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Preprint · September 2020

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Implementation of a Magnetometer based Vehicle Detection System for Smart Parking applications

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***Abstract*—The time lost looking for a free parking spot in a city impacts negatively not only on the mood of the drivers but also on the environment in terms of air quality and fuel consumption. The vehicle detection can be considered as the most important task in Smart Parking systems as it allows to automatically monitor the occupancy state of the parking spots in a city. In this paper, we implement and test a vehicle detection system based on a magnetometer sensor, which is part of a complete Smart Parking system under development at the University of Cagliari. After a preliminary analysis conducted to test the performance of the magnetometer, we conducted two specific experiments to investigate the suitability of the magnetometer as the mean to detect the presence of a vehicle in the parking spots. The first experiment, involving 15 different vehicles, has demonstrated that the magnetometer can be used to reliably detect the presence of a vehicle in a parking spot if it is placed under the front or rear axle of the vehicle. From the second experiment it resulted that, when considering 3 adjacent parking spots and only one magnetometer placed in the central spot, it is not possible to reliably detect the vehicles parked on the adjacent spots. Therefore, one magnetometer for each considered parking spot is needed.**

***Index Terms*—Internet of Things, Vehicle detection, Smart Parking, Magnetometer sensor, Smart City.**

I. Introduction

During the last years, the term traffic congestion has brought together all crowded towns. Carrying out daily activities in the centre of the city has become a hard task. Stores, markets and also big companies are mostly located in downtown. This implies looking for a parking spot in a busy city and sometimes taking also public transport if the parking spot is far from the centre. Nowadays, looking for a free parking spot is definitely a waste of time. This long research has also a direct impact on the mood of the driver, as well as on the air quality and the fuel consumption. For these reasons, environmentalists started monitoring the quality of the air in the cities and the statistics are worrying. A recent analysis of particle concentration-effect highlighted an excess of 8.9 million deaths per year, specifically from outdoor air pollution [1]. This alarm must change the people habits approach, for instance, by using different kind of transport means, such as the public transport. Unfortunately, not all the big cities are well connected to the hinterland and then using the car in some cases is the only possible choice.

This work was supported in part by Italian Ministry of University and Research (MIUR), within the Smart Cities framework (Project: Netergit, ID: PON04a200490).

Car-companies have started to work on a smart way to find the parking spot. For example, Ford [2] and Mercedes-Benz [3] implemented car radars to scan the streets during the ride to find a free spot. This solution can help the drivers owning these vehicles but does not solve the parking problem in a city. Also, the cost of these vehicle is not affordable to all citizens. Therefore, a more general solution is needed. Recently, the ICT-related research groups have taken a central role in the support of the parking problem in the cities by proposing smart solutions based on emerging technologies, such as the Internet of Things (IoT) [4]. With IoT-based solutions, different kinds of sensor can be used to detect the occupancy of a parking spot, such as magnetometer [5], infrared [6] or ultrasonic sensors [7]. The information regarding the occupancy of the monitored parking spots is then transmitted to a cloud IoT platform, where it is processed and then made available to the citizens typically through mobile applications.

Off-street parking, such as municipal car parks or large fields that can accommodate hundreds of vehicle, are typically easier to monitor by applying entrance counters and cameras or sensors to identify the occupation of precise parking spots [8]. Being closed and controlled buildings, common issues of on-street parking, such as vandalism and extreme weather conditions, are avoided. Indeed, monitoring on-street parking is more challenging and it is the focus of this study. In particular, we focused on on-street vehicle detection based on a magnetometer sensor. Although there are several studies in the literature considering the magnetometer in Smart Parking systems, it is difficult to find comprehensive and extensive results regarding experiments that tested the performance of this sensor for the vehicle detection task.

