KAUNAS UNIVERSITY OF TECHNOLOGY

MINDAUGAS ČEPĖNAS

RESEARCH ON SENSORS FOR TRANSPORTATION CONTROL SYSTEMS

Summary of Doctoral Dissertation
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2018, Kaunas

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MINDAUGAS ČEPĖNAS

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INTRODUCTION

Due to the increasing number of vehicles, the systems of transportation control must solve more complicated issues than ever before. Over the last couple of years, electronic traffic control systems have been developed continuously, but problems with traffic control, traffic jams, vehicle parking and many more remain relevant. In terms of improving traffic conditions on the streets, accurate detection of transport flow and the ability to estimate it are vital tasks for solving the difficulties of traffic control. The precise estimation of transport flow is strongly related to the plans of traffic infrastructure, design, development and transportation control. Moreover, mass gathering places are linked with an increased risk of dangerous situations, which also can be reduced with the help of traffic flow control systems. Therefore, effective, integrated, unitedly working intellectual transportation control systems are needed for the smooth and rapid movement of traffic flows.

The current development of electronic technologies and the possibility to apply them for traffic control enables new opportunities in solving issues with safety, control of transport flow, decrease of fuel consumption and environment pollution etc. The installation of advanced transportation control systems requires fewer expenses when compared to investments in improving other transport infrastructure facilities, such as laying new highways or expanding the existing ones.

A system for detecting automotive vehicles is one of the essential parts of the transportation control system. Since there are no cheaper and more reliable alternatives, technologies based on image analysis are used widely, although they are expensive, not secure and require many calculations. Simple car detection methods and ordinary cameras in transportation control systems do not always ensure precise vehicle detection, especially during severe weather or night-time. It is almost impossible to collect and process data from cameras in real time. These systems require large amounts of equipment, high speed communication lines and financial resources.Therefore, it is practical to create alternative transportation detection systems using other types of sensors.

Research tasks and objectives

The aim of this research is to create new and analyse the existing alternative sensors used for transportation detection and propose the means and methods to ensure their effective functionality. The following objectives were established to complete this task:

- to analyse different technologies used in transportation detection sensors and clarify the advantages and drawbacks of technologies used in most widespread types of sensors;

- to introduce sensors for detecting vehicles with acceptable technical parameters;
- to create algorithms for detecting transportation means and to analyse the resistance of their hardware and software equipment to disturbances and weather factors;
- to estimate the efficiency of detection methods and the reliability of algorithms used for vehicle detection as well as to optimise the suggested methods and algorithms while applying them at specific working conditions;
- to verify the detection sensors in real transportation control systems;
- to evaluate and investigate the influence of external impacts (disturbances).

Practical value

The created methods are used for building and producing vehicle detection sensors with adaptive climate impact compensation and a complex detection algorithm, which are dedicated for transportation control systems.

Scientific novelty

A new vehicle detection method is proposed. The working principle is based on measuring field intensity using magneto-resistive sensors, which detect changes in the homogeneity of magnetic field of Earth. A complex detection criterion and the related calculation algorithm are developed.

Methods and tools

The ongoing processes are modelled using the created mathematical models in Matlab programming environment. The detection devices were created using embedded microcontroller systems and the code for them was written in C language in IAR programming environment. The experiments with magneto-resistive field sensors were performed at actual car parking lots under different weather conditions. Results of the experiment were computed using Matlab program package and the physical processes were simulated using the ComsolMultiphysics program package.

Practical value

The shortcomings of detection methods currently on the market has resulted in an absence of uncovered vehicle parking lots where car detection sensors would be installed. The introduced magnetic field measurement method using magneto-resistive sensors is universal and can be used in both covered and uncovered parking lots, hence increasing the control of parking places. In addition, sensors with more advanced technical parameters compared to the existing ones were presented. Their resistance to disturbance, weather conditions and practical recommendations regarding installation of the systems with the mentioned sensors were investigated and delivered. The supplied practical magnetic field analysis data allows to estimate the efficiency of the system based on the mentioned method. The models for electromagnetic disturbances and the means of transportation detection were derived in Matlab and ComsolMultiphysics, which can be used later for designing and improving other transport detection systems with magnetic sensors.

A prototype of vehicle detection sensor to be used in the transportation control system was designed, produced and applied for the study needs.

Approbation

Results of the research were announced in four international scientific conferences. The results of this work were published in ten scientific publications, including the main ISI list.

Results presented for the defence

1. Methods and algorithms for detecting a vehicle at the parking place based on the measurement of Earth‘s magnetic field changes.
2. Detection principles which allow to determine the status of a parking space and follow its occupation.
3. Car speed identification methods based on the measurement of Earth's magnetic field changes.
4. Practical research results which describe the possibilities of detecting cars and emerging critical spots at unfavourable conditions.
5. The magnetic disturbances and climate impact elimination and sensor calibration algorithms.

Structure and volume of the thesis

This research consists of an introduction, four chapters, conclusions, and a list of references. The volume of the research is 94 pages. There are 8 tables, 96 images and 70 references.

1. AN ANALYSIS OF THE PROBLEMS WITH TRANSPORTATION DETECTION SYSTEMS

Development of transportation systems in Lithuania and EU. In recent years, the automotive transportation sector has been continuously growing both in the EU and Lithuania. The European Commission predicts that the cargo carriage will grow by 55%, while passenger carriage will grow by 36% before 2020 [1][2][3].

Increasing transport flows enhance the development of infrastructure. In long-term, the transportation system development strategy of the Lithuanian Republic and the significance of intellectual transport systems (ITS) in main cities are emphasised [4][5].

OPTIPARK (funded by the EU, http://www.optipark.eu) research has concluded that parking spaces on the parking lots are used ineffectively, since the approximated value of efficiency reaches 50 percent. 75 percent out of 200 million European drivers would like to find parking spots easier and faster. Searching for a parking space in city centre takes from 20 to 60 percent of the whole driving time. For more than 50 percent of cars parking time in the city centre is under 1 hour [6].

