# Analysis of Magnetic Field Disturbance Curve for Vehicle Presence Detection

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***Abstract*—This article deals with a method of vehicle detection in a parking space by measuring the Earth's magnetic field alteration. The magnetic field measurements were performed by the means of three axis anisotropic magneto-resistive magnetic field sensors. Research was performed on how to detect a vehicle in a parking space even when the vehicle enters a parking space and is located in a critical point where the Earth's magnetic field alteration is equal to that of an empty parking place. A static detection method with a detection parameter in a critical point is suggested and a modeling of this method is performed.**

***Index Terms*—Vehicle detection, Earth's magnetic field, magnetic sensor, detection criterion.**

## I. INTRODUCTION

Vehicle detection by measuring the Earth's magnetic field alteration is an alternative to the currently used common methods: induction loops, video cameras, ultrasonic sensors, microwave radars, etc. [1]. Research was performed using a LSM303DLH magneto-resistive magnetic field sensor from ST Microelectronics. By employing this method, it is evident that: 1) the parameters vary in time and are unstable; 2) the sensor's parameters are effected by temperature, the dissipation of the sensor's parameters, the slow variation of the Earth's magnetic field, the magnetization of adjacent objects [2]. The temperature impact on the sensor's parameters is shown in Fig. 1. In this case, the magnetic field is constant, the ambient temperature varies from -38 °C to +78 °C. The sensor's initial level offset and sensitivity change due to the temperature. As shown, the component Bz of the magnetic field's axis Z is affected the most.

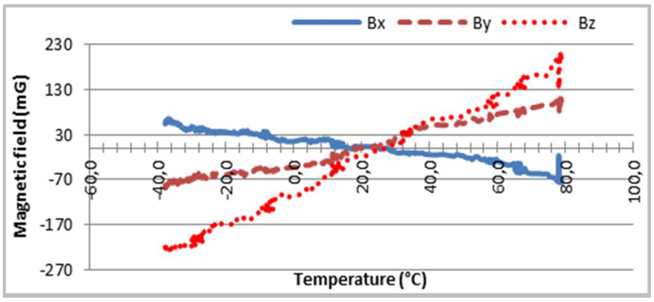



Fig. 1. Temperature dependencies between magnetic field's components Bx, By and Bz.

The temperature coefficient of the magnetic sensor – 0.32 %/°C, the coefficient of the initial offset – 0.01 %/°C[3]. Because of this, static detection methods are hardly used without special mathematical processing. This problem could be solved in various ways. One of them - to perform thermo-compensation and eliminate other interferences by means of mathematical processing. Thus, the influence of temperature and adjacent objects can be eliminated. These mathematical methods have already been analysed in previously published research [4].

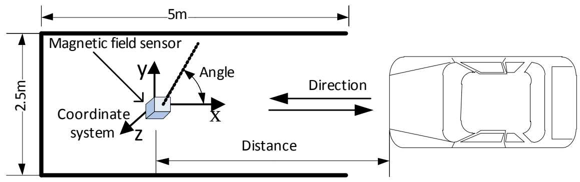



Fig. 2. Setup of the experiment.

The very moment the vehicle enters and leaves the parking space the magnetic field's components are measured and the magnetic field's alteration is monitored. It is not constant and differs remarkably depending on the vehicle construction as well as the position of the sensor. The setup for measuring the magnetic field is shown in Fig. 2. The vehicle is often located just above the sensor, but the alteration of the Earth's magnetic field is insignificant or even absent. Since there are many different vehicle brands and it is impossible to park them precisely, the local critical points are determined when the magnetic field is not distorted. These actions can have a negative impact on vehicle detection. The dependency of the magnetic field's alteration on the vehicle is called the characteristic magnetic field's curve. The magnetic field's components time dependency is shown in Fig. 3.

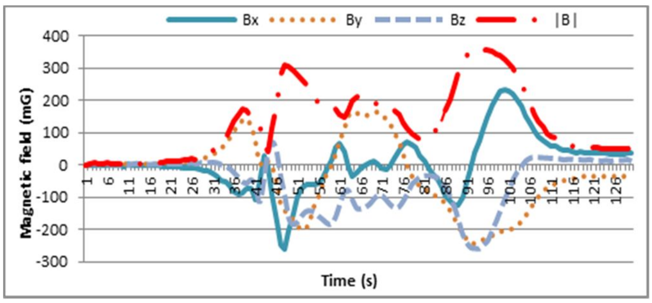



Fig. 3. Magnetic field components Bx, By, Bz and module |B| variations due to moving vehicle in/out of the parking place.

