Parking monitor system based on magnetic field senso

Conference Paper · February 2006

DOI: 10.1109/ITSC.2006.1707398 · Source: IEEE Xplore

Haibin Gao
Universität des Saarlandes

U. Hartmann
Universität des Saarlandes

Proceedings of the IEEE ITSC 2006
2006 IEEE Intelligent Transportation Systems Conference
Toronto, Canada, September 17-20, 2006

Parking monitor system based on magnetic field sensors

Joerg Wolff, Thomas Heuer, Haibin Gao, Michael Weinmann, Stefan Voit and Uwe Hartmann

***Abstract*—To easily find an unoccupied parking space in a large car park is a problem for many drivers. Thus it is useful to have technical solutions which can provide information on parking space occupancy. A new monitor system is described in the following. It is based on passive magnetic field sensors. It provides occupancy information for car park users and helps them to place the car in a most efficient way.**

I. Introduction

Today's cities are increasingly congested by cars. In average, a considerable part of a drive is spent by searching for an unoccupied parking space. The impact on environment, living quality and national economy is considerable since fuel is consumed, exhaust gas is produced and time is spent unnecessarily [1]-[5].

Finding an unoccupied parking space in the maze of a downtown area often works on a trial-and-error basis. Time needed and distance to drive could be significantly reduced if drivers were directed to an unoccupied parking space. First systems indicating the remaining capacities of car parks are operational and there are visions of onboard navigation systems guiding the driver to the next unoccupied parking space [1], [3].

All those systems require reliable information about the occupancy situation in car parks. Currently there are two common approaches to detect whether there are unoccupied parking spaces: inductive loops and ultrasonic sensors [2], [3], [6].

Today, inductive loops prevail in detecting moving traffic. An alternating magnetic field is applied, which is affected by the conductivity of metallic objects. The change of the impedance of the loop is evaluated and used for the detection of a vehicle. Since this technique requires a moving vehicle, the occupancy status of a parking space cannot be observed directly. Instead, the number of cars in a car park, or in a section of it, is determined by monitoring the entrance and exit lanes. The durability, the considerable installation effort and the energy consumption are further major drawbacks in the employment of inductive loops [1], [6].

Ultrasonic sensors are capable of determining whether a specific parking space is occupied or not. Since they need a direct line-of-sight to the parked car or to the empty parking space and are hard to protect against dust, accidental damage or vandalism, the only feasible position for those sensors is the ceiling directly above the area to be monitored. Thus, ultrasonic sensors can only be used in multi-story car parks. There is no possibility to monitor the occupancy situation of a single parking space without a ceiling above [1], [3], [7].

The need for an inexpensive and easily installable detector to monitor a single parking space without a ceiling demands for a novel approach. Because of this general demand, a detector system based on magnetoresistive sensors was developed and a test system was installed in a local car park. In large quantities the detector's costs are expected to be competitive to common technologies.

II. Principle of Magnetic Sensing

Magnetoresistive sensors utilize the Earth's magnetic field as a bias field for detecting the presence of ferromagnetic objects. The resulting completely passive method of sensing requires no energy to be emitted, thus minimizing both energy consumption and risk of electromagnetic interference. Furthermore, the compact size of the magnetoresistive sensors allows for versatile placement options.

One significant source of signal to be expected is the deformation of the field lines by flux concentration in ferromagnetic components of the vehicle. Though permanent magnetization might also play a role here, it is impossible to predict since it is easily changed during assembly and service of a vehicle. Thus, currently only field concentration effects are considered. Most of the signal can be expected to emanate from rather massive components like engine, gearbox, driveshaft, axles and wheel suspensions. The thin-sheet body of a typical car should have only minor influence on the magnetic field [8]-[14].

In order to predict the magnetic field near a vehicle, a simple 2-D simulation was done using the Finite Element Method. In Figure 1 the magnetic flux lines around a typical car are presented. Note that no specific car was simulate

Manuscript received on April 11th, 2006. This work was supported by the Saarland Ministry for Education, Culture and Science, Germany, under the Grant D4-14.2.1.1. LFFP 0431.

