Intelligent Remote Monitoring of Parking Spaces Using Licensed and Unlicensed Wireless Technologies

Rahat Iqbal, Tomasz Maniak, and Charalampos Karyotis

Abstract

Short- and long-range wireless communication is imperative for many remote monitoring applications such as industrial automation, digital health, and smart cities. Remote monitoring is one of the components of complex systems that can be optimized with the use of machine-learning-based techniques. In this article, an intelligent parking system is presented. The system exploits the benefits of a synergy between licensed and unlicensed wireless technologies, IoT, computer vision, and artificial intelligence. We discuss how an end user can interact with the system and manage it with a user interface. The user interface provides a range of dashboard facilities that provide various statistics about car park utilization and optimization facilities. Our proposed solution comprises a range of sensors including high-resolution cameras, which are distributed throughout a car park. The cameras are connected using different types of wireless communication. The data is processed in real time by the sensors and sent to a cloud server, where it is analyzed, stored, and presented to the end user. The object detection, tracking, and optical character recognition system are executed by the vision sensor, which utilizes a combination of convolutional neural networks and a proprietary deep-learning-based object detection algorithm. This solution has achieved high levels of classification accuracy (99.97 percent) and high image processing speeds (66 ms).

Introduction

Nowadays, there is an identified need to enhance interoperability between licensed and unlicensed spectrums and corresponding wireless technologies to enable the transfer of higher data volumes and fuel the development of effective applications such as remote monitoring applications. One emerging remote monitoring application area is the development of smart parking systems. Smart parking systems continue to gain popularity due to their benefits for drivers, car park owners and managers, as well as the environment. These benefits include exploitation of the accumulated data for informing managerial decisions and optimizing pricing strategies, reduction of air pollution caused by vehicle emissions, decrease in fuel consumption due to reduced vehicle travels, and reduction of traffic congestion [1].

Smart parking applications have a significant impact on the economy. The parking turnover in the United Kingdom alone is valued at £1500 million per annum for local authorities, while the private sector market is estimated to be even higher. Modern advances in wireless technologies and big data analytics provide the basis for developing a new generation of smart parking applications.

The main motivation for this work is to propose a robust and novel solution to the problem of automated remote monitoring of parking spaces with the use of wireless and machine learning technologies.

In this article we present an innovative solution to monitor car parking availability in car parks of all shapes and sizes. This solution will alleviate the frustration of crawling around a car park looking for a space, optimize billing and parking allocation, and allow businesses to intelligently manage their own car parks. Smart parking will become the latest of many services to benefit from the use of smart wireless and machine learning technologies.

The novelty of the approach presented in this article results from a unique combination of sensors, wireless technology, and data processing techniques that enables accurate detection of parking space occupancy and high accuracy predictions of the future utilization of car park spaces. The combination of deep learning techniques exhibits high performance in license plate and object detection with Internet of Things (IoT) technology, and solves an established challenge of linking a parking space with a specific car in an innovative fashion. Additionally, the utilization of parking sensors to identify the number and movement of people in a given area has not been applied before in this context.

This article initially provides an overview of smart parking technologies, describes wireless technologies that can be used for developing smart parking applications, and presents machine learning techniques and big data methodologies. Later, the authors describe the proposed smart parking solution. Finally, the benefits of deploying this solution are highlighted, and future research directions are discussed.

Background

Smart Parking Technologies

Recent research has combined sensory equipment and wireless technologies to deliver effective smart parking systems. In [2] the vehicle is

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> Short- and medium-range communication has become crucial for a number of applications related to vehicle-to -ehicle (V2V), vehicle-to -nfrastructure (V2I), and infrastructure-to-user (I2U). Its usefulness results mainly from how it improves the accessibility and data collection capabilities of many systems.

connected to the WiFi network of a specific parking space. Infrared sensors are used to send the status of the parking slot to a microcontroller. Finally, this information is uploaded to a webpage that is used to inform the driver of the vacancy of a particular space [2]. In the smart parking system presented in [3] IoT is used to monitor the status of parking spaces. A mobile application is used to inform the driver to check availability and pre-book a parking space [3]. Other researchers combined intelligent algorithms and network architectures to develop smart parking systems that enable drivers to automatically find the most suitable parking space by considering the distance and space availability [4]. Recently, research combined WiFi and wireless network technologies (geomagnetic sensors) to detect parking space availability and navigate the driver to an available space [5].