It is hard to set the precise location of the vehicle with

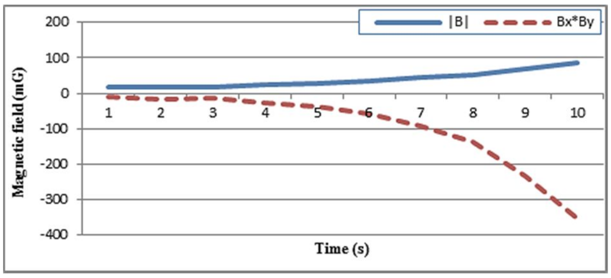
Manuscript received July 28, 2013; accepted November 14, 2013.

regards to the sensor from the characteristic curve, but it is simple to distinguish the vehicle's front part and axis interspace, i.e. pronounce the vehicle's bodywork and rear part.

The critical point appears in the front part of the vehicle (41 s–44 s), where it is rather difficult to detect properly the vehicle's presence or absence in the parking space. Vehicle parking is achieved through the use of detection event criterion when the parking space's state is defined. It is a static detection method that estimates the dynamic signal variation.

## II. Static Vehicle's Detection Method

The main task is to properly detect the parking space's status even when the vehicle is at the critical point. In order to detect the place, it is possible to use the different variations of the magnetic field's components X, Y, Z near the axis and the vehicle's front or rear part that is entering or leaving the parking space. For example, it is noted that when entering or leaving the parking space the variations of X and Y components are different signs, while next to the vehicle's axis these variations can be the same as well as different signs. By multiplying the variations of the components mentioned above and by integrating this product in the selected variation range of the magnetic field's module as well as other main criterion of parking place detection, we can determine, according to the mathematical sign or value of the result obtained, whether the vehicle at the critical point is in the parking place or not.

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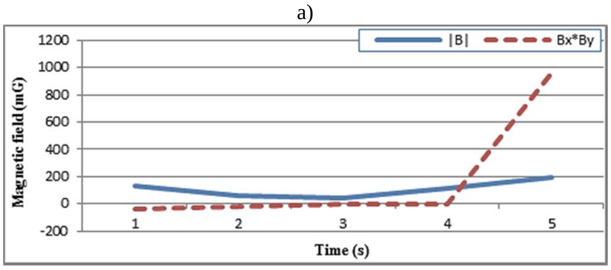


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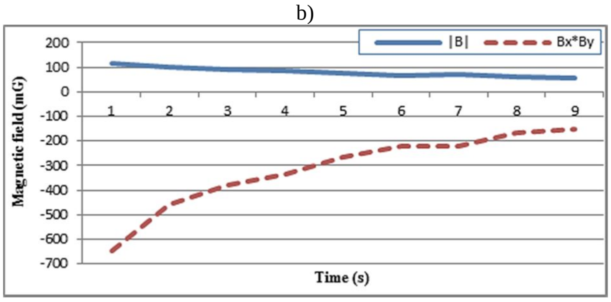
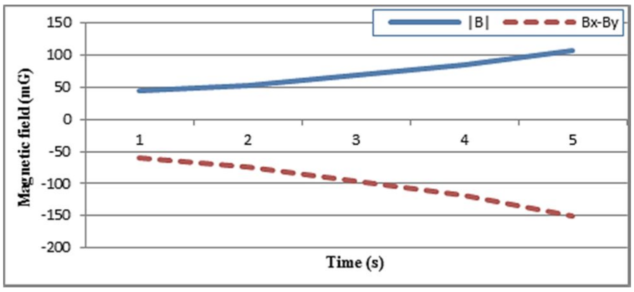



c)

Fig. 4. Product of the magnetic field's X and Y components (Bx*By) and magnetic field's module |B| variations for vehicle (Toyota). Orientation in 0 degrees.

Figure 4 shows the product of the magnetic field's X and Y components and the magnetic field's module variation for a vehicle (Toyota) entering the parking space (Fig. 4(a)), while in the critical point (Fig. 4(b)) and leaving the parking space (Fig. 4(c)). After an analysis, it may be assumed that this extra information can help definitively detect the parking space's availability. Similar results can be obtained when the difference of the magnetic field's X and Y components is used instead of the product.

