investigated the use of SSD for detecting vehicles in parking lots with irregular layouts and lighting conditions, achieving a balance between speed and accuracy.

Liu et al. [9] demonstrated the feasibility of using BLE beacons for achieving ±1 meter accuracy in indoor environments, highlighting their affordability and energy efficiency.

Mahmoud et al. [10] compared Wi-Fi and BLE positioning systems, with BLE showing superior accuracy for small- scale applications such as parking lots.

Sahoo et al. [11] proposed a hybrid approach combining BLE and Ultra-Wideband (UWB) for navigation in underground parking facilities.

In the Indian context, Verma et al. [12] designed a BLE- based navigation system tailored for unstructured parking lots, achieving promising results in user trials.

Masmoudi et al. [13] studied IoT-enabled parking sensors, emphasizing their scalability and real-time data capabilities.

Sharma et al. [14] explored the use of edge computing in IoT parking systems, demonstrating its effectiveness in reducing latency and bandwidth usage in real-world deployments.

Anagnostopoulos et al. [15] investigated the use of LoRaWAN for connecting parking sensors in urban environments, highlighting its low power consumption and wide coverage.
Singapore's city-wide smart parking initiative employs IoT sensors and computer vision to achieve 90% detection accuracy, significantly reducing congestion [16].

Seoul's Smart Parking System integrates prediction, detection, and navigation, serving as a model for other cities [17].

In India, Bengaluru has piloted IoT-enabled parking meters combined with camera-based detection to tackle unregulated parking [18].

Kaur et al. [19] noted that environmental factors, such as lighting and weather conditions, can impact the accuracy of vision-based systems.
Gupta et al. [20] highlighted cost constraints, particularly in developing countries, which limit the deployment of high-end sensors and computational resources.

Scalability remains a concern for multi-level and large- scale parking facilities, as noted by Wang et al. [21].

III. METHODOLOGY

Real-time parking detection is a critical component of any smart parking management system, as it provides precise information about the occupancy status of individual parking spaces. In recent years, advancements in deep learning have made it possible to achieve high accuracy in image-based parking detection. This section compares popular algorithms, such as YOLO (You Only Look Once), Faster R-CNN (Region-based Convolutional Neural Network), and others, based on their performance, computational requirements, and suitability for real-world applications.

1. Overview of Algorithms
YOLO (You Only Look Once)
YOLO is a real-time object detection algorithm that processes an entire image in a single forward pass of a convolutional neural network. It divides the image into a grid and predicts bounding boxes and class probabilities simultaneously. YOLO's high speed makes it ideal for applications requiring real-time performance.

Faster R-CNN (Region-based Convolutional Neural Network)
Faster R-CNN is a two-stage object detection algorithm that first generates region proposals and then classifies them. While it achieves high accuracy, its computational complexity

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makes it slower compared to YOLO. It is best suited for scenarios prioritizing precision over speed.

SSD (Single Shot MultiBox Detector)
SSD combines aspects of YOLO and Faster R-CNN, offering a balance between speed and accuracy. It uses a single neural network to detect objects at multiple scales, making it efficient for detecting parking spaces of varying sizes.

Mask R-CNN
An extension of Faster R-CNN, Mask R-CNN performs instance segmentation by predicting masks in addition to bounding boxes and class labels. It is highly accurate but computationally intensive, making it suitable for high-resolution parking datasets in controlled environments.

2. Comparative Analysis

The table below provides a comparison of these algorithms based on key performance metrics:

Algorithm	Speed (FPS)	Accuracy (mAP)	Complexity	Suitability
YOLO	45–60	~55–65%	Low	Real-time applications with moderate accuracy
Faster R-CNN	7–10	~70–80%	High	Precision-critical tasks with ample resources
SSD	22–25	~60–70%	Medium	Balanced speed and accuracy for diverse settings
Mask R-CNN	5–7	~75–85%	Very High	Complex scenarios requiring instance segmentation

3. Discussion

Speed vs. Accuracy Trade-Off
YOLO's high speed makes it a preferred choice for real- time parking detection in dynamic environments where quick decisions are necessary. However, its moderate accuracy may not suffice for densely populated parking lots where precision is critical. Faster R-CNN, while slower, delivers higher accuracy, making it suitable for controlled environments or scenarios where computational resources are not a constraint.