JustPark is a commercial smart parking system that offers a car park search and location service for all local sites, while it provides a reservation facility and allows individual users to register with the service and offer their private spaces for rental. Clearview Intelligence is another solution that offers bay monitoring using a combination of infrared and magnetic field detectors to determine occupancy. The method of communication is 868 MHz radio with approximately 35 m range. The devices are laid out in a mesh-type network. Repeater units are used on the surface of the road. Finally, Appy Parking provides parking sensors and general information regarding parking space prices. The sensors use Bluetooth for short-range communication. The sensors are glued onto the road.

Smart parking applications are divided into the following categories.

Parking Guidance and Information Systems (PGISs): These systems help drivers to reach their destination and locate an available car park and a vacant space within the car park.

Transit-Based Information Systems: These systems are differentiated from PGISs by guiding drivers to park and ride facilities.

Smart Payment Systems: These systems are designed to overcome the delays and limitations caused by conventional payment methods.

E-Parking: E-parking systems check the availability of parking spaces in a car park, enable parking space reservations, and ensure the availability of parking space before the driver arrives at the parking area.

Automated Parking: These systems include computer-controlled mechanisms that are responsible for automatically placing the car in the designated parking space.

The most crucial part of a car parking system is car park occupancy detection. Toward this goal, a multitude of sensory equipment has been used. The choice of equipment relies on the car park type and layout. Sensory equipment includes sensors that are invasively installed on the parking area, such as: active infrared, inductive loops, magnetometers, magneto resistive sensors, pneumatic road tubes, piezoelectric cables, and weigh in motion sensors; and non-obtrusive sensors and technologies such as microwave radar, passive acoustic array sensors, passive infrared sensors, RFID, ultrasonic, and computer vision [6]. These sensors are connected together with different wireless technologies of which we provide a brief description in the next section.

The application of smart parking technology presents a number of challenges that are a barrier and a reason why the solutions are still not very popular and widely used. The first challenge is the actual price of a device ranging from £150 to £1000 per unit. This cost along with the support contract cost make smart parking inaccessible and not a viable solution for many companies. Another challenge is the high power consumption of those devices that are mainly battery-based. This means that the power units have to be replaced frequently, which adds to the maintenance and utility costs. In addition, the usefulness of the data generated by those devices is highly reduced by the lack of a high-performance generative algorithm that can make predictions and model car park utilization. The next challenge is the integration between the different sensors and technologies to achieve seamless functionality and optimize the value for the end customer. Finally, there is the challenge of integration with a robust automatic payment system, which ensures customers are charged correctly and do not need to waste unnecessary time using physical money and accessing payment stations.

Wireless Technologies

Short- and medium-range communication has become crucial for a number of applications related to vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-user (I2U). Its usefulness results mainly from how it improves the accessibility and data collection capabilities of many systems. In V2V, for example, the data collected by a vehicle's embedded sensors and cameras described by specific characteristics of the data such as heterogeneity, redundancy, incompleteness, and size make the analysis and extraction of valuable information very challenging. This challenge requires the application of new mechanisms that can process the data efficiently. One of the challenges in data collection therefore is the volume of data, which makes the communication exchange between all parties via V2Vand V2I very difficult and sometimes impossible. This is due to the opportunistic, occasional, and not long lasting characteristics of these communication capabilities. Furthermore, the security aspect poses another challenge that for a long time has been considered one of the most important tasks of data collection. This is especially true in wireless communication because open wireless connections to others expose the data and its holder to various kinds of attacks. The ease of data exchange in short- and medium-range communication makes it vulnerable to malicious behaviors and an easy target to attackers mainly due to the sensitivity of information they hold.

In this section, we briefly present the most popular wireless technologies, which are currently being used by smart parking applications. We highlight the main features of wireless technologies that can be used to exploit both licensed and unlicensed spectrum, and develop state-of-the-art smart parking applications such as the one described in this article.