Joerg Wolff is with physics department, Saarland University, Saarbruecken, 66041 Germany. (e-mail: j.wolff@mx.uni-saarland.de).

Thomas Heuer is with physics department, Saarland University, Saarbruecken, 66041 Germany. (e-mail: t.heuer@mx.uni-saarland.de).

Haibin Gao is with physics department, Saarland University, Saarbruecken, 66041 Germany. (e-mail: h.gao@mx.uni-saarland.de).

Michael Weinmann is with Votronic GmbH, St. Ingbert, 66386 Germany (e-mail: mweinmann@votronic.com).

Stefan Voit is with Votronic GmbH, St. Ingbert, 66386 Germany (e-mail: svoit@votronic.com).

Uwe Hartmann is with physics department, Saarland University, Saarbruecken, 66041 Germany. (corresponding author to provide phone: 0049 681 302 3798; fax: 0049 681 302 3790; e-mail: u.hartmann@mx.uni-saarland.de).

1-4244-0094-5/06/$20.00 ©2006 IEEE

and that the model was strongly simplified in order to provide a rough idea of the Earth's magnetic field deformation. Ferromagnetic components were assumed in the axles, the engine and the underbody with a relative permeability of 1000, 300 and 150, respectively. The simulation is based on a homogeneous Earth's field with a magnitude of 40 µT and an inclination of 60°, representing a typical situation in Europe.

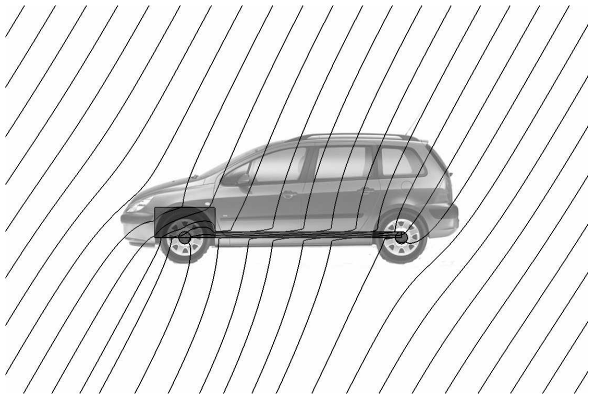

Fig. 1. Simulation of the deformation of the Earth's magnetic field by a car

As it can be seen, the field lines are considerably deformed, especially underneath the vehicle. This suggests that a detector will produce best results when placed on the floor or closely underneath the surface. Placing the detector in front of the car also would produce acceptable signal levels in a car park application, at least for a front engine car. Figure 2 shows the simulated signal with the detector placed at the floor level.

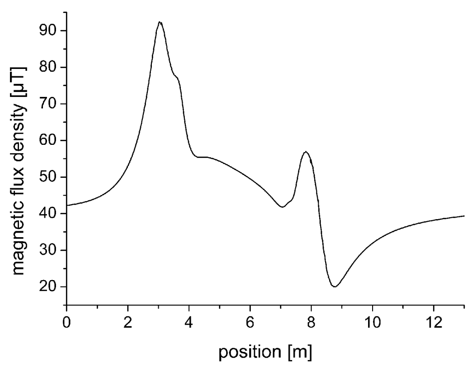

Fig. 2. Plot of the magnetic flux density (absolute value) along the car at ground level

The largest signal level can be found, as expected, underneath the front axle and the engine, showing the optimum position for a sensor in a car park application. However, it has to be taken into account that cars might move backwards into a parking space and that not all cars have the engine in front. The maximum variation of the simulated magnetic field is about 50 µT. Even if modeling is not precise because of the simplifications made, it at least gives the order of magnitude.

III. Description of the Detector Module

The detector module is based on a three-axes arrangement of off-the-shelf low-cost magnetoresistive sensors. Anisotropic Magneto-Resistive (AMR) sensors were chosen because of their small size, low energy consumption and their competitive price [15]. Each of the sensors consists of four permalloy strips arranged in a meander fashion on a silicon substrate. Those resistive elements are connected in a Wheatstone bridge configuration in order to improve the temperature behavior and to increase the signal output. Two integrated planar coils allow the manipulation of the magnetic field components along the sensor's sensitive axis and along the permalloy strips' easy axis.