Specifically, in this paper, we implement and test a vehicle detection system based on a magnetometer sensor, which is part of a complete Smart Parking system under development at the Department of Electric and Electronic Engineering at the University of Cagliari. The architecture of the proposed Smart Parking system and its main functionalities are firstly presented to introduce the considered scenario. Then, we describe the hardware devices considered to implement the vehicle detection system. Specifically, a tri-axial magnetometer and an Arduino have been considered as the vehicle detection sensor and the board to collect and process the sensed data, respectively. After a preliminary analysis conducted to test the performance of the magnetometer, we conducted two specific experiments to investigate the suitability of the magnetometer as the mean to detect the presence of a vehicle in the parking spots. The first experiment has demonstrated that the magnetometer can be used to reliably detect the presence of a vehicle in a parking spot if it is placed under the front or rear axle of the vehicle. Fifteen different vehicles were used for this experiment. From the second experiment it resulted that, when considering 3 adjacent parking spots and only one magnetometer placed in the central spot, it is not possible to reliably detect the vehicles parked on the adjacent spots. Therefore, one magnetometer for each considered parking spot is needed.

The paper is structured as follows. Section II discusses the major related works in this area. Section III presents the proposed smart parking system. In Section IV, we perform a preliminary analysis on the hardware devices considered for the vehicle detection task whereas Section V presents the result of the experiments conducted to test the suitability of the magnetometer sensor for vehicle detection. Finally, Section VI concludes the paper.

II. Related work

There are many studies considering Smart Parking systems in the literature. A comprehensive survey of Smart Parking solutions is provided in [9], [10]. A specific overview of technologies used for the vehicle detection is proposed in [11], [12]. In [13], a comparison of the strengths and drawbacks of vehicle detection sensors and technologies for open parking spots is provided.

The vehicle detection system can be considered as the fundamental part of every Smart Parking system and state-of-the-art Smart Parking systems have considered many different kinds of technologies to achieve this task, ranging from sensors and RFID to cameras and smartphones. In [14], [15], on-street parking spots are monitored with roadside cameras, which send captured pictures to a trained Convolutional Neural Network (CNN) that analyzes the street image to check if there is a free spot or no. In [7], the vehicle detection device consists of two ultrasonic sensors, which measure the free space in both the front and back sides of the vehicle. If the measured space is greater then a threshold, the spot is free otherwise is occupied. In [8], ultrasonic sensors are mounted on the side of a vehicle to measure the distance from the vehicle to the roadside. A supervised learning algorithm is designed to analyse the structure of the sonar trace to differentiate parked cars from road clutter. In [6], RFID readers are used to control the entry and exit gates of an indoor parking whereas infrared reflective sensors act as in-spot sensors that detect the occupancy state of the parking spot. The system proposed in [16] is designed to take advantages of the embedded sensors and of the short-range communication capabilities of smartphones. The aim is to identify parking actions automatically by analyzing the states of some sensors, such as accelerometer and gyroscope, and by identifying the transitions occurring between modes of transportation (e.g., from the car to walking and vice-versa).

With regard to the magnetometer sensor, which is the one considered in our proposed vehicle detection system, there are several works that already considered it in their smart parking systems. However, it is difficult to find a study providing comprehensive and extensive results regarding experiments that tested the performance of this sensor for the vehicle detection task. In [17], a sensor node with magnetometer is placed between two adjacent parking spots on the ground to detect which spot is free/occupied. The vehicle detection rate of this module is said to be 98% but no details about experiments are provided. In [18], an array of 5 tri-axial magnetic sensors were placed on the roadside to detect the presence of a vehicle near the sensor. Only two cars were used for experiments (Peugeot and Volkswagen Beetle) and four case studies were considered. Experimental measurements showed that the sensor placed in front of the single car clearly detects the vehicle both in the parking and during the approach whereas in presence of other cars it is necessary to remove the "background noise" (i.e., the signal detected with just one car parked) to detect the vehicle. The vehicle detection method proposed in [5] combines the magnetic signal with the signatures of UWB (Ultra Wide Band) channel to improve the accuracy of detection results. From the acquisition of magnetic signal, authors found that the maximum magnetic strength appears in the vicinity of the front or rear axles of the measured vehicle. On the contrary, the magnitude of measured magnetic variation is very weak between these axles. The detection accuracy of the proposed combined method is 98.81%. In [19], a distance sensor is used to support the vehicle detection performed by a magnetic sensor to minimize errors. However, no performance measurements are provided. A vehicle detection algorithm based on the magnetic variations induced by a car parking in a spot is provided in [20], which achieves an accuracy of about 98.5%. However, it is not clear if experiments were performed with different vehicles or with the same vehicle.