According to the 2009 statistical data of the European parking lots association AIPARK, the total number of parking spaces was 40,8 million in cities which have more than 20 000 inhabitants and 8,8 million out of these were in buildings. The biggest parts of market for parking services belong to Germany, France, the UK, Italy and Spain [53]. All these countries together constitute for 78 percent of the entire European parking market [1]. For 1000 citizens there are 107 regulated parking places, which comprises only 19 percent of all parking places. 81 percent of parking spaces are in the streets (open air parking lots), 19 percent are parking lots and garages; 29 percent of all parking places in town are paid [3] [19].

After evaluating the statistical data, the demand for intellectual parking control solutions is obvious. In the city centres, up to 60 percent of traffic time is dedicated to the search of parking place. This time can be decreased by ensuring an effective usage of parking lots by installing electronic vehicle detection systems in parking lots [7].

An intellectual parking control system is a part of transport infrastructure. The development of transport infrastructure directly influences the demand for car parking places. The growth of market for intellectual parking control systems is directly proportional to transport market development and fully reflects the characteristics of transportation market.

The advantages of an intellectual parking control system can be proven by analysing scientific researches of other authors. Parking time for cars decreases by

65 percent after the installation of an electronic parking and surveillance system [8] [9] [10].

2. THESIS METHODOLOGY FORMATION

The suitability of the magnetic field method for car detection can be investigated by analysing the impact of cars on the disturbances of the local Earth's magnetic field. To solve this task, a specialised magnetic field measurement system and an algorithm must be created, which would allow to estimate the magnetic field parameters at the parking places. The detection of vehicles has to be stable in a wide range of temperatures (from -30 to +70 C) and during the entire exploitation period, which is from 5 to 10 years.

2.1. Magnetic field measurement system

For a car detection measurement system based on local Earth's magnetic field, a method for recording disturbances was created (pic. 2.1), which enabled to perform an interaction analysis of the Earth's magnetic field and the metal parts of a vehicle.

With the help of measurement system, the sensitivity, stability, temperature dependency and other parameters of the magnetic field sensors were analysed:

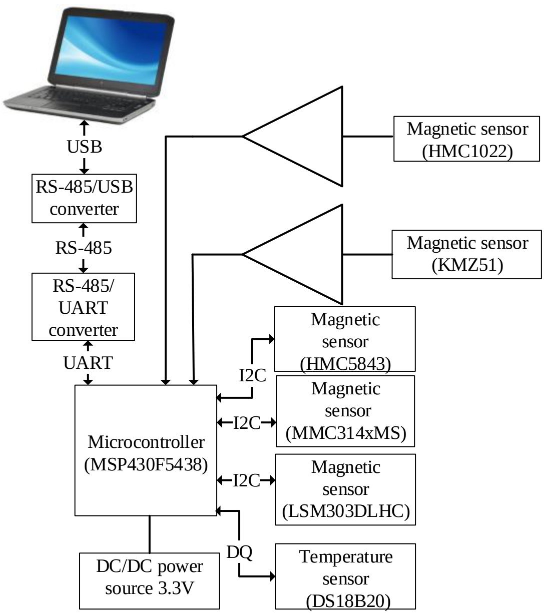


Figure 2.1 The structure of the magnetic field measurement system

The collected data is saved as a text file for further processing and imaging.

2.1.1. Temperature stability analysis

Temperature stability tests were performed using different sensors in the temperature chamber while the temperature varied from -30C° to 60C°. The results of temperature stability analysis for some of the sensors are presented below. Note that graph data is normalised at 25C° temperature:

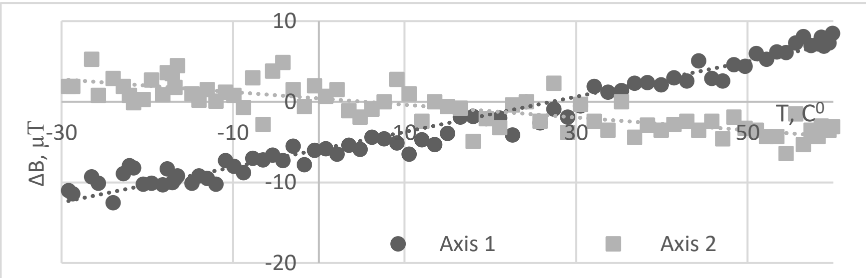


Figure 2.2 Temperature impact on HMC1022 sensor

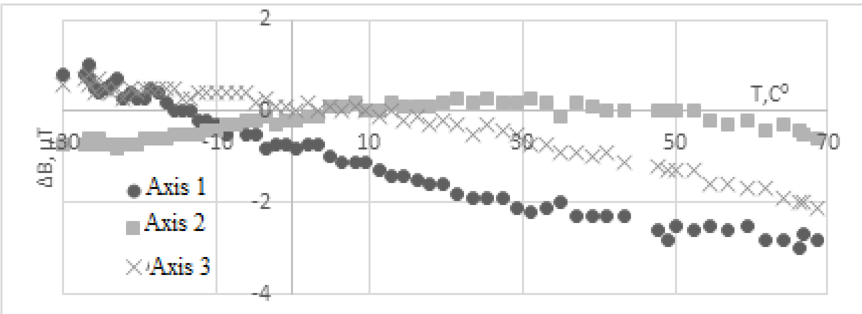


Figure 2.3 Temperature impact on LSM303DLHC sensor

2.2. The development of data registration system for the impacts of car construction on Earth's local magnetic field

To analyse the application of LSM303DLHC AMR sensors in transportation control systems, a data registration system was created which allows to investigate how the Earth's magnetic field changes under the vehicles at the parking lots. The measurements were completed with two AMR sensors, which were placed at the distance of 30 cm from each other in the direction of X axis. At the scan moment, the position of the car was recorded every 1 cm measuring the parameters of the magnetic field. The scan on the Y axis was completed in the direction of Y axis while moving both sensors.

For data registration, a digital distance meter was used which transmits information to a PC using the RS485 interface. The data was processed using a specially developed PC program. The sensor data was registered every 1 cm via the RS485 interface. A low power consumption MSP430 microprocessor was used to transmit data and read the information from AMR sensors within I2C connection.