As initial experiments showed, the temperature dependence of the sensing element could not be sufficiently compensated for by classical techniques like a positive-temperature-coefficient thermistor in the first amplifier stage's feedback loop. The remaining temperature coefficient of the detector's analogue part still produced up to some µT of equivalent signal for a temperature change of 10 K.

In order to overcome these shortcomings, a feedback loop is used to compensate the external field to be measured. As the sensor's output voltage changes, an electronic controller circuit adapts the current through the integrated compensation coil (Figure 3). This coil's magnetic field is equal but of opposite direction to the external field, thus eliminating the external field perceived by the sensor. Information on the measured magnetic signal is given by the current fed to the compensation coil. Because the sensor always is used at its zero point, the compensation current is independent of the actual sensitivity of the sensor and thereby of the sensitivity drift with temperature.

Software?

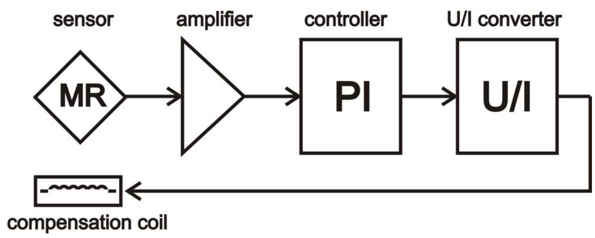

Fig. 3. Magnetic field compensation by a feedback loop

The output signal of the controller needed to compensate the external magnetic field is connected to the Analogue-to-Digital Converter (ADC) input of a microcontroller. This microcontroller has digital signal processing (DSP) capabilities, allowing real-time digital filtering of the signals produced by the three-axis sensor setup. Its computing power enables the microcontroller to autonomously decide whether the presence of a car is detected.

As the absolute noise power of a signal is mostly determined by the bandwidth of the background noise, a bandwidth limitation is a necessity when measuring weak signals. Thus, a two stage Finite Impulse Response (FIR) low pass filter was realized by means of the microcontroller.

Its lower frequency stage's cutoff frequency is 8 Hz. Augmented by the field compensation loop's low pass character with a cutoff frequency around 20 Hz, this filter allows a detector resolution of some nT.

Finally, the microcontroller handles the communication of the individual detector with a master via a RS485 bus. This industrial standard was chosen for its low price of electronic components and wiring, its maximum line length of 1,200 m and its insensitivity to interference. The communication protocol was specifically defined for use in a network of magnetic detectors. Data rates up to 57.6 kbps can be selected in order to optimize the network both for speed and for reliability. The maximum number of detectors per bus line is limited to 128 by the choice of the bus transceiver integrated circuit.

The prototype detector in low volume production is constructed on a 116 mm x 55 mm x 13 mm printed circuit board. It can be accommodated by a variety of different housings and encapsulations specifically for the place of installation. Since magnetic fields penetrate through non-ferromagnetic materials, the housing can easily be designed to protect against overrunning, accidental damage and vandalism.

IV. Architecture of the Test System

A local multi-story car park was chosen to build up a test system to monitor the occupancy of parking spaces. As shown in Figure 4 the system consists of a PC, three displays and 108 detectors.

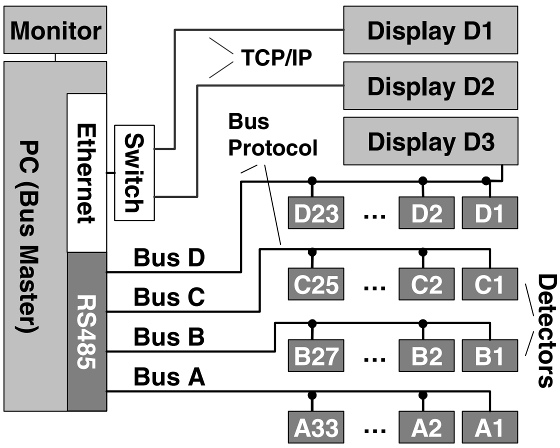

Fig. 4. Structure of the test system

The detectors are connected via four busses to a standard RS485 interface card of the PC. The PC runs the application software that implements the functionality of the RS485 bus master and controls the displays. The bus master refreshes the occupancy status by a cyclic polling of the detectors. This status information is sent to the corresponding display.