Commercial devices with magnetic sensors are also available in the market, which are already used to implement vehicle detection for Smart Parking systems in many towns around the world [21]. The Smart Parking Systems solution developed by Intercomp[1] has been considered by many cities, such as Singapore, Vienna, Treviso and Madrid. This solution includes the installation of a sensor buried under the road surface, which tracks the changes in the earth's magnetic field generated by the vehicle's presence. Another solution, developed by Libelium[2], benefits from a dual detection system based on radar and magnetic technologies for vehicle detection. This combination allows for greater precision, improved detection and stability performance: 99% accuracy. Libelium smart parking technology has been installed in different cities, such as Montpellier and Dubai, to monitor free parking spaces in places such as shopping malls.

III. Smart Parking system

In this section, we describe the reference IoT architecture (Section III-A) and the functionalities of the proposed Smart

[1] https://smartparkingsystems.com/en/smart-parking-system/
[2] http://www.libelium.com/products/smart-parking/

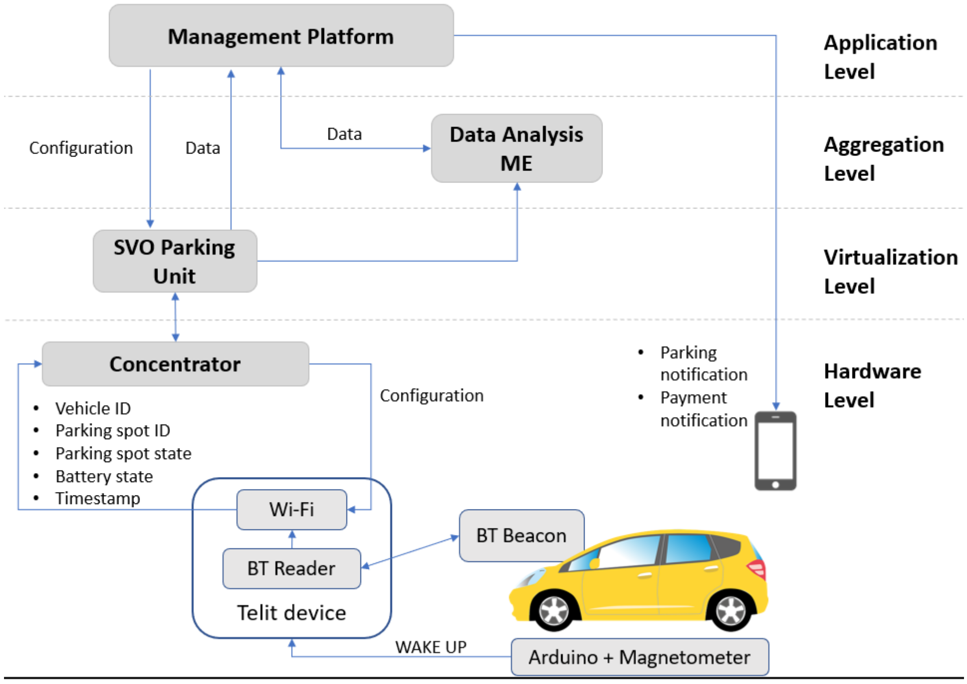

Fig. 1. Reference architecture of the proposed Smart Parking system.

Parking system (Section III-B).

A. Reference IoT architecture

The reference IoT architecture that has been used in our implementation is given by the Lysis architecture [22], which is divided in 4 levels: the Hardware level includes the physical devices that acquire data from the real world, whereas the Virtualization, Aggregation and Application levels identify the software platform that is developed in the cloud and allows to process the data.