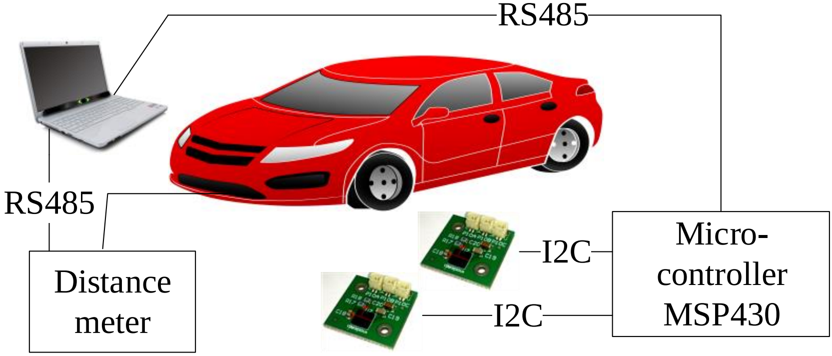


Figure 2.4 Automatic vehicle scan system

Earth's magnetic field disturbances were scanned to study the most suitable position for the sensors at the parking lot or highway and define what field disturbances are created by different vehicles at various places. It was determined that the type of magnetic field disturbances depends on the car model, the position of the sensor regarding the vehicle and the direction of movement. Due to this, when a car is placed over a sensor in various places (regarding Y axis), very different magnetic field component profiles are recorded. Therefore, methods based on measuring and comparing absolute values are not suitable for cars and their speed detection.

When a vehicle is over a sensor, all three magnetic field components should be measured and only this data can be used for defining the position and the formation of detection criterion.

3. STABILITY TEST

The changes in magnetic field are influenced not only by the vehicle. The surrounding objects and different processes happening in the immediate area have a vast influence on the parameters of magnetic sensors. There are a lot of factors which influence car detection, thus it becomes complicated to separate the signal which is caused by the car (actual signal) from the one caused by the surrounding objects (noise signal).

It is important to define the cause of interfering signal. Possible sources of disturbances:

1. The magnetic field can be uneven due to the geographical location. Therefore, it is compulsory to analyse the equability of the magnetic field at every spot of the parking lot.
2. The influence of other metal objects which are close to the detection object.
3. The influence of electromagnetic disturbances.
4. Cars from the same manufacturer are not completely alike: they may differ in number of metal parts and their placement, which also has impact on the signal.
5. The impact of self-magnetism of the sensor.
6. The influence of temperature changes the sensor data. Slow and fast changing of climate conditions.
7. The influence of geomagnetic storms.

The following task is to analyse the abovementioned disturbances and find out their influence on correct vehicle detection using the magnetic detection method.

3.1. Magnetic field continuity analysis

A constructional model of a car is similar to an enclosed rectangular cuboid model which was discussed before. Usually, the bottom part of the car under the engine is magnetically open and there is a metal-magnetic separator between the engine and salon, and between the salon and the trunk. These separators introduce some troubles since they can be detected as a car standing aside or car standing above, depending on the distance towards the magnetic sensor, meaning that the sum of the magnetic field and its separate components when the separator is close to magnetic sensor can be increased or reduced. Therefore, Earth's magnetic field induction component B_z located under the car is not always amplified. It makes defining the status of the parking lot extremely complicated.

To evaluate the possibilities of usage along with the advantages and drawbacks of AMR sensors in transportation control system, the fluctuations of Earth's magnetic field intensity at the parking lot were research. The experiment was performed with different car manufacturers and their models. An automatic car scanning system (pic. 2.17), which was explained in the previous chapter and allows to measure the disturbances created by a vehicle to Earth's magnetic field, was used for this research. The cars were scanned using two sensors; a 40 cm distance was left between the sensors. The measurements were taken every 1 cm, recording the position of the car and the parameters of magnetic field in the direction of axis X. A scan in the direction of axis X was repeated every 40 cm, while both AMR sensors were moved in the direction of axis Y (Fig. 3.1):

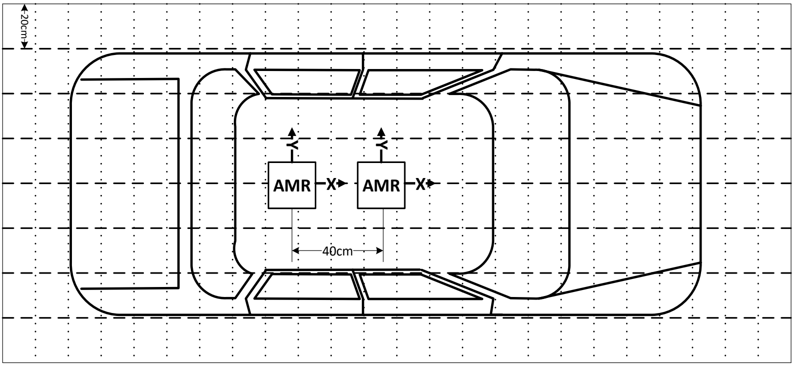


Figure 3.1 Scheme of magnetic field measurement at the parking lot

The Earth's magnetic field disturbances were scanned using different vehicles. For some of them, the magnetic field disturbance data is given in Fig. 3.2. The results of the research show that while the car is above an AMR sensor, the difference in the MF module and multiple components fluctuates differently and depends on the construction of the car and the position of sensors regarding the vehicle. Therefore, when a car drives over the sensor in various places (with regards to axis Y), very diverse profiles of the magnetic field component are obtained. Therefore, methods based on measuring and comparing absolute values are not suitable for vehicle detection.

The recorded data shows that there are zones underneath the car where the magnetic field is not distorted (as there was no vehicle). This state is critical for using AMR sensors for static detection of vehicles.