Bluetooth: Bluetooth is one of the most common wireless communication systems, and is used mostly to exchange data over short distances. Bluetooth is specifically designed for short-range and low-cost devices, and it is based on two network topologies, namely the piconet and the scatternet. The maximum number of devices in a Bluetooth network building cell is eight [7]. Bluetooth features short wavelength radio transmission in 2400–2480 MHz, which is unlicensed spectrum in most countries, frequency hopping with 79 channels and 1 MHz bandwidth, and features low power consumption, fast data exchange, widespread availability, and limited effect on battery life [8].

WiFi: WiFi includes IEEE 802.11a/b/g standards for wireless local area networks (WLANs). WiFi is oriented to about 100 m and enables Internet access at broadband speeds when there is a connection to an access point (AP) or in ad hoc mode. WiFi protocols have spread spectrum techniques in the 2.4 GHz band, which is known as the industrial, scientific, and medical (ISM) band. WiFi nominal transmission power is estimated to be 20 dBm. WiFi utilizes transmission power control and dynamic frequency selection, direct sequence spread spectrum (DSSS), complementary code keying, or orthogonal frequency-division multiplexing (OFDM) modulation with 14 RF channels and a bandwidth of 22 MHz. The basic cell of an IEEE 802.11 LAN is the basic service set (BSS). The BSS is a set of mobile or fixed stations. In the cell there could be a maximum of 2007 devices for a structured WiFi BSS. WiFi consumes more power than Bluetooth and Zigbee since it is designed for a longer connection and supports devices with a substantial power supply.

LTE-U: Toward enabling users to effectively use both licensed and unlicensed spectrum under a unified LTE network infrastructure, LTE-Unlicensed (LTE-U) is able to support improved coverage and greater capacity than cellular/WiFi interworking. At the same time, LTE-U enables smooth data flow between licensed and unlicensed spectrum through a single Evolved Packet Core (EPC) network. As reported in recent research studies, LTE-U performance shows some instability especially when there is interference by WiFi activities. This reality makes it difficult for LTE-U applications to guarantee quality of service. LTE-U is focused on providing multimedia services and operates on the 5 GHz band. LTE-U devices utilize dynamic frequency selection, clear channel assessment (CCA), or listen-before-talk [9].

ZigBee: ZigBee can be described as a wireless mesh network based on IEEE 802.15.4. Zigbee is a reliable, cost-effective, long-battery-life, and low-power solution for an operating space of approximately 10 m. ZigBee utilizes DSSS with a bandwidth of 2 MHZ and 16 channels. Zigbee's data rates are low (250 kb/s/channel in the 2.4 GHz band, 40 kb/s/channel in the 915 MHz band, and 20 kb/s/ channel in the 868 MHz band). As described in the comparative study by Mahmood *et al.*, in a Zigbee network all connections can be optimized and updated dynamically, and each of the network nodes can be reached by multiple links, features that make Zigbee a resilient network that can deal with node and link failures. Zigbee also provides IP functionality and offers interoperability and compatibility by supporting communication with IPv6-based nodes using other network architectures like WiFi and Ethernet.

> The proposed solution is based on the use of small sensors mounted in each parking space. The sensors are designed in such a way as to reduce the power consumption to the minimum with the use of a low-power circuit that is powered with solar energy and rechargeable battery.

Ultra-Wideband (UWB): Ultra-wideband technology can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. One of the key characteristics of UWB is that it can support demanding applications, such as video, and its bandwidth can be up to 480 Mb/s. Therefore, UWB usage is suggested for short-range and high data rate applications. The basic cell of UWB is the same as for Bluetooth: a piconet with a maximum of 8 cell nodes. UWB has a frequency band of 3.1–10.6 GHz, a range of 10 m, a max signal rate of 110 Mb/s, and 1–15 RF channels with a channel bandwidth of 500 MHz–7.5 GHz. UWB uses adaptive frequency hopping, and modulation types binary or quadrature phase shift keying (BPSK or QPSK), and direct sequence UWB (DS-UWB) or multi-band OFDM (MB-OFDM).