Specifically, the 4 levels of the architecture have the following functionality:

a) Hardware level: includes all sensors and devices that acquire information and preprocess data before transmitting it to concentrators using short-range wireless communication technologies. The concentrators collect all pre-processed data from the sensors within the coverage area and transmit it to the virtualization level using long-range wireless communication technologies.

b) Virtualization level: a Social Virtual Object (SVO) is created for each of the hardware level sensors. The SVO is a virtualization of the physical device with which it interfaces directly and represents it with all its features and functionality. In this case, the SVOs will receive and store all the data acquired by the sensors and make them available to the upper levels.

c) Aggregation level: is populated by Micro Engines (MEs), or super entities that inherit the functionalities of the SVOs of which they are composed and increase their capabilities and functionality. In addition, MEs can perform aggregation and processing functions of the data stored by SVOs using Machine Learning (ML) algorithms to meet specific requirements and functionalities required by applications. For example, a ME could aggregate the occupation of the spots of a certain parking area to provide statistics.

d) Application level: it consists of a Management Platform which, on the basis of the data received from SVOs and MEs, provides the user with the requested services such as parking payment, communications with mobile app, real-time map of free / occupied parking spaces.

B. The Proposed System

With the proposed Smart Parking system, we aim to automatically detect the occupancy of parking spaces in a city, allow the user to pay the actual parking time via a smartphone App and provide a complete real-time map of the state of occupancy of parking spots in a city.

The architecture of the Smart Parking system is shown in Fig. 1. At the hardware level, the following physical devices should be installed in each spot:

- *Vehicle detection sensor*: detects the presence of a vehicle parked in the spot to determine whether the spot is free or occupied. In our case, a magnetometer sensor is used together with an Arduino electronic board. When a change on the state of the parking spot is detected, a wake up signal (interrupt) is sent to the Telit device board.
- *Beacon Bluetooth (BT)*: must be placed into the vehicle in order to uniquely identify it.
- *Telit device*: battery-powered electronic board equipped with BT reader and Wi-Fi interface. When this board is wake up by the Arduino board, the BT interface is activated to identify the BT Beacon of the vehicle that

TABLE I
MAGNETIC STRENGTHS AS A FUNCTION OF THE SENSOR'S BEARING.

Parameter	Metric	Bearing			
		0°	90°	180°	270°
Magnitude	**Mean**	19.36	23.19	45.51	45.92
	Std. Dev.	0.25	0.12	0.15	0.27
***x*- axis**	**Mean**	12.49	19.11	45.25	38.91
	Std. Dev.	0.16	0.11	0.15	0.29
***y*- axis**	**Mean**	14.36	-13.12	-4.70	23.66
	Std. Dev.	0.23	0.18	0.20	0.12
***z*- axis**	**Mean**	3.54	-0.74	1.28	5.87
	Std. Dev.	0.19	0.16	0.17	0.22

occupies the parking spot. Then, it activates the Wi-Fi data transmission module that transmits the data to the concentrator device.

- *Concentrator*: collects and transmits the data of all sensors installed in the spots to the Virtualization layer via the LTE interface.

At the Virtualization level, an SVO Parking Unit is created for each parking spot that must be monitored. The SVO Parking Unit receives from the physical devices installed in the spots the information regarding: vehicle ID (beacon), spot ID, status of occupation of the spot, state of charge of the battery of the Telit device and timestamp.

At the Aggregation level, the Data Analysis ME uses all the data collected by the SVOs to perform statistical analysis useful for providing information for the improvement of the Smart Parking service. For example, the areas where citizens park most often, the average number of vehicles parked in different areas of the city, and the average parking time can be shown.

Finally, at the Application level, the Management Platform provides support for the smartphone App developed for citizens. In particular, it sends the parking notification which confirms to the citizen that its parking has been registered, calculates the parking time once the occupant vehicle has released the spot, and sends the payment notification by automatically calculating the parking cost based on the time spent in the car park and the rates applied by the city for that area. For citizens, there is also the possibility of associating an electronic account with the App so that the cost of parking is deducted without the need for further payment actions.

The Management platform also, thanks to the monitored data and citizen registrations, is able to provide various services, such as the ability to identify the status of occupancy of a spot (for example, disabled, resident) and to establish the occupation of an unauthorized spot and reporting to the competent authorities (for example the occupation of a spot for disabled/residents by a non-disabled/non-resident citizen). In addition, through a dashboard it provides a mapping of the city car parks, reporting in real time the state of occupation so as to direct citizens to the areas where it is possible to find parking, avoiding having to go around empty in the city and therefore wasting fuel with a consequent reduction of pollution and of parking search times.