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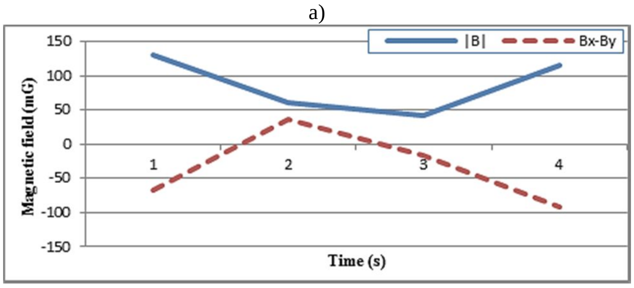


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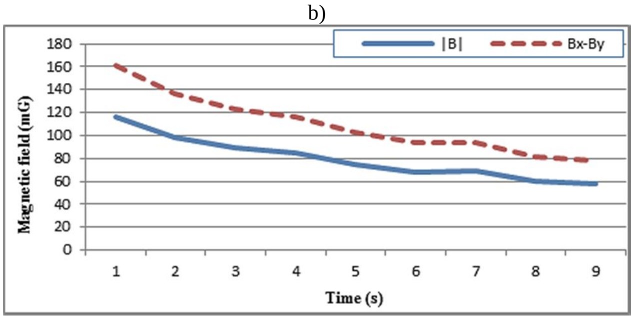
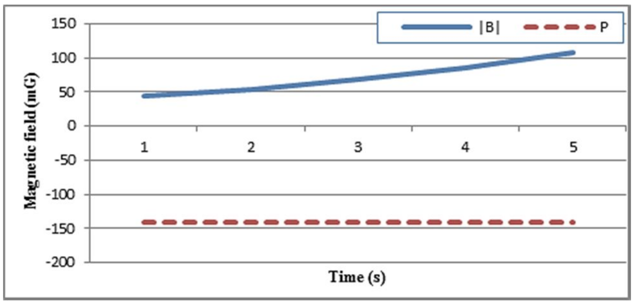



c)

Fig. 5. The difference of the magnetic field's X and Y components (Bx-By) and the magnetic field's module |B| variations for vehicle (Toyota). Orientation in 0 degrees.

The similar dependencies of the vehicle entering the parking space, while in the critical point and leaving the parking place are shown in Fig. 6(a), Fig. 6(b) and Fig. 6(c) charts.

Additional information is obtained from the difference of the magnetic field's components X and Y. The sign of difference integration is not an indication of the critical point, whereas the integral value could be - near the critical point, it is bigger.

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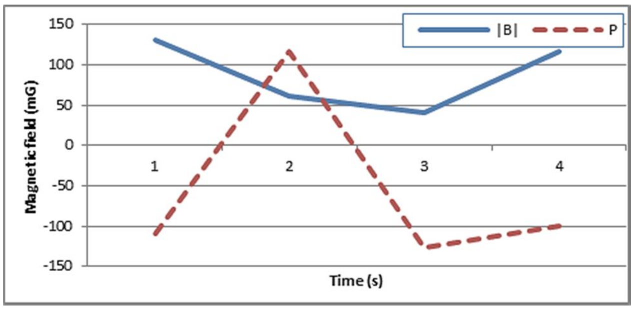


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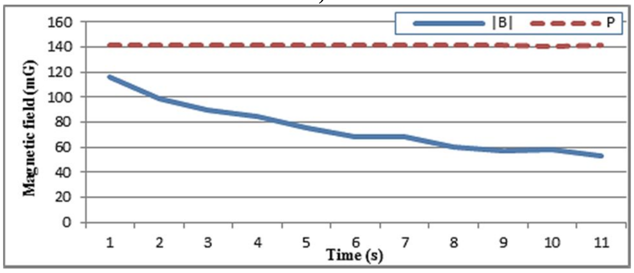


c)

Fig. 6. Magnetic field's parameter P and module |B| variations for vehicle (Toyota). Orientation in 0 degrees.

The difference of the magnetic field's components X and Y and their modules ratio is quite intricate

$$P = (B_x - B_y) / \sqrt{B_x^2 + B_y^2}. \quad (1)$$

The dependencies of this ratio (parameter P) are presented in Fig. 6 charts – when the vehicle enters the parking space, when it is in the critical point and when it leaves the parking space. An interesting phenomenon is observed: when the vehicle enters the parking space as well as leaves, parameter P varies little and its absolute value is high. Near to and in the critical point, the parameter varies considerably and the value is noticeably lower. Parameter P's integral value at the maximum of the critical point will be considerably lower.