6LoWPAN: The concept of 6LoWPAN stems from the need for a protocol to enable small low-power devices to participate in IoT. As described in [7], 6LoWPAN enables IEEE 802.15 and IPv6 to work together in order to achieve IP-enabled low-power networks of sensors, controllers, and so on. 6LoWPAN is an emerging technology in the market that aims to replace WiFi. 6LoWPAN is mostly used in home automation systems that utilize the open IP standard, mesh routing, and multiple PHY support. As presented in [10] 6LoWPAN is able to connect the devices within a network wirelessly at low power while maximizing the diversity and flexibility of the interconnections and communications. This technology enables the interactions between devices to be configured remotely by the user connected to a local network with remote access control [10]. 6LoWPAN features low power consumption, long lifetime and transparent internet integration. These features can support the development of effective IoT applications. In addition, this technology is a license-free standard for IoT and provides better quality of service (QoS).

Relative Comparison between the Protocols: The number and variety of the wireless communication protocols described above makes it necessary to briefly discuss their advantages and disadvantages. Thus, for example, Bluetooth is cheap to implement and easy to install, and connecting the devices is relatively simple. However, it is vulnerable to security breaches and can connect only two devices at once. It is therefore more desirable to use Zigbee instead in applications where security and connectivity are

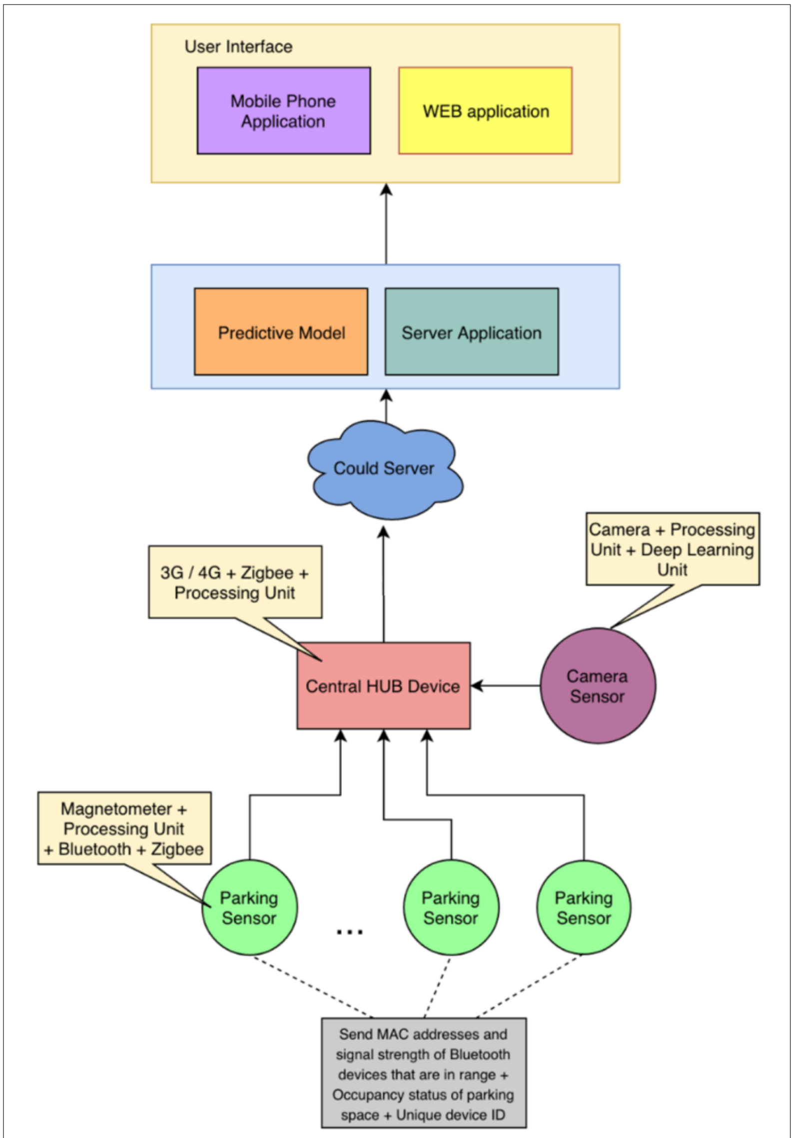

FIGURE 1. Smart parking system architecture.

required. Another advantage of using Zigbee is the low power consumption and ease of access. The disadvantage, however, is cost and speed; the price of a Zigbee module is sometimes 10× the price of a Bluetooth module. In applications where the communication distance and speed are important, the right choice would be to use third/fourth generation (3G/4G). However, they are much more expensive and not suitable for small distributed sensor networks.