Fig. 2. Three sensor positions under the vehicle. P1: front axle; P2: center of the vehicle; P3: rear axle.

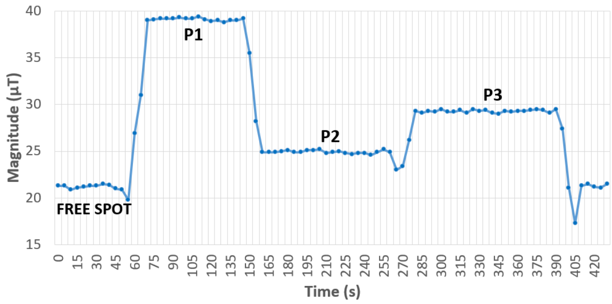

Fig. 3. Magnitude measured for a Nissan Micra with the sensor placed in three different positions under the vehicle. P1: front axle; P2: center of the vehicle; P3: rear axle.

IV. HARDWARE DEVICES FOR VEHICLE DETECTION

One of the main objectives of the proposed Smart Parking system, which is the focus of this study, is the detection of the parking spot occupancy with no human intervention. Therefore, with regard to the system presented in Section III-B, we focused on the hardware devices that have the task to detect the presence of vehicles and then determine the occupancy state of the parking spots. Specifically, we considered the tri-axial magnetometer sensor (QMC5883L) as the vehicle detection sensor and the Arduino as the board to collect and process the sensed data. The magnetometer is a sensor able to measure the changes of the geomagnetic strengths caused by the presence of ferromagnetic metal objects, such as the vehicles. Therefore, we conducted specific experiments, described in Section V, to investigate the suitability of the magnetometer as the mean to automatically detect the presence of a vehicle in the parking spot and to monitor the occupancy state of a parking spot. However, we previously conducted a preliminary analysis of the magnetometer to test its performance, which we describe in this section.

The magnetometer outputs are the magnetic strengths measured in x-, y-, and z-direction (G_x, G_y, and G_z, respectively) and the magnetic vector magnitude (we will refer to it only as the magnitude in the following), which is computed as

$$G = \sqrt{G_x^2 + G_y^2 + G_z^2}. \quad (1)$$

TABLE II

MAGNETIC VARIATIONS MEASURED FOR 12 DIFFERENT VEHICLES AND 3 SENSOR POSITIONS. PS: PARKING SPOT.

Vehicle	Magnitude - occupied PS			Magnitude - variance			Not occupied PS (Reference)			
	P1	P2	P3	P1	P2	P3	Magnitude	*x*- axis	*y*- axis	*z*- axis
Toyota Aygo	45.98	47.86	27.98	24.21	26.09	6.21	21.77	10.52	-10.31	-16.03
Nissan Micra	39.11	24.92	29.29	17.90	3.71	8.08	21.21	9.41	-12.70	-14.15
Citroen C3	25.05	34.48	24.82	**3.33**	12.76	3.11	21.71	14.77	-15.87	-1.10
FIAT Grande Punto	41.29	20.03	33.98	19.50	-1.76	12.19	21.79	15.85	-14.59	-3.01
Ford Focus	33.98	21.30	33.67	12.34	**-0.34**	12.03	21.64	13.11	-15.99	-6.36
Alfa Romeo 147 serie 1	31.40	25.65	24.13	9.56	3.80	**2.28**	21.85	12.78	-16.66	-6.03
Peugeot 308	121.29	35.23	28.93	99.64	13.58	7.27	21.66	15.19	-12.70	-8.75
Alfa Romeo 147 serie 2	31.12	25.34	15.48	9.44	3.66	-6.20	21.68	12.44	-15.89	-7.88
KIA RIO	11.40	36.89	43.32	-10.88	14.61	21.04	22.28	19.28	-1.03	-11.11
Citroen C2	29.70	37.70	30.44	8.34	16.33	9.08	21.36	17.31	-7.49	-10.03
Lancia Ypsilon	29.90	35.26	31.61	8.23	13.58	9.94	21.68	18.26	-3.27	-11.21
Citroen C1	47.02	17.53	31.91	25.04	-4.44	9.93	21.98	17.38	-8.43	-10.46
Mean							**21.72**	**14.69**	**-11.24**	**-8.84**
Standard deviation							**0.26**	**2.97**	**5.01**	**4.12**