The 108 detectors were installed on two and a half floors of the parking garage as shown in Figure 5. The parking garage is constructed similar to a double helix with alternating stories for upwards and downwards directions.

As outlined inside Figure 5 the detectors were installed in two different positions. About half of the detectors were fixed to the wall and the others were put on the ground. Figure 6 shows the different positions and the directions of the corresponding axes of the sensor boards.

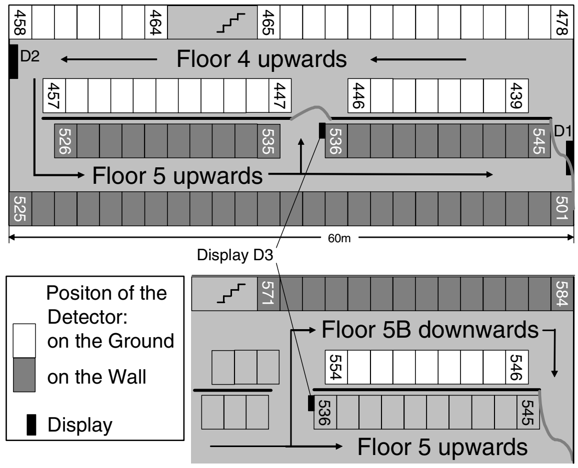

Fig. 5. Plan of the parking garage

Figure 6a shows the principle for on-wall installation. The cable duct was opened which allows a view to the sensor board. By placing the sensor boards into the cable duct, the installation effort could be reduced considerably. Additionally no housing of the sensor is needed.

Figure 6b shows a detector installed on the ground. In this position the sensor board has to be protected against overrunning, dust and moisture by a solid plastic housing. By gluing the detector on the ground, considerable installation time could be saved.

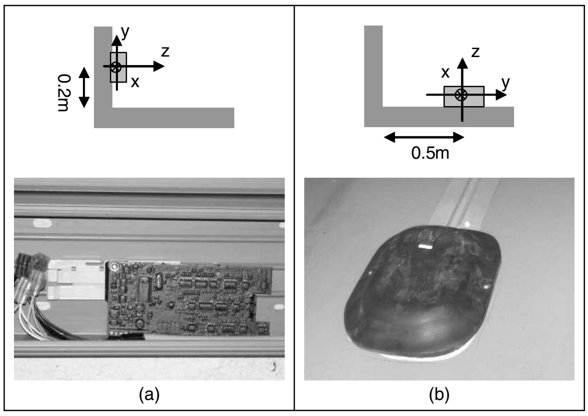

Fig. 6. Detector positions and axes directions for the installation on the wall (a) and on the ground (b)

There are three different displays showing the occupancy information to the costumers. The graphical displays D1 and D2 (Figure 5) are controlled by the PC via TCP/IP over Ethernet connections. The numerical display D3 is controlled by the bus protocol over the RS485 bus.

V. Results and Postprocessing

The developed system can be installed in different parking sites using various detector positions. This flexibility is an obvious advantage compared to systems based on other detectors. Two typical detector positions inside a multi-story car park are covered by the test system. Other detector positions are possible, for instance under the ceiling or sideways of a parking space. In general, the detection reliability will be improved by shortening the distance to the monitored car and extending the distance to influencing objects, like cars in adjacent parking spaces.

After the setup of the test system in the parking garage initial tests were made to check the detectors, communication issues and the application. Furthermore the signal levels of different detector positions were checked. For this purpose different types of cars were used for various simulated parking scenarios. For instance, a car was parked in a parking space with and without cars in adjacent spaces.