Deep Learning for Data Analytics and Computer Vision

Deep learning is an artificial intelligence technique that imitates the human brain in processing data and creating patterns to be used in decision making. It utilizes multiple levels of artificial neural networks to deliver its machine learning services. Deep learning has been the computational basis for developing innovative solutions in many scientific domains and for setting new records in machine learning tasks, such as image recognition, speech recognition, and sentiment analysis, where it has achieved superior forecasting and classification performance.

Recently, deep neural networks (DNNs) have shown outstanding performance on image classification tasks. Convolutional neural networks (CNNs) are the most successful architectures. A CNN is a special type of multi-layer neural network inspired by how a human brain processes visual sensory information. They are designed to recognize visual patterns directly from pixel images with minimal preprocessing to an input image. Despite the differences in the neural network architectures and their compositions, they all share a number of common features. They are structured in a layered fashion with each consecutive layer learning more complex representations of hidden features that compose an image. The neural network training is performed by iteratively adjusting the parameters called weights of the model to reduce an error of a cost function that expresses how well a model fits the data. Finally, they all use a concept of receptive fields, which is a region of the input space that affects a particular unit of the network. CNNs are used to solve a wide range of computer vision problems such as:

- Classification: classifying an image into one of many different categories
- Localization: finding the location of a single object inside the image
- Instance segmentation: not only finding objects inside an image, but also finding a pixel-by-pixel mask of each of the detected objects

Object detection combines the problem of localization with object classification. Although the application of DNNs to the problem of object detection is well established, the use of linear filters and standard computer vision techniques is still the norm in the context of vehicle license plate detection.

Smart Parking System

In this article, we integrate a short-range unlicensed wireless communication with long-range licensed wireless communication in a novel application of a remote car parking monitoring system. This combination of wireless communication allows for a synergy in technologies that achieve a robust, easy-to-maintain, and inexpensive network of IoT devices. The proposed system (shown in Fig. 1) is an innovative way to track car parking availability in car parks of all shapes and sizes.

The proposed solution is based on the use of small sensors mounted in each parking space. The sensors are designed in such a way as to reduce the power consumption to the minimum with the use of a low-power circuit that is powered with solar energy and rechargeable battery. This design ensures that the device can run with no interruption or need for maintenance for many years. The very low cost of the individual sensors means that the devices can be used in high volumes and cover large areas. The device, in the most simplistic form, contains a processing unit, a sensor, a short-range wireless transceiver, and a power source (Fig. 2). The devices are in sleep mode most of the time, and they are enabled on an interruption generated by the sensor. This interruption executes the part of a firmware device that is responsible for analyzing the continuous signal generated by the sensor, and with the use of a previously trained artificial neural network it can detect a unique pattern that indicates a movement of a car. The movement of a car can be classified into two classes "car moving into a parking space" or "car leaving a parking space." When the sensor detects the movement, it identifies and saves all the Bluetooth devices in its vicinity, together with the strength of their signals. The positive verification of the signal indicating that a car has parked or left a parking space together with a set number of the closest Bluetooth devices and a unique device identification is transferred to a wireless transceiver that sends the information to a central hub. The information is further transferred from the hub to a cloud server with the use of long-range wireless communication protocol. The server application stores the occupancy information in a database together with the date/timestamp and a list of Bluetooth devices for further data processing. The list of Bluetooth devices is also compared to the list of all subscribers to the automated payment system. Given a positive data filtering and identification of an individual system user, the server sends information to a mobile phone application for that specific user. The client has the option to select the amount of time they plan to use the parking space and arrange the payment for the car park usage.

The above described functionality also helps to identify people's movement and a "business" for a given location that can be defined as the number of people per a defined fixed area of space. This is achieved by using the sensor to passively scan and identify nearby signals every fixed interval of time for all wireless devices accessible to that particular sensor. By coordinating the readings from different sensors and using a triangulation algorithm, one can track the movements of individual people with high precision. This information can be used to better design public space, business outlets, and other access points.

In order to detect a car's presence, the device uses a magnetometer sensor. This sensor detects the strength of the magnetic field to which it is exposed. When the metallic body of the car is in the way of the earth's field, the flux lines are absorbed into the metal, creating non-uniformity in the distribution of flux lines. By measuring the output of the sensor in a continuous way, it is possible to identify those distortions to the magnetic field and detect car presence. With the use of a sensitive enough sensor, it is possible not only to identify the presence of a car but also to identify the type of car by looking at the individual footprint generated by that car.