First of all, since the magnetometer is influenced by geomagnetic strengths, such a compass, we conducted experiments to investigate the influence of different bearing of the magnetometer. To this, we placed the magnetometer at the center of a free parking spot and we measured each 15 s the magnitude and the magnetic strengths along the x-, y- and z-direction. The magnetometer was then rotated by 90° every 90 s. Table I summarizes the collected measures. It can be seen that the bearing has a strong influence on the measured magnetic strengths and magnitude. For this reason, for the vehicle detection experiments the magnetometer will be always placed oriented to the North in order to set the same bearing reference for each measurement and avoid the bearing influence.

Then, we investigated the reliability and variance of the measures of the magnitude over time and temperature. To this, we placed the magnetometer at the center of a free parking spot and we measured the magnitude each 30 s for 12 hours, from 8 a.m. to 8 p.m., which is typically the time window during which parking spots are to be paid in a city (and therefore the window time during which the proposed parking system must work reliably). It must be highlighted that these measures were done in the city of Cagliari in June, where the temperature can span from $15°C$ to $35°C$ during the day. From the collected measures of the magnitude, we obtained a mean of 40.56 μT, a standard deviation of 0.34 μT and a minimum and maximum value of 39.6 μT and 41.6 μT, respectively. We can conclude that the measures are quite stable over time and temperature.

Finally, we investigated the influence of the position of the magnetometer sensor under the vehicle. Indeed, as highlighted by [5], the induced magnetic variation is also related to the distribution of ferromagnetic materials in the measured vehicle. Therefore, we measured the magnitude by placing the sensor in 3 different positions under the vehicle, i.e., front axle (P1), center of the vehicle (P2), and rear axle (P3), as shown in Fig. 2. As it can be seen from Fig. 3, which shows the measured magnitude for a Nissan Micra, the magnitude values change as a function of the sensor position. In this case, the Nissan Micra induces greater magnetic variations when the sensor is placed under the front axle, i.e., about 20 μT more than the magnitude measured when the parking spot is free. However, there is a relevant difference of magnitude even when the sensor is placed under the rear axle (about 10 μT) and the center of the vehicle (about 5 μT).

V. EXPERIMENTAL RESULTS

In this section, we present the results of the experiments conducted to investigate the suitability of the magnetometer as the mean to automatically detect the presence of a vehicle in the parking spot.

Specifically, the two conducted experiments were:

- *Experiment1*: detection of the occupancy of the parking spot where the magnetometer is placed;
- *Experiment2*: detection of the occupancy of the 2 parking spots adjacent to the parking spot where the magnetometer is placed.

For both the experiments, the magnetometer was always placed oriented to the North so as to set the same bearing reference for all measurements (see Section IV). In Sections V-A and V-B, we present the experimental results obtained for the considered Experiment1 and Experiment2, respectively.

A. Experiment1

The Experiment1 regards the investigation of the detection of the occupancy of the parking spot where the magnetometer is placed. To this, we placed a magnetometer on one parking spot and we measured the magnitude and the magnetic strengths along the x-, y- and z-direction first in the absence of the vehicle and then in the presence of the vehicle. These measures were collected with the magnetometer sensor placed in the 3 different positions as shown in Fig. 2. We measured the induced magnetic variations caused by 12 different vehicles, which are summarized in Table II. Each value in the table is the mean value of about 36 measures since the device was set to acquire data with a time step of 5 s for a total of 3 minutes. On the right of the table (Not occupied PS (Reference)), we show the magnitude and the magnetic strengths along the x-, y- and z-direction measured in the absence of the vehicle. These are the *reference* values. As it can be seen, the only parameter which is stable for all vehicles is the magnitude (standard deviation of 0.26 μT) whereas the variations induced along the 3 axis change more (standard deviation between 3 and 5). Therefore, the magnitude is the parameter that we decided to observe to detect the vehicle occupancy in the parking spot. On the left of the table (Magnitude - occupied PS) we show the magnitude values measured when the parking spot is occupied by the vehicles for the 3 sensor positions. It can be observed as different vehicles cause very different variations in the measured magnitude, even when the sensor is placed in the same position. Finally, on the center of the table (Magnitude - variance), we show the difference between the magnitude measured in the absence and in the presence of the vehicle. We highlighted in bold the smallest values for each of the 3 sensor positions, i.e., 3.33 μT for P1 (Citroen C3), -0.34 μT for P2 (Ford Focus), and 2.28 μT for P3 (Alfa Romeo 147 serie 1).