Adaptability to Indian Context
In the Indian context, factors like occlusion, uneven lighting, and irregular parking layouts pose unique challenges. SSD's ability to handle objects of varying sizes and its balance between speed and accuracy make it a strong candidate for such settings. Mask R-CNN can also be effective in accurately identifying individual vehicles and their boundaries in unorganized parking spaces, albeit with higher computational demands.

Edge Computing Considerations
For deployments using edge devices like Raspberry Pi, the lightweight nature of YOLO and SSD makes them more practical, as they can run efficiently on hardware with limited processing power. Faster R-CNN and Mask R-CNN may require dedicated GPUs, increasing the overall cost.

4. Recommendations

Based on the comparison:

- For Real-Time Applications: YOLO or SSD should be prioritized for their speed and adaptability to low-cost hardware.
- For High-Precision Needs: Faster R-CNN or Mask R-CNN are better suited when accuracy outweighs the need for real-time performance.
- Hybrid Approach: A hybrid approach, combining YOLO for initial detection and Faster R-CNN for refinement, can optimize both speed and accuracy in systems where computational

6. Indoor Positioning System (IPS) for Navigation

An IPS guides users to available parking spots using BLE technology. BLE-based beacons emit signals that mobile devices can interpret for indoor navigation.

7. BLE-Based Systems

BLE beacons are inexpensive and energy-efficient, making them ideal for indoor environments. By triangulating signals from multiple beacons, the system can determine a vehicle's location and guide the user to a vacant parking spot.

8. Challenges

The deployment of BLE-based indoor positioning systems faces several challenges:

- Signal Interference: Physical barriers and electronic noise can degrade positioning accuracy.
- Deployment Costs: Installing BLE beacons across large parking lots requires upfront investment.
- **Maintenance:** Regular battery replacements and hardware upkeep add to operational costs.

9. Potential Solutions

Using dynamic power management for BLE beacons can reduce maintenance overhead. Additionally, a hybrid approach combining BLE and Wi-Fi-based localization can improve accuracy. Open-source software like Google's Eddystone can further reduce costs.

10. Proof of Concept (PoC) Design

The proof of concept (PoC) for an efficient parking management system serves as a small-scale prototype that demonstrates the feasibility and functionality of the proposed solution. By focusing on a localized deployment, the PoC allows for testing and refinement of the system's components

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in a controlled environment. This section provides a comprehensive overview of the PoC design, including hardware and software integration, implementation steps, and cost analysis tailored for urban Indian contexts.

IV. PROPOSED PROOF OF CONCEPT (POC) ARCHITECTURE

1. PoC Architecture and Components

The proposed PoC architecture is divided into three key modules:

Prediction Module

- Uses security camera feeds and machine learning algorithms to predict the probability of parking availability.
- Employs inexpensive cameras connected to edge computing devices like Raspberry Pi for real-time data processing.

Detection Module

- Analyzes video streams using computer vision techniques to identify vacant and occupied parking spaces.
- Utilizes image segmentation and object detection models, such as U-Net or YOLO (You Only Look Once), for accuracy in various lighting and environmental conditions.

Indoor Navigation Module

- Leverages Bluetooth Low Energy (BLE) beacons for guiding users to available parking spots.
- Incorporates mobile applications for users to receive turn-by-turn directions based on their current location.

2. Implementation Steps

Site Selection and Preparation

- Select a small parking lot with 10–20 spaces to serve as the test site.
- Ensure adequate coverage of the area with security cameras placed at strategic vantage points to capture clear views of all parking spaces.

Hardware Deployment

- Install low-cost Raspberry Pi units connected to standard CCTV cameras for local image processing.
- Deploy BLE beacons at fixed intervals throughout the parking lot to create a grid for indoor positioning.