The individual sensors are assembled into a network. The network of sensors is organized in a star topology where all nodes are individually connected to a central connection point, a dedicated mini-hub that combines the simplicity and low cost of short-range wireless communication with long-range 3G/4G wireless mobile telecommunications technology. The central hub keeps track of the occupancy status of a group of sensors using a short-range wireless protocol. This information is transmitted using WiFi/GPRS to the main server for further processing.

In addition to the network of sensors and a central hub, the proposed system integrates a number of automated vision inspection devices

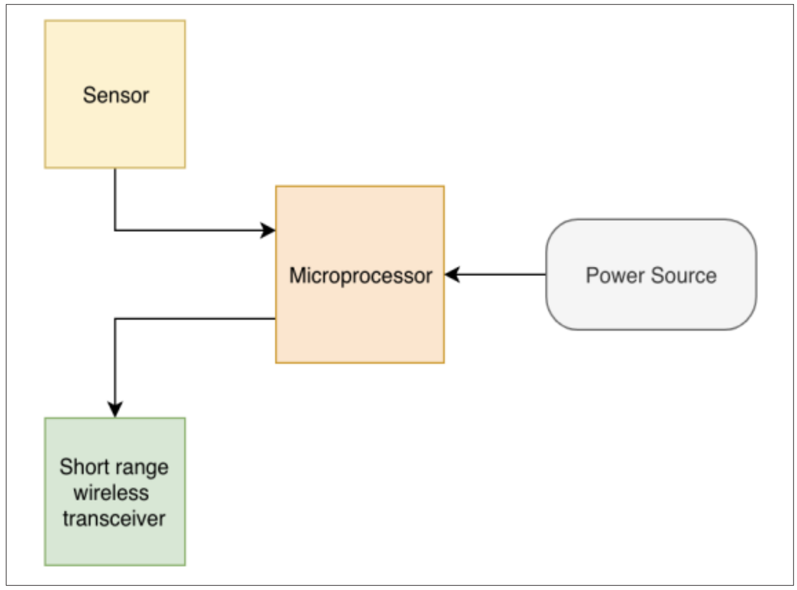

FIGURE 2. Device diagram.

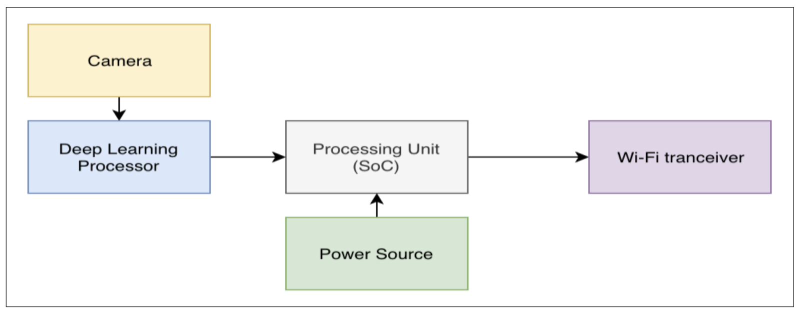

FIGURE 3. IoT vision inspection device diagram.

that are connected to the central hub via WiFi communication protocol and are capable of identifying vehicles, tracking them between individual video frames, and performing number plate recognition. The IoT automated vision inspection devices are designed in such a way as to perform all the vision and related data processing tasks on the actual device. In order to enhance functionality, the devices consist of a high-resolution camera, a processing unit in the form of a system on a chip (SoC), a machine learning processor, and a WiFi transceiver. The object detection, tracking, and optical character recognition system is based on deep learning, and utilizes a combination of CNNs and a proprietary deep-learning-based object detection algorithm [11, 12].