## III. Modelling of Vehicle Detection While Parking

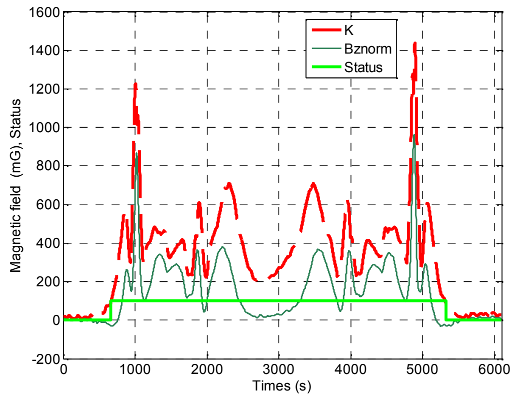


Fig. 7. Detection modeling results for vehicle Renault. The sensor is at 0 degrees with respect to the vehicle.

The vehicle detection was modelled by the means of a Matlab modelling package, using a slightly modified additional information criterion P from (1). The modelling was performed with collected data from a LSM303DLH magnetic sensor. Direction cosine variations product CP - which does not depend on temperature – was used instead of the magnetic field's components X and Y variations product

$$CP = (B_x / |B| - B_{x0} / |B_0|) * (B_y / |B| - B_{y0} / |B_0|), \quad (2)$$

where $|B| = \sqrt{B_x^2 + B_y^2 + B_z^2}$ - magnetic field's module for any vehicle's position in the parking space; $|B| = \sqrt{B_x^2 + B_y^2 + B_z^2}$ - magnetic field's module for the vehicle's initial position in the parking space (parking space is empty).

Parking space status detection criterion K was used while modeling. The shape of the criterion repeats the magnetic field's module variation during vehicle entrance.

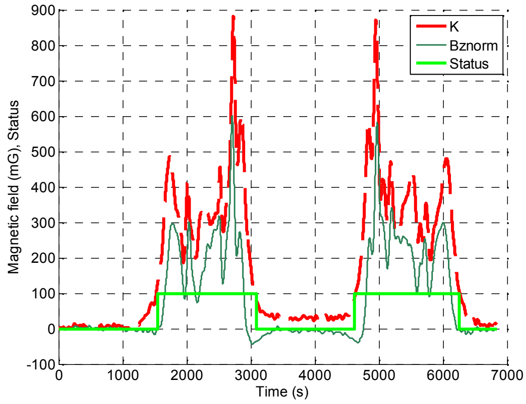


Fig. 8. Detection modelling results for vehicle Renault. The sensor is at 135 degrees with respect to the vehicle.

$$K = 1000 \cdot \left( \left| \frac{B_x}{|B|} - \frac{B_{x0}}{|B_0|} \right| + \left| \frac{B_y}{|B|} - \frac{B_{y0}}{|B_0|} \right| + (\frac{B_z}{B_{z0}} - 1) \right). \quad (3)$$

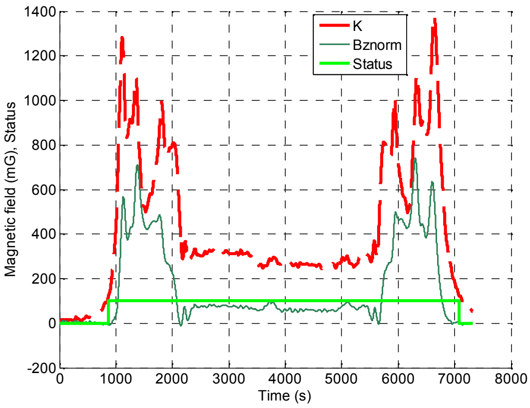


Fig. 9. Detection modelling results for vehicle Skoda. The sensor is at 0 degrees with respect to the vehicle.

The suggested criterion K decreases the status impact of parking places on the side and straightens the slopes of the criterion. Since the first two members are insignificantly dependent on temperature (both nominator and denominator of ratios $B_x/|B|$ and $B_y/|B|$ vary in temperature in a similar way), the entire criterion will depend less on temperature than the magnetic field's module. The modeling results are presented in Fig. 7–Fig. 12. In the graphs, the Bz values are normalized, $B_{znorm} = 1000 \cdot (B_z / B_{z0} - 1)$. The following provisions were chosen when modelling: The detection of the critical point or entrance /departure to/ from parking space shall be launched when the chosen criterion K is between the threshold value $K_r$ and the double threshold value $2 * K_r$. The criterion's threshold value is the amount which lets us presume that the vehicle is in the parking space.