A typical signal for a standard parking situation is presented in the following. The car was a Peugeot 307 Break Diesel and the detector was fixed on the ground of the parking space. The test car entered the parking space, stayed there for about 15 seconds and then left the space. The values of the ADC of the detector's microcontroller were read out via the bus interface. Due to the 12 bit resolution of the ADC the values cover a range from 0 to 4095 for each axis. The upper diagram in Figure 7 shows the signals of every axis of the detector for this particular parking situation. The corresponding orientations are described in Figure 6.

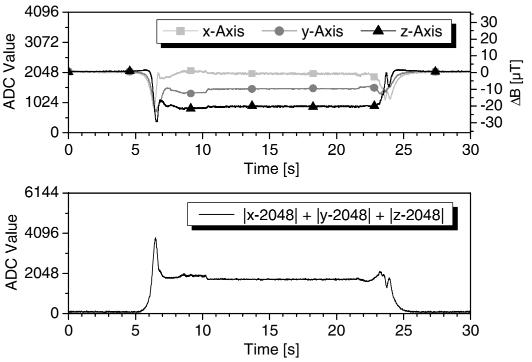

Fig. 7. Typical signal produced by the test car entering and leaving a parking space

After the installation of the system, as well as after changes of the detector's position and orientation, the offset of the detector has to be adjusted in order to compensate the local static magnetic field. In the example above the detector was compensated before the measurements, when the parking space was unoccupied. Therefore in Figure 7 all three curves start at 2048, which is the center of the detection range.

After five seconds the car was driven into the parking space. All three signals change significantly. Eight seconds after starting the measurement the car was stopped and the engine was turned off at 10.5 seconds. At 20.5 seconds the engine was started again and the car left the parking space at the time of 22.5 seconds.

The signals are not solely influenced by the car type and the position. In addition to the ferromagnetic components of the car, onboard electrical systems cause significant signals, e.g. the preheating of a Diesel engine.

The lower diagram in Figure 7 shows one possible treatment of the three-axes data. The curve represents the sum of the differences of the magnitudes from the respective calibration points. By defining a threshold level, the presence of a car can be detected with an appropriate level of confidence. The threshold level was determined by tests utilizing different cars and parking situations.

Numerous tests show that the detectors positioned on the ground deliver a good signal level that is nearly independent from the parking situation of the adjacent parking spaces.

The positioning of the detectors on the wall results in a signal that is sometimes influenced by the occupancy situation of parking spaces nearby. This influence depends on the direction of the space relative to the Earth's magnetic field. Through more advanced algorithms, like the selection of the most expressive magnetic field component, this influence can be reduced. The advantage of this detector positioning is straightforward installation without effects on the parking garage's daily operations.

Continuous tests have been carried out for both detector positions. Current surveys on accuracy are performed during the garage's normal operations, covering real life's influences of various car types and parking situations. Significant evaluation results will be available soon after enough data has been analyzed. The present threshold algorithm results in a decision for either an unoccupied or an occupied parking space. As described before this information is read out by the bus master and then sent to the respective display.

Figure 8 shows the output of display D1 visualizing floor 4 upwards. Additionally to the number of unoccupied parking spaces, the detailed positions are represented by green and red boxes representing unoccupied and occupied parking spaces. Thus the customers of the parking garage have full information on the parking space occupancy situation, and they can find an unoccupied space in an efficient way.

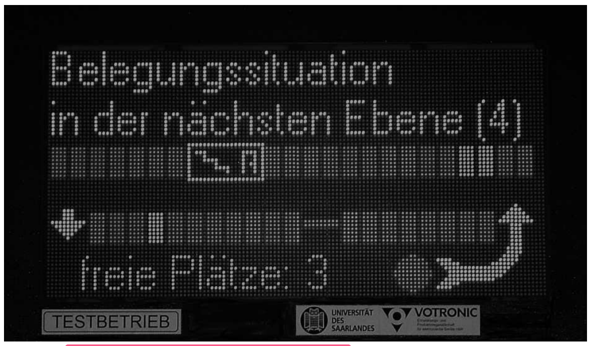

Fig. 8. Graphical output of the display D1

VI. Conclusion and Outlook

In conclusion, a parking monitor system based on passive magnetic field sensors has been developed. The characteristics of the magnetic sensors were tested and full activity of the model system was described. This system provides occupancy information for the car park. It is easy to operate and the detectors can be flexibly installed at various positions. The system can be further extended to a complete car park guidance system.