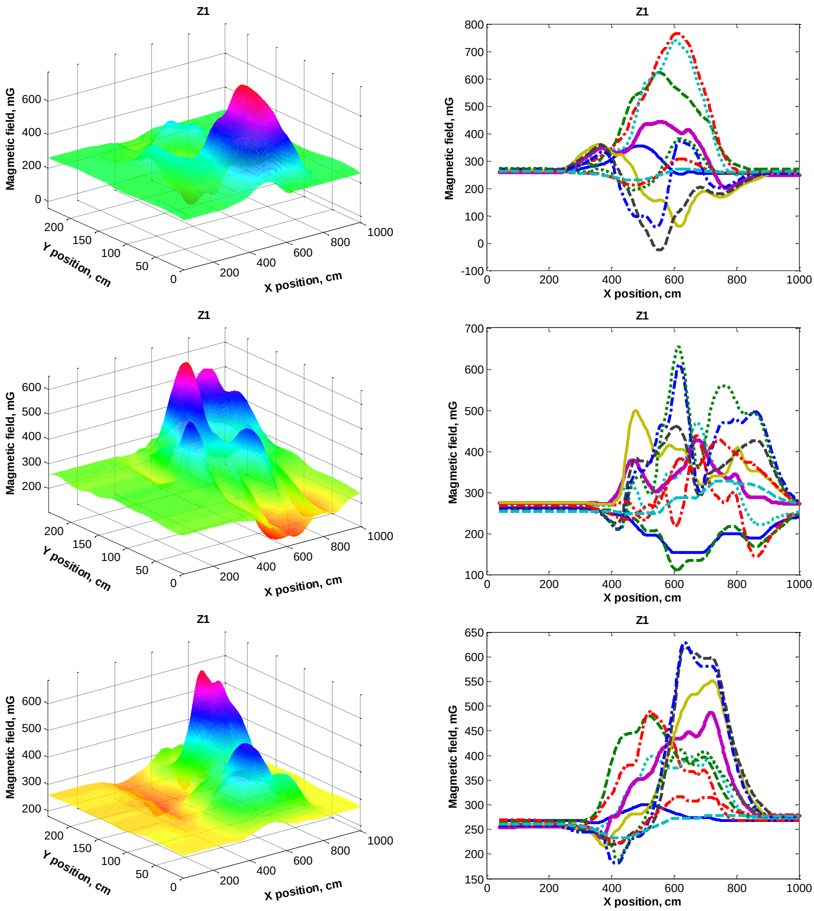


Figure 3.2 The distribution of distortion affected by Earth's magnetic field for different vehicle models

Parking places without magnetic anomalies and with no metallic objects nearby were selected when performing the magnetic field analysis. Results of this research demonstrate that there are no Earth's magnetic field anomalies at a free parking space, but when a car is parking the place, the biggest field distortions are around the front and rear axes of the car. This happens because most ferromagnetic parts, such as the engine, the engine separator, the hood, the gearbox, the front axis are all located in the front part of the vehicle. At the back of the car, the distortion of magnetic field is bigger compared to the middle part due to the rear axis and the trunk separator. The Earth's magnetic field is distorted not only by vehicles, but also by vast metal objects which are located nearby [54]. The accuracy of detection would be bigger if the magnetic field would not be interrupted by different unwanted objects, but it is hard or sometimes even impossible to eliminate them. Therefore, car detection using the Earth's magnetic field is a much more complicated task compared to inductive loop method. When using the magnetic field method for transportation detection, extrinsic factors must be liquidated.

It is proven by measurements that magnetic field induction module |B| and a separate variation of components varies unequally when the car is above the magnetic sensor. It depends on the model of the car, but, most importantly, some car models influence the vertical metallic separators quite significantly. It is possible to spot this influence in other car models. For some vehicles, the ratio in time environment variation of a component changes sign, while the variation of the induction module is close to zero. Other induction component variations are negligible, thus if a vehicle with the mentioned construction parks in this spot, its detection becomes a complex task. When a car is parked at a specific spot regarding the magnetic sensor, the area where the sum of the variation of magnetic field is almost zero is referred to as critical point. More detailed formation of the critical point is shown in Fig. 3.3, where the critical point area is highlighted with a rectangle. The horizontal axis refers to car position number-distance (the gap between two neighbouring positions is 20 cm). It is seen that the width of the critical point is not very large (around 20 cm). It improves the current situation because the probability of the car stopping at this point is decreased:

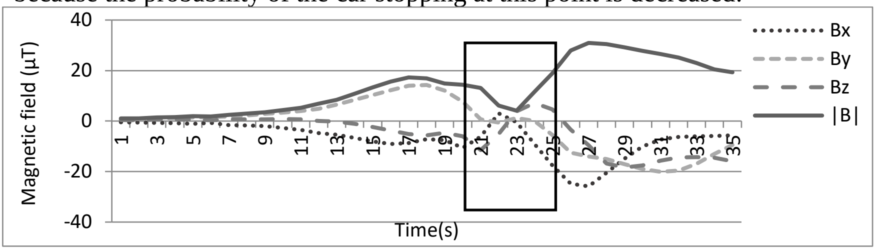


Figure 3.3 A detailed analysis of a vehicle critical point

3.2. Experimental research of magnetic field created by a coil and a line

The magnetic field induction is directly proportional to the electric current flowing over the conductor. The magnetic field also exists in the area around magnetic materials. These magnetic fields are extraneous distortion sources on the sensor board. The power circuit of impulse converter and its inductive coil are also distortion sources. Terminals of resistors, capacitors or other board components could be made from magnetic materials. If the impact of the external magnetic field is strong enough, they can be magnetised. To avoid these side distortions, a magnetic sensor was developed separately from the microprocessor circuit board.

For experimental research of the magnetic field, an analogue two-axis (BX and BY) probe using an HMC1022 chip was created.