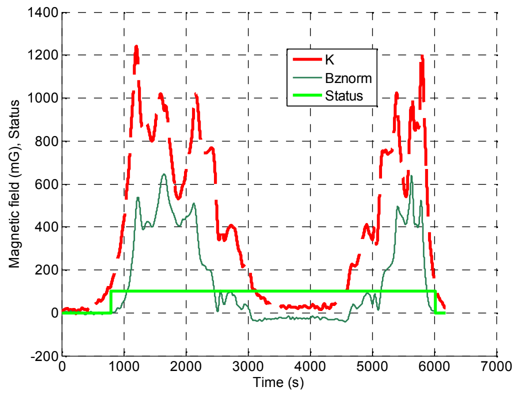


Fig. 10. Detection modelling results for vehicle Skoda. The sensor is at 90 degrees with respect to the vehicle.

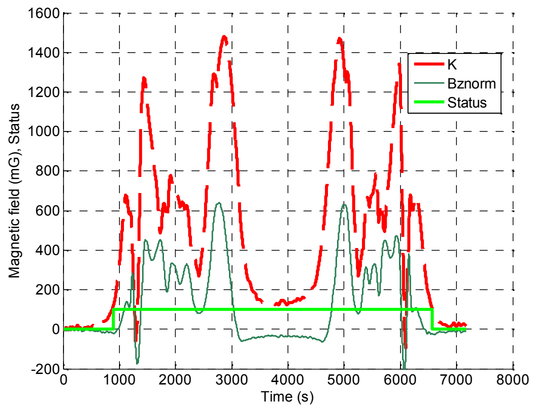


Fig. 11. Detection modelling results for vehicle Toyota. The sensor is at 0 degrees with respect to the vehicle.

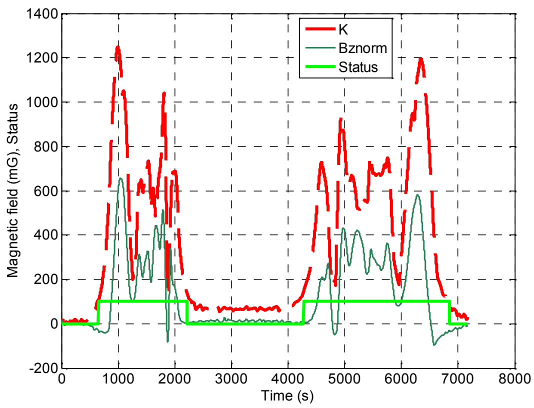


Fig. 12. Detection modelling results for vehicle Toyota. The sensor is at 135 degrees with respect to the vehicle.

The parking space detection procedure is launched when the criterion value is below the threshold. During the procedure, a decision is made regarding the additional information – CP in our case. The modelling results in Fig. 10 show that in case of Skoda, when the sensor was placed at 90 degrees with respect to the vehicle, unfortunately the algorithm performed incorrectly: the vehicle's departure from the parking space was not detected. In other cases, the algorithm performed correctly: the vehicle's entrances and departures were detected, and most importantly, the critical point was identified.

In the case in which single vehicle parking detection methods are not accurate enough, a complex method can be used instead. It means that several of the methods discussed above are used together. The final decision can be made by the algorithm in various ways: according to reliability hierarchy, "majority vote" principle, identification importance, etc.

Until now, all of the above discussed methods of parking space detection were based on moment indications of the magnetic sensors. Such methods can be defined as static.

A dynamic method in which a magnetic sensor measures only the magnetic field's alteration during a considerable time span would be of great interest [5]. By having recorded the sensor's indications in this span and having a library of signals about different vehicles' impact on the magnetic field, not only the parking space's status can be detected but also the entering or departing vehicle's brand or even model. In this case, it is quite simple to identify the critical point. Also there would be no need for thermo-compensation of magnetic sensors as it is possible to eliminate the slow variations of magnetic sensors' indications. However, this method has some disadvantages. The magnetic sensors have to transmit more information to the central processor which has to store this information in their rather higher storage capacity. The processors are required to have high performance capacity. Thus, the price of such systems will considerably increase.

Also a combined static – dynamic system could be an option in which the dynamic section will process only some procedures without much mathematical treatment.

## IV. CONCLUSIONS

The research and modelling confirmed that by employing the suggested static detection method it is possible to detect the vehicle even in the critical point. Only once in the case of Skoda when the sensor was placed at a 90° angle with respect to the vehicle, the algorithm failed. In order to eliminate this disadvantage, more information is needed to resolve the task correctly.

Since the research revealed some disadvantages and imperfections of the static method, we should proceed with a further research objective: dynamic analysis and modelling of the magnetic field's signal which is received when parking a vehicle.

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