From the obtained magnitude results, we set a threshold of 2 μT to detect the parked vehicle when the sensor is placed under the front axle or the rear axle. The position under the center of the vehicle is not considered as the minimum obtained variance is too small (-0.34) to be detected. For validation tests the sensor was then placed at about one meter of distance from the start of the parking spot. In this way, when the vehicle parks on the spot the sensor will be under the rear or the front axle, depending on the parking direction decided by the driver. For validation tests, we parked 3 vehicles different from those used to collect the data in Table II, i.e., a Ford Kuga, a Renault Clio and a Renault Zoe. All the 3 vehicles were detected by the sensing device for both the parking directions, which means that the measured magnitude difference was greater than the set threshold.

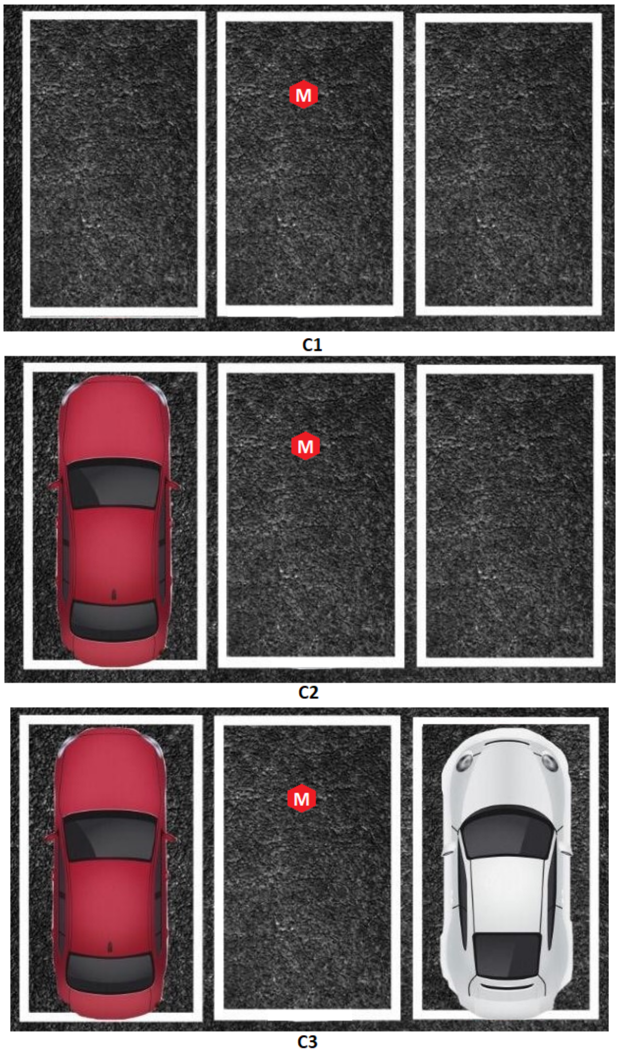

Fig. 4. Combinations of cars parked in 3 adjacent parking spots. C1: all spots are free. C2: only one vehicle parked at the adjacent spot (left in this case). C3: both the adjacent spots are occupied by a vehicle.

B. Experiment2

The Experiment2 is a step forward compared with the Experiment1, i.e., the aim is to also detect the occupancy of the 2 parking spots adjacent to the parking spot where the magnetometer is placed. No magnetometers are placed in the adjacent spots. The considered combinations (C1, C2, and C3) of cars parked in 3 adjacent parking spots are shown in Fig. 4. In C1, all spots are free; C2 considers only one vehicle parked at the adjacent spot (left in this case); in C3, both the adjacent spots are occupied by a vehicle. As shown in the figure, the magnetometer was placed at the central spot at about one meter of distance from the start of the parking spot.