The system's shortcomings are mainly due to the method of passive magnetic sensing. First of all, the positioning of the detector determines the interference ratio, which is primary affected by cars in adjacent parking spaces. Thus, the placing of the detector close to the monitored car yields in signals that can be easily processed. Furthermore, a car can only be recognized as long as ferromagnetic structures of it cause significant deformations of the Earth's magnetic field inside the detector.

In the parking garage hosting the test system, relatively high static magnetic fields up to a multiple of the Earth's magnetic field were observed at particular locations. The detector's compensation capability had to be extended to comply with these flux concentrations, primarily caused by ferromagnetic components inside the building.

To extend the ability of the system, some technical improvements have to be performed. Additionally, the detection algorithm will be enhanced to be not only depending on signal levels.

Acknowledgment

The authors are grateful for the support from Q-Park Saarbruecken GmbH, Germany, which provided the parking garage for the test activity of the system, and Siebert Industrieelektronik GmbH, Eppelborn, Germany, which provided the graphic displays used in this system.

References

[1] J. H. Kell and I. J. Fullerton, *Traffic detector handbook*, 2nd. ed., Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, 1990.

[2] L. E. Y. Mimbela and L. A. Klein, (November, 2000), A summary of vehicle detection and surveillance technologies used in intelligent transportation systems, http://www.nmsu.edu/~traffic/.

[3] R.L. Gorden, R.A. Reiss, H. Haenel, E.R. Case, R. L. French, A. Mohaddes, and R. Wolcott, *Traffic control systems handbook*, FHWA-SA-95-032, Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, February, 1996.

[4] M. Betke and H. Nguyen, "Highway scene analysis from a moving vehicle under reduced visibility conditions", *Intelligent Vehicles*, 131, 1998.

[5] C. A. MacCarley, S. Hockaday, D. Need, and S. Taff, *Evaluation of video image processing systems for traffic detection*, Transportation Record No. 1360, Washington, D.C., National Research Council, 1992.

[6] R. L. Anderson, "Electromagnetic loop vehicle detectors", *IEEE Trans. Vehic. Technol.*, 19, 23, 1970.

[7] J. Fraden, *Handbook of modern sensors.* Springer, New York, 1996.

[8] P. Ripka, "Magnetic sensors for industrial and field applications", *Sensors and Actuators A*, 42, 394, 1994.

[9] J. Heremans, Magnetic field sensors for magnetic position sensing in automotive applications, in *1997 Proc. Conference on properties and applications of magnetic materials*, Chicago, IL.

[10] J. Kranig, E. Minge, and C. Jones, *Field test of monitoring of urban vehicle operations using non-intrusive technologies*, FHWA-PL-97-018, Washington, D.C., Federal Highway Administration, U.S. Department of Transportation, 1997.

[11] P. Ripka, "Magnetic sensors for traffic control", in *1999 Proc. ISMCR 99*, Tokyo, 241.

[12] U. Hartmann, (2001), Magnetosensorische Erfassung von Verkehrsströmen, http://www.uni-saarland.de/fak7/hartmann/files/docs/pdf/information/TrafficSensor.pdf

[13] R. Lao, "Magnetoresistors for automobile detection and traffic control systems," *Sensors*, April, 70, 1996.

[14] M. Caruso, (1999), Applications of magnetoresistive sensors in navigation systems, http://www.ssec.honeywell.com/magnetic/datasheets/sae.pdf

[15] *Magnetic field sensors*, Philips Semiconductors, SC17, 20, 1998.