The raw image from the camera is processed with the use of a previously trained deep learning algorithm that is stored and executed on a deep learning processor. The annotated data is then sent to the main processing unit, which in turn sends it to the cloud server. This information is processed by the server and stored in the database (Fig. 3). The main use of this information is to facilitate the automated payment system or allow selective access to a gated carpark. In this case, unlike in the previous example where a sensing device is used, there is no need to run a separate application on a mobile phone but rather use the information acquired by an automatic OCR system. The IoT vision inspection devices can also count the traffic in a given

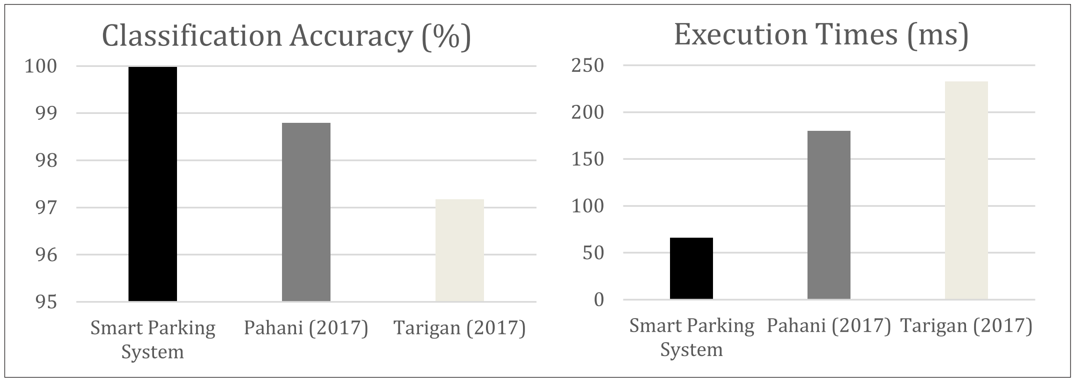

FIGURE 4. OCR recognition classification accuracy and execution time comparison.

area and identify a driver's undesirable behavior, for example, automatically report fly-tipping or illegal waste dumping. The proposed automated object detection (AOD) system uses DNNs to accurately identify the exact position of an object in a field of view of an imaging sensor. The system for any given input image or a video sequence outputs a probability mask corresponding to each pixel of an input image or a current video frame. The probability mask is defined as an output vector where each element of that vector is in a range between 0 and 1 and represents a probability of a corresponding element of an input vector belonging to the object that is being detected. In practice, this means that all elements of an input vector which do not belong to the target object are assigned a value of 0, and all the pixels which belong to that object have a value of 1. The DNN is built in a symmetrical way such that the inputs are fed to multiple blocks of convolution and pooling layers, each time reducing the size of a block. When the convolution layer is small enough, the process is reversed, and the outputs are fed through multiple blocks of de-convolution and up-sampling to the point where the convolution layer is of the same size as the input. The DNN is trained using one of the gradient descent optimization algorithms. The loss function used is mean square error.

Comparative Evaluation

We compared our OCR results with state-of-the-art research and development [13, 14]. Pahani *et al.* utilized CCA and RANSAC as a detection method and a probabilistic support vector machine for recognition, and as can be seen in the comparative study in [13], they managed to outperform other existing methods. Pahani *et al.* achieved a plate detection accuracy of 98.7 percent with a processing time of 180 ms [13]. Tarigan used a GA optimized backpropagation neural network. Tarigan *et al.* achieved 97.18 percent for character recognition accuracy with average pre-processing time 229.88ms and average feedforward time 2.50 ms [14]. The proposed algorithm has outperformed the existing approaches for classification accuracy. The method discussed in this article is based on DNNs and integrated with proposed IoT hardware architecture, and improves the accuracy rate to 99.98 percent with an image processing speed of 66 ms. The comparative results are shown in Fig. 4.

Conclusions and Future Work

In this article, we have presented an innovative smart parking solution based on IoT, deep learning, and wireless technologies. This solution can be used by municipal authorities and private companies owning parking areas, as well as individual drivers in order to eliminate the stress of driving around and reduce the time looking for a space by finding the best suitable available space for each driver and direct them to it; support local businesses and authorities to maximize their parking capacity and profit through predictive analytics; and promote drivers' well being and parking management through providing functions such as automated payment, pre-booking, automatic vehicle location detection, and others. Autonomous vehicles can benefit from real-time information about car spaces availability to plan their routs more effectively [15].

Our future work will involve integrating the system with other services such as satellite-navigation systems, local council information systems, and traffic management systems to provide users with real-time information. The richness of data acquired during the operation of the car park monitoring system will help to improve the access to the services, buildings, and infrastructure.

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