The data registration device was connected with a laptop via a USB cable and information was transferred to a data file using a developed program. The created software allowed to register sensor data at a predefined pace starting from ten times per second to once a day. The probe was attached above the actuated PCB components (inductors, transmission and power lines):

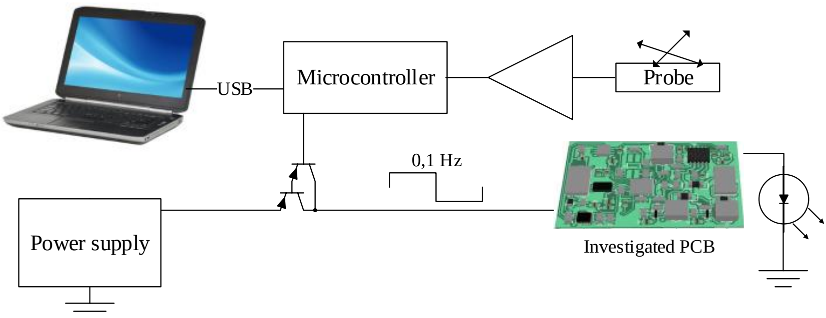
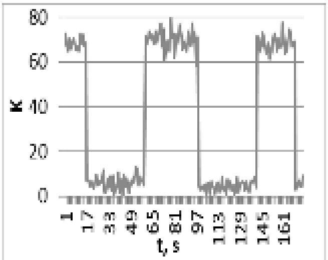


Figure 3.4 The structural scheme of measurements

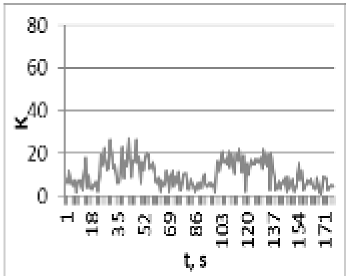
The research has revealed that the throttle of the LED controller creates a strong permanent magnetic field which is directly proportional to the current flowing through the diode. It also creates a weak and almost negligible alternating magnetic field. An alternating magnetic field current was noticed while analysing the constructions of other manufacturers, but the intensity of an alternating magnetic field never went above 2 % of the permanent field value. This fact allowed to simplify the experiments and use a 0.1 Hz stimulation pulse. The influence of magnetic field components was evaluated with K coefficient.

$$K = \sqrt{(B_x - B_{x0})^2 + (B_y - B_{y0})^2 + (B_z - B_{z0})^2} \tag{3.1}$$

where B_x, B_y B_z - measured magnetic induction values at a given moment, B_{x0}, B_{y0} B_{z0} - values of magnetic induction when a PCB power supply is turned on. During the experiment, the LED controller current was set at 150 mA, while the power line current was around 0.5 A.



a)



b)

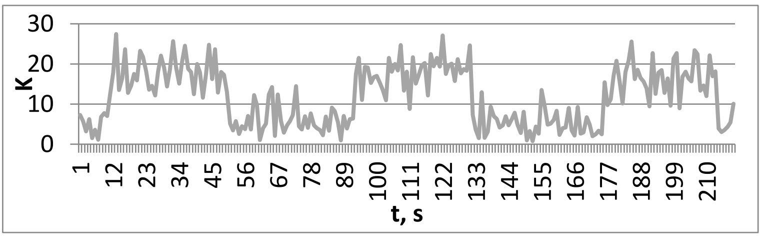
Figure 3.5 The value of coefficient K using an open-type throttle of an LED controller: a – 30 mm from sensor,d – 60 mm from sensor

The minimum distance between the throttle of an open-type LED controller and a sensor should be no less than 60–70 mm as seen from Fig. 3.5.

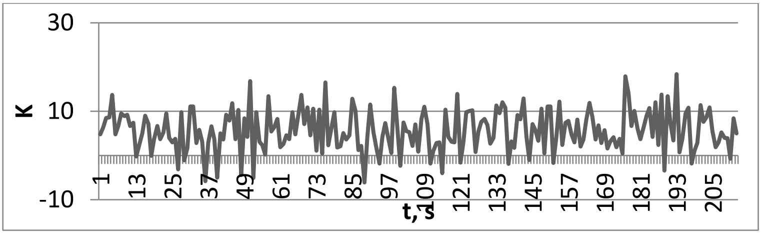
The influence of current flowing over power cables

During the experiment, parameters of power lines were measured in realistic conditions. The influence of multiple values of current flowing through the power cables on the magnetic field sensors were inspected.

Research was done with a digital LSM303DLH sensor. The values of magnetic induction were recorded with a different current flow. Results are given in Fig. 3.6 and it is seen that the current flowing through a power cable also has an impact, while the minimum distance between the sensor and the power cable should be no less than 30–40 mm. Attention has to be paid to the fact that the current was from 0.5 A to 2 A, while in a real sensor network, the current can reach values from 2 A to 4 A and more, thus the created magnetic field would be accordingly stronger.



a)



b)

Figure 3.6 The values of coefficient K using a two-wire power indicator: a – 10mm, b – 40mm

3.3. The influence of magnetic field effect on the displacement and sensitivity of parameters of a magneto-resistive sensor

During the analysis of magnetic fields of different shapes it was observed that the bridges of AMR magnetic field sensor LSM303DLH after a short impact of magnetic field (above 3mT) receive a displacement of parameters, which do not disappear even after removing the magnetic field. The goal of this research is to determine the intensity, the saturation of intensity and the influence of a strong magnetic field on the sensitivity of the field which creates the remaining bridge displacement.

To minimize measurement error caused by inaccurate positioning of the sensor, monolithic and calibrated magnetic field with indirectly measurable intensity should be created in a bounded area (which must be larger than the sensor under test).

The ANSI/IEEE standard defines two magnetic sensor calibration methods: a one-layer square loop and a circular Helmholtz coil [70, 71].

A pair of circular Helmholtz coils with relevant radius (55.2 mm) were selected for calibration, where the intensity of the created magnetic field was calculated relying on current flow through them.

To affect the AMR sensor with a more intensive field, a high-capacity electrolytic battery of capacitors (1420 μF, 400V) were used as power supply, which can be charged only to a fixed voltage.