Software Development

- Develop a machine learning model trained on parking lot datasets, including locally gathered data to account for Indian conditions.
- Integrate OpenCV and TensorFlow for image processing and real-time classification of parking spaces.
- Build a mobile application for users, featuring a real-time map of the parking lot, navigation assistance, and an interface for reservation if applicable.

Data Processing and Storage

- Use edge computing for preliminary data analysis to reduce latency and bandwidth usage.
- Store historical data in cloud servers for continuous improvement of the prediction model through retraining.

System Testing and Validation

- Perform multiple test runs under different conditions, such as varying lighting, vehicle sizes, and user volumes, to assess system performance.
- Validate the accuracy of prediction, detection, and navigation against ground truth observations.

3. Cost Analysis

A major design goal of the PoC is affordability, especially in the Indian context. Table 1 provides a detailed cost breakdown for each component of the system.

Component	Quantity	Unit Cost (INR)	Total Cost (INR)
CCTV Cameras	1	6,000	6,000
BLE Beacons	3	700	2,100
Miscellaneous (Cables, Mounts)	-	500	500
Total			8,600

This cost analysis demonstrates that the PoC can be implemented within a reasonable budget, making it scalable for larger deployments.

4. Expected Outcomes

The PoC is expected to deliver the following outcomes:

- **Prediction Accuracy:** Reliable estimation of parking availability with an accuracy of at least 85%.
- **Real-Time Detection:** Accurate identification of vacant and occupied spots with minimal latency.
- **User Navigation:** Seamless indoor navigation with a positional accuracy of ±1 meter.

5. Limitations and Scope for Improvement

While the PoC demonstrates the technical feasibility of the system, certain limitations need to be addressed in future iterations:

- **Environmental Factors:** Adverse weather conditions, such as rain or fog, may impact camera performance.
- **Power Management:** Ensuring consistent power supply to BLE beacons and edge devices in outdoor settings.
- **Scalability:** Expanding the system to handle larger parking lots with multi-level structures.

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By addressing these challenges, the PoC can evolve into a robust solution for smart parking management in urban areas

The small-scale PoC for the Indian context involves:
- **Hardware:** Low-cost Raspberry Pi boards, standard CCTV cameras, and BLE beacons.
- **Software:** Python-based image processing libraries (e.g., OpenCV, TensorFlow) and BLE signal processing tools.
- **Deployment:** A parking area with 10–20 spots monitored through IoT-enabled cameras and BLE beacons.

V. PROPOSED SYSTEM ARCHITECTURE

The system architecture of this smart parking management system consists of six main components:
- Camera (Data Source)
- Preprocessing Unit
- Machine Learning Model
- Historical Data
- Indoor Positioning System (using BLE)
- User Interface

These components collectively support the primary functionalities: real-time parking space detection, parking availability prediction, and user navigation within the parking area. Here is a detailed breakdown of each component and the overall data flow within the system:

1. Camera (Data Source)
The cameras serve as the primary data sources for the system, capturing real-time video feeds of the parking area. These feeds are crucial for detecting available and occupied parking spaces.
- **Placement and Coverage:** Cameras are strategically placed throughout the parking lot to ensure full coverage, minimizing blind spots and enhancing detection accuracy.
- **Data Type:** The video data generated by the cameras is high-dimensional and requires processing to identify cars and empty spaces.
- **Transmission:** This data is sent to the Preprocessing Unit for further analysis.

2. Preprocessing Unit
The preprocessing unit is an essential component responsible for transforming raw video data into a format suitable for machine learning analysis. This unit may use edge computing devices, such as Raspberry Pi or local servers, to handle preprocessing tasks.
- **Frame Extraction:** Video feeds are broken down into individual frames, reducing the computational load.
- **Image Enhancement:** Techniques like noise reduction and contrast adjustment are applied to improve image quality, which is essential for accurate detection.
- **Object Detection Preparation:** Regions of interest (e.g., potential parking spots) are identified to reduce processing time for the machine learning model.
- **Data Transfer:** Preprocessed data is then passed to the Machine Learning Model for further analysis.