We measured the induced magnetic strengths acquired by the magnetometer placed at the central spot, starting from combination C1, passing to C2 and then C3. The measured magnitude results are shown in Fig. 5. Table III summarizes all measured magnetic strengths; the reported values are the mean and standard deviation values computed from all the data acquired during the acquisition window times, which lasted about 4 and 5 minutes for each combination. The magnetic data was acquired each 15 s. It can be seen from these results that the measured magnetic strengths do not vary so much for the different combinations. In particular, the first vehicle (C2) seems to not induce any relevant magnetic variation to the measured magnetic strengths. Instead, when also the second vehicle is parked (C3), some variations are observed as the magnitude decreases due to changes on the magnetic strengths in the y- and z- directions. However, even if the case of two vehicles parked on the adjacent vehicles would be detectable, this information would be useless since one single parked vehicle is not detected by the magnetometer's measures. One possible reason may be that when 2 vehicles are parked around the magnetometer, the geomagnetic field at the central spot is like a bit 'compressed' by these ferromagnetic objects. But since the main objective was to be able to detect the occupancy for both the 2 combinations (C2 and C3), in order to install only one magnetometer each 3 spots, we must consider this option not possible from the obtained results.

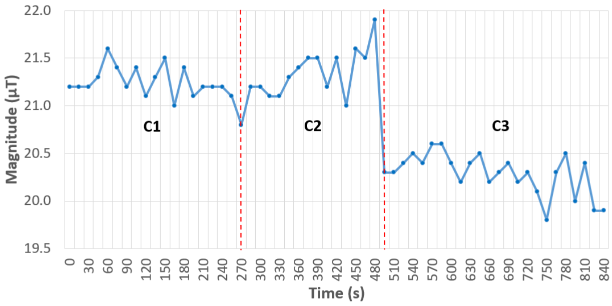

Fig. 5. Magnitude measured for the 3 combinations illustrated in Fig. 4.

TABLE III
MAGNETIC STRENGTHS MEASURED FOR THE 3 COMBINATIONS ILLUSTRATED IN FIG. 4.

Parameter	Metric	Combination		
		C1	C2	C3
Magnitude	**Mean**	21.29	21.28	20.29
	Std. Dev.	0.14	0.24	0.21
***x* axis**	**Mean**	14.59	14.77	14.48
	Std. Dev.	0.19	0.39	0.23
***y* axis**	**Mean**	7.72	7.93	9.87
	Std. Dev.	0.19	0.43	0.31
***z* axis**	**Mean**	-13.42	-13.10	-10.22
	Std. Dev.	0.17	0.40	0.25

VI. CONCLUSIONS

Experimental studies have been conducted to investigate the suitability of a magnetometer sensor as the mean to automatically detect the presence of a vehicle in the parking spot. A first experiment, involving 15 different vehicles, has demonstrated that the magnetometer can be used to reliably detect the presence of a vehicle in a parking spot if it is placed under the front or rear axle of the vehicle. On the contrary, when the magnetometer is placed under the center of the vehicle, this may not be detected.

A second experiment considered 3 adjacent parking spots and only one magnetometer placed in the central spot. From magnetic variations acquired by the sensor it is not possible to reliably detect the vehicles parked on the adjacent spots. Specifically, when both the adjacent spots are occupied the measured magnitude has quite relevant variation; however, when only one spot is occupied no relevant variations are detected. Therefore, one magnetometer for each considered parking spot is needed.

Future works include further experiments and data collection to consider a greater number of vehicles and to observe the performance of the magnetometer when subjected to different environmental situations that may affect its sensitivity, such as the temperature span between summer and winter seasons. Moreover, we will focus on the implementation and testing of the rest of the proposed Smart Parking system and in particular on the communication of the hardware devices with the cloud platform and the provision of real time information regarding parking spots in the city to the citizens through mobile App.

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