During the experiment, a sensor was affected by an intensive magnetic field for brief period (≤20ms) of time which is above its range and the display parameters were recorded. The scheme of the experiment is given below:

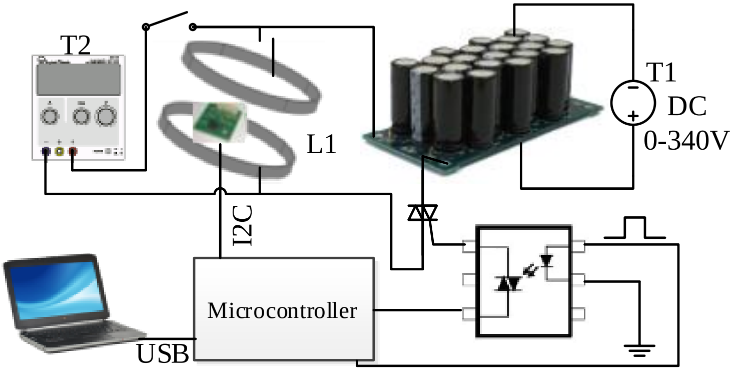


Figure 3.7 The structural/principal scheme of the experiment. L1 – a pair of Helmholtz coils which create a magnetic field; T1 – an automatic laboratory transformer for capacitor charge control; V1 – a voltmeter for capacitor charge level control; S3 – a switch for discharging the battery; Q1 – a double thyristor for connecting capacitors to the coil.

T2 was used for creating a low-intensity field (<6mT) to assure the accuracy of the experiment. It was also applied for creating a magnetic field of different directions for measuring of the sensitivity of the sensors and calibration.

The AT90USB1287 microprocessor was used as a data logging and registration device. It was connected to a PC via a USB cable and magnetic sensor information was transferred to a data file using the developed program.

When analysing the displacement of a sensor of displayed parameters, it was affected by short magnetic field impulses the intensity of which was raised with every step. The values of sensor-supplied separate magnetic field components were recorded between separate impulses.

When investigating on the sensitivity of the sensor, it was demagnetised with a fading amplitude (50 Hz) via an alternating magnetic field, then the data was recorded while affecting it only with the Earth's magnetic field and low-intensity magnetic field, which fits the measurement limits of the sensor. Afterwards, the sensor was magnetised with an intensive magnetic field (100 mT) and the field components were recorded in the same manner as before. Analogical measurements were performed while magnetising the sensor with a different direction magnetic field.

Firstly, the ratio of AMR sensor parameters to applied magnetic field intensity was measured (Fig. 3.8). The graph shows that the biggest data displacement is seen on axis Z, which conforms with the direction of magnetic field lines.

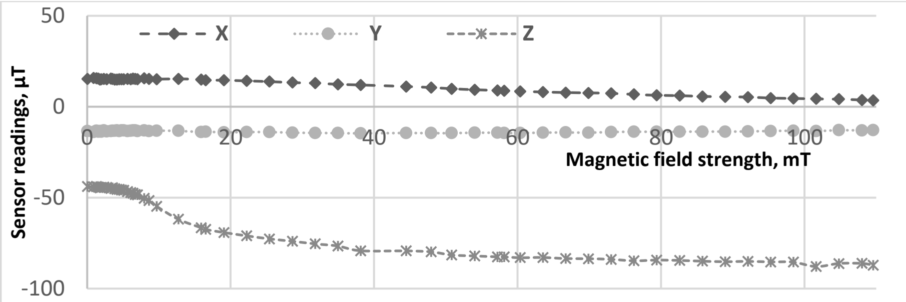


Figure 3.8 The dependency of sensor-displayed parameters on the applied magnetic field

The results of the test demonstrate that to create an observable (≥5 %) displacement of the sensor-displayed parameters, the necessary magnetic field intensity depends on the initial sensor magnetisation. When the sensor is demagnetised, a field of ~5 mT intensity is required. When the sensor elements are magnetised and parameter displacement is observed, then the obtainable displacement can be created with a ~2 mT magnetic field intensity.

Then the influence of different items affected with high-intensity magnetic field on the sensitivity of the sensor was measured depending on distance of the item to the sensor. The results are plotted on orthogonal axes with absolute values being normalised with a module (Fig. 3.9). The graph shows that the minimal distance between passive SMD components must be no less than 10 mm.

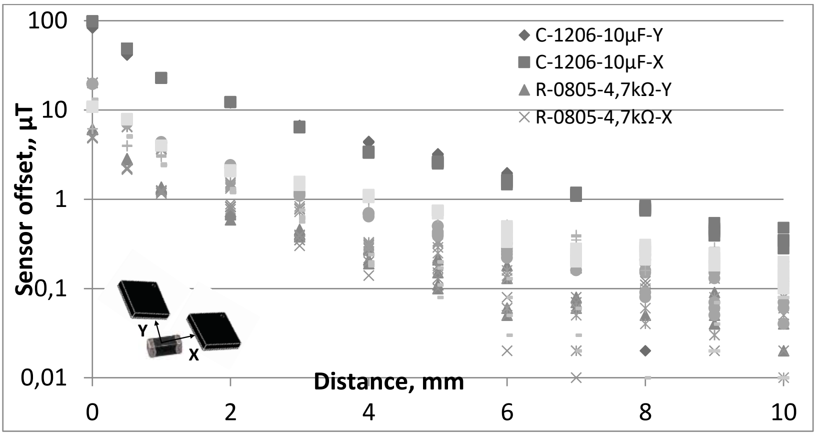


Figure 3.9 The influence of passive components influence on AMR sensor

To define the influence of components in the direction of axes X and Y on the AMR sensor, measurements with a substituting position of a component on the other side of PCB were done. on the data in Fig. 3.9 shows that the bridges of AMR LSM303DLH magnetic field sensor are not situated in the centre of a chip. The research has revealed that the magnetised passive components create an adequate high-intensity magnetic field which affects the measurements.

4. EXPERIMENTAL RESEARCH

4.1. Research of transport detection algorithms

A transportation detection system contains magnetic field variation signals, analyses their alteration and concludes whether there is a vehicle. To solve this problem, different signal processing methods and detection algorithms may be applied. A structural scheme of the transportation detection system where algorithms are applied and implemented is given in Fig. 4.1. The main object is a vehicle which should be detected or not.