3. Machine Learning Model
The machine learning model is the core analytical engine of the system, performing predictive and detection tasks using both real-time and historical data. This model relies on various deep learning algorithms for both occupancy detection and availability prediction.
- **Parking Detection:** The model uses object detection algorithms like YOLO, Faster R-CNN, or SSD to classify parking spots as either occupied or vacant.
- **Algorithm Comparison:** Faster R-CNN provides high accuracy but may be slower, whereas YOLO offers real-time detection capabilities, making it suitable for environments requiring quick responses.
- **Prediction:** Leveraging historical parking data, the model can forecast parking availability, allowing users to check the probability of finding an available space before leaving home.
- **Model Type:** Time-series models, such as LSTM, or other machine learning algorithms are applied here to capture temporal patterns in parking lot usage.
- **Output:** The model outputs real-time occupancy status and predictive availability data to the User Interface.

4. Historical Data
Historical data plays a vital role in improving the accuracy of parking availability predictions. This data is accumulated over time, allowing the model to learn patterns related to peak hours, weekends, holidays, and other factors that influence parking demand.
- **Data Collection:** Historical data is gathered from past occupancy records and user interaction logs.
- **Data Storage and Access:** Stored in a cloud or local database, this data is readily accessible by the machine learning model to continuously refine its predictions.
- **Pattern Recognition:** Analysis of historical trends allows the model to make informed predictions based on past usage patterns, weather conditions, or special events.

5. Indoor Positioning System (Using BLE)
The Indoor Positioning System (IPS) provides real-time navigation assistance within the parking facility using Bluetooth Low Energy (BLE) beacons. Once a user arrives at the parking facility, this system helps them navigate to an available parking spot.
- **BLE Beacons:** BLE beacons are strategically placed throughout the facility to provide signal triangulation for accurate positioning.

International Journal of Scientific Research & Engineering Trends
Volume 11, Issue 1, Jan-Feb-2025, ISSN (Online): 2395-566X

- **User Device Communication:** The BLE signals are detected by the user's smartphone, which calculates its position within the facility.
- **Navigation:** Based on the user's location, the system provides step-by-step directions to the nearest available parking spot.
- **Accuracy:** BLE is chosen for its cost-effectiveness and capability to provide meter-level accuracy, which is sufficient for indoor navigation within a parking lot.

6. User Interface

The user interface (UI) is a mobile application that serves as the main point of interaction for end-users. Through this app, users can check real-time parking availability, access predictions, and receive navigation guidance.

- **Real-Time Availability Display:** The UI provides a live map of the parking lot, showing available and occupied spots, updated continuously by the machine learning model.
- **Predictive Availability:** Users can check the probability of finding a vacant parking spot before leaving home, which is useful for planning.
- **Navigation Assistance:** Once on-site, users receive directions to the nearest vacant parking spot through the IPS system.
- **Additional Features:** The app may also support functionalities like parking reservation, payment options, and notifications to enhance user convenience.

7. Data Flow

The system operates in a continuous data flow, summarized as follows:

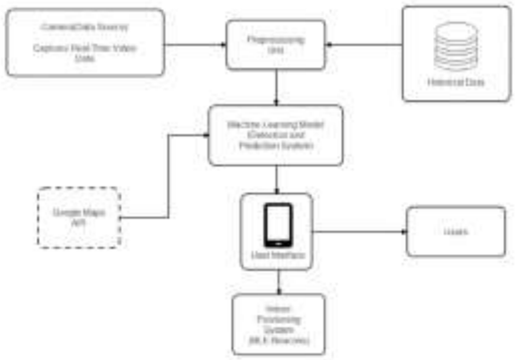
- **Data Collection:** Cameras capture live video feeds of the parking area.
- **Preprocessing:** Video frames are processed in the preprocessing unit to enhance image quality and reduce data volume.
- **Detection and Prediction:** The preprocessed data and historical records are analyzed by the machine learning model, which outputs real-time occupancy status and predictive data.
- **User Access:** The processed data is sent to the user interface, where users can view parking information and receive navigation guidance.
- **Indoor Navigation:** Once at the facility, the IPS module guides the user to an available parking spot, using BLE signals to triangulate their position.