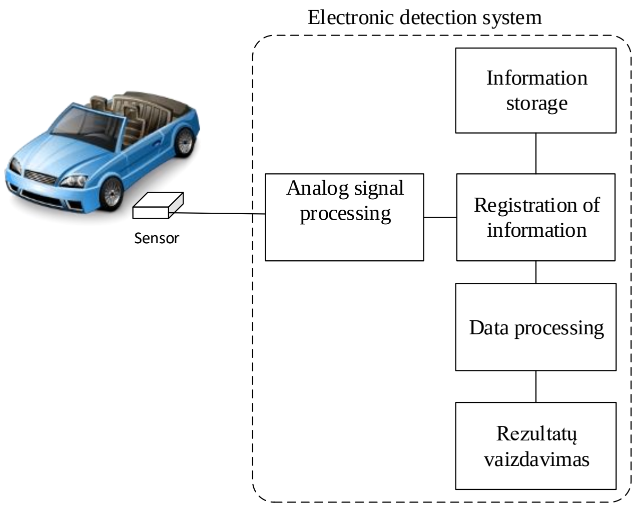


Figure 4.1 A structural scheme of complex for transportation detection system

There are many various algorithms devoted for digital signal processing [29]. The essence of the algorithm is to solve the task in the simplest and fastest way, while minimizing the amount of resources used. The application of certain algorithms depends on the type of signal and where it is going to be used. The possibilities of using algorithms for analysing a magnetic field signal and vehicle detection are shown in Fig. 4.2. In this case, a magnetic field signal is classified as unsteady and random, thus it makes the task more difficult, since the algorithms for reoccurring or harmonic signals cannot be applied.

4.11. Amplitude threshold detection method

The easiest algorithm for vehicle detection is to measure all three magnetic field components and calculate the module of magnetic field. Depending on the alteration of module value, detection of a vehicle is determined. The car is detected while following the amplitude of the signal. The upper and lower magnetic field alteration limits are identified. The magnetic field of the Earth can vary from to . A car is detected when the condition is met, meaning that the alteration of a magnetic field module must be bigger than the top limit or lower than the bottom limit. Signals for transportation status determination are given in Fig. 4.2. The ordinary threshold detection algorithm has a lot of drawbacks. If there are long-lasting alterations of the signal because of temperature fluctuations, fixed threshold values of magnetic field alterations do not change. Because of this issue, a mistake in detection of a vehicle is probable. As Fig. 4.2a presents, the alteration of magnetic field is bigger than the threshold value, although there is no car there; this happens because of temperature fluctuations. Therefore, false detection occurs. To avoid this faulty slow signal, alteration caused by extrinsic factors must be taken into consideration.

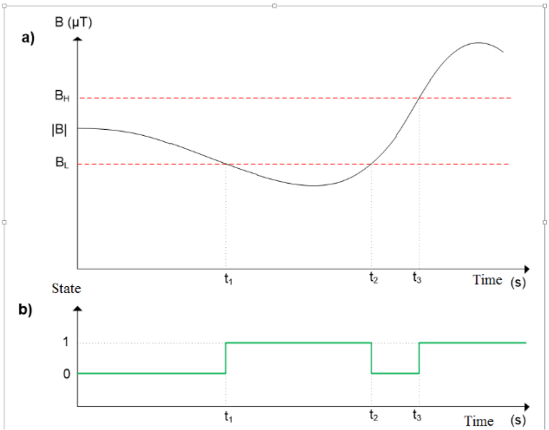


Figure 4.2 The threshold detection algorithm with a fixed threshold value: a) magnetic field signal, b) state signal

The threshold detection algorithm is supplemented with additional alternating threshold limits. The threshold changes adaptively repeating a slow drift of magnetic field signal. As seen from Fig. 4.3, at t1 time the signal does not exceed the defined threshold and detection happens at t3 when a car appears.

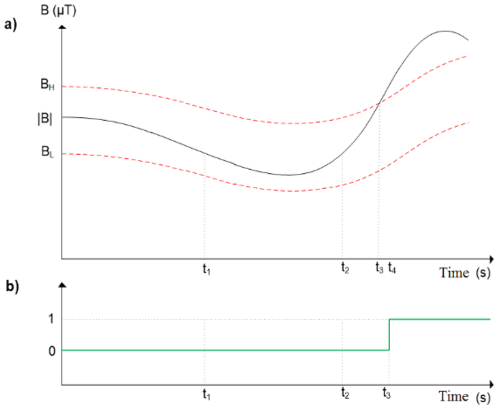


Figure 4.3 The threshold detection algorithm with an adaptive threshold limit: a) – magnetic field signal, b) – state signal

This detection algorithm eliminates slow variation of a signal caused by extrinsic impact, but has no effect on transient disturbances. It is possible to use this algorithm if there are no transient disturbances. The advantage of it is that it does not require any complicated calculations.

The threshold value can be changed by sending a respective instruction from the microprocessor at the parking lot. The threshold value can be determined considering the constructional solutions, climate, etc.

4.2. Detection status criterion

The decision about the occupation of a parking space should be made based on magnetic field alteration at the parking space.

To implement the status, principles should be defined which would let to decide whether the parking space is "free" or "taken". To formulate these principles, the aforementioned assumptions and limitations will be used.

There are multiple ambiguities when "dynamic" car detection is not possible. When a car is passing over or turning around close to the sensor, it reacts in the same manner as if the vehicle had stopped. This situation is relevant when goods are loaded/unloaded or passengers are getting in/out of the vehicle. Even though the car is not moving, the sensor reaction might be similar as to transport motion.

When the vehicle is above the sensor, all three magnetic field components can be measured and only this information should be used to define the formation of static criterion.

Square criterion. A particularly easy criterion, the calculations of which require minor amount of microprocessor resources.

$$K = \sqrt{(B_x - B_{x0})^2 + \left(B_y - B_{y0}\right)^2 + (B_z - B_{z0})^2} \qquad (4.1)$$

where $B_x,\ B_y,\ B_z$ are measured magnetic induction values at a given time, B_{x0}, B_{y0}, B_{z0} are magnetic induction values at the current temperature of free parking space at the given moment. This criterion has a rather straightforward implementation in the microprocessor but there are multiple shortcomings, such as strong sensitivity to the impact of temperature (all three temperature coefficients of the bridges should be fixed and the values of B_{x0}, B_{y0}, B_{z0} should be calculated) and low resistance to nearly parked vehicles.