8. Benefits of the System Architecture

This architecture is designed to be:

- **Modular and Scalable:** Components like the preprocessing unit, machine learning model, and IPS are modular, allowing easy expansion to accommodate more parking lots or additional functionalities.
- **Efficient and Real-Time:** Edge computing for preprocessing and high-speed algorithms like YOLO enable real-time detection, ensuring users receive up-to-date information.
- **User-Friendly:** The mobile application provides an intuitive interface that combines prediction, detection, and navigation for a seamless parking experience.
- **Cost-Effective:** By leveraging affordable components like BLE beacons and edge devices, the system is economically feasible for large-scale deployment, especially in urban settings.

This comprehensive system architecture effectively addresses the major challenges of urban parking management—predicting availability, detecting occupancy, and guiding users to available spots—all in real time.



VI. EVALUATION AND DISCUSSION

The IoT and computer vision-based parking management system offers substantial benefits in improving parking efficiency, reducing search time, and enhancing user convenience in urban areas. However, its effectiveness hinges on certain performance metrics and practical considerations.
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1. System Accuracy and Responsiveness

- The object detection algorithms (e.g., YOLO, Faster R-CNN) effectively identify parking occupancy, with YOLO being favorable for real-time applications due to its faster processing speed. However, accuracy is often compromised in low-light conditions or when vehicles partially obscure each other, leading to occasional false positives or negatives.
- The BLE-based Indoor Positioning System (IPS) provides effective navigation within the facility, though its

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accuracy is limited to 1-5 meters. This precision level is generally adequate but can sometimes make exact spot navigation challenging, especially in dense parking areas.

2. User Experience

- Users benefit from real-time availability updates and guided navigation, significantly reducing parking search times and frustration. The mobile application interface is crucial for user adoption; a clean, intuitive design is essential for frequent usage.
- Predictive capabilities based on historical data enable users to assess the likelihood of finding a parking spot before arrival. This feature improves planning but requires continuous refinement as parking behavior may vary significantly over time or during peak events.

3. Scalability and Infrastructure Requirements

- While effective in small-scale deployments, expanding to larger or multiple parking facilities demands additional computational resources and network infrastructure, especially for video processing and data storage. Cloud integration may help but introduces dependency on internet connectivity and potential latency issues.
- Installation and maintenance of IoT devices (cameras, BLE beacons) incur costs that may be prohibitive in resource-limited environments. Additionally, regular maintenance is essential to ensure system reliability, which may increase long-term operational expenses.

4. Privacy and Security

- The system's reliance on video data and user location raises privacy concerns. Data encryption and access controls mitigate risks, but adherence to data protection regulations is essential to gain user trust.
- The system must balance data collection for predictive modeling with minimal intrusion into users' privacy, particularly by avoiding excessive personal data storage.

5. Environmental and Operational Constraints

- Weather and environmental conditions affect both computer vision accuracy and BLE signal strength, potentially impacting detection reliability in outdoor settings. These limitations underscore the need for backup solutions, such as redundant sensors or alternative navigation options.

Future Directions

Future research should focus on enhancing the scalability of the system, particularly for multi-level parking structures. Advancements in edge computing and 5G networks can further reduce latency and improve system responsiveness. Integrating renewable energy sources, such as solar panels for powering BLE beacons and cameras, can also reduce operational costs and support sustainability goals.

VII. CONCLUSION

IoT and computer vision technologies hold immense promise for transforming urban parking management systems. By integrating predictive models, real-time parking detection, and BLE-based indoor navigation, this project aims to alleviate parking challenges in Indian cities. Future research should focus on refining prediction algorithms, addressing environmental limitations in image processing, and optimizing the scalability of BLE-based navigation systems.

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