Vector criterion.

$$K = |\cos\alpha - \cos\alpha_0| + |\cos\beta - \cos\beta_0| + |\cos\gamma - \cos\gamma_0| \qquad (4.2)$$

where – $\cos\alpha, \cos\beta, \cos\gamma$ – cosines of magnetic field vector angles when car is parked –$\cos\alpha_0$, $\cos\alpha\beta_0$, $\cos\gamma_0$ – cosines of magnetic field vector angles at a free parking place at current moment temperature.

$\cos\alpha = B_X/M,$

$\cos\beta = B_Y/M,$

$\cos\gamma = B_Z/M,$

$M = \sqrt{B_X^2 + B_Y^2 + B_Z^2}$ – the module of magnetic field at any car position at the parking lot. The advantage of this criterion is great sensitivity and much better resistance to impact of temperature compared to the “square” criterion, because the ratio of magnetic field induction components is used to formulate this criterion. When performing criterion compensation of temperature, it is enough to compensate only one dimension – criterion (while compensating 3 in “square” criterion). This criterion enables car detection which is up to 2 m away, but a vehicle parked nearby (especially, a large one) can cause a false decision.

Combined vector criterion.

This criterion is compiled from “square” and “vector” criterion. Taking advantage of the increased Z component when the car is above and decreased at the side of the car, it is possible to enhance the sensitivity of a sensor when the car is parked and reduce effect of the nearby cars.

$$\mathrm{K} = |\cos\alpha - \cos\alpha_0| + |\cos\beta - \cos\beta_0| + (\mathrm{B_z}/\mathrm{B_{z0}} - 1) \qquad (4.3)$$

It seems illogical from the first sight, because different dimensions are summed up – cosines and ratio, but both of them are dimensionless. The advantage of this criterion is sensitivity and temperature stability compared to the parameters and the resistance to nearby cars of “vector” criterion.

In some cases, it is observed that component Z of the magnetic field is decreased by 20 %–50 % and more (very wide critical point) when a car is driven above. In these situations, the “square” and “vector” criterions would detect a car correctly, but not the combined criterion. This can be easily solved by introducing an additional logical condition L:

$$K = |\cos\alpha - \cos\alpha_0| + |\cos\beta - \cos\beta_0| + L(B_z/B_{z0} - 1); \quad (4.4)$$

where $L = 1$, when $(B_z/B_{z0} - 1) > -Kd$, $L = -1$, when $(B_z/B_{z0} - 1) < -Kd$, Kd– critical point threshold.

One of the drawbacks of this criterion is the need to compensate the temperature impact on the sum of the cosines and component Z or correlate the criterion to the “left” or “right” from the points of temperature calibration.

A constructional model of a vehicle compared to a simple geometrical figure is much more complicated. Based on the results of experimental measurements it was defined that various car constructions affect the local Earth’s magnetic field differently.

After an analysis of mathematical magnetic field expressions, it was concluded that a car which is situated above a magnetic sensor now increases the magnetic field component Z, while a car parked at the nearby parking lot does not always decrease the magnetic field component Z.

The alteration of magnetic field when a car is moving above the sensor is almost unpredictable. If a car is situated at the critical point, it can be detected only with the help of a complex detection criterion. All three discussed detection criterion require compensation of temperature impact. At the moment there is no single decision made on which of the three detection components should be used. To elucidate this matter, research on efficiency of vehicle detection for all criterions must be performed.

4.3. Simulation of detection criterion

Transportation detection was simulated in Matlab using a modified expression with an additional informational criterion P. Instead of using multiplication of X and Y components of magnetic field, the multiplication of directional cosines CP, which is not dependent on temperature, was used:

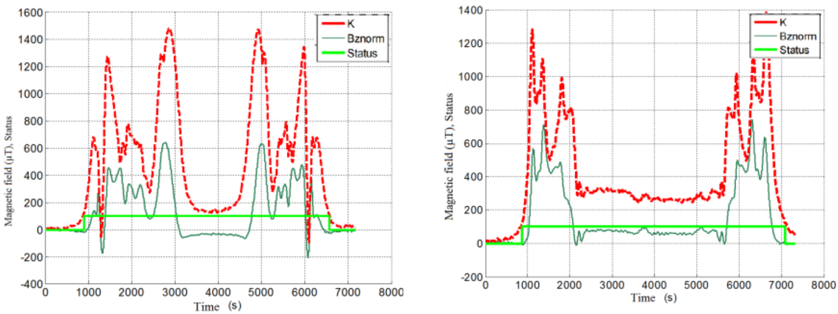
$$CP = \left(\frac{B_x}{|B|} - \frac{B_{x0}}{|B_0|}\right) \cdot \left(\frac{B_y}{|B|} - \frac{B_{y0}}{|B_0|}\right) \quad (0.5)$$

where $|B| = \sqrt{B_x^2 + B_y^2 + B_z^2}$ – the module of magnetic field at any position of vehicle at the parking slot; $|B_0| = \sqrt{B_{0x}^2 + B_{0y}^2 + B_{0z}^2}$- the module of magnetic field at initial vehicle position at the parking slot (parking slot is free).

The parking place state detection criterion K was selected for simulation. The shape of criterion repeats an alteration of magnetic field module when a car is entering. The scheme of the algorithm is given in Fig. 4.11.

$$K = 1000 \cdot \left(\left| \frac{B_x}{|B|} - \frac{B_{x0}}{|B_0|} \right| + \left| \frac{B_y}{|B|} - \frac{B_{y0}}{|B_0|} \right| + \left(\frac{B_z}{B_{z0}} - 1 \right) \right) \quad (0.6)$$

The suggested criterion K reduces the influence of states of side-situated parking places and makes the slopes of the criterion sharper. Because two first components are hardly dependent on the criterion of temperature (ratio of $\frac{B_x}{|B|}$ and $\frac{B_y}{|B|}$ numerator and denominator change in the very same manner because of temperature) they are be less dependent on temperature compared to the magnetic field module.



a) b)

4.1 pav. Detection simulation results with different vehicle construction models, (sensor is at 0 degrees regarding car)

The results of the simulation are plotted in Fig. 4.4.The following conditions were selected for the simulation: the critical point or entrance and exit of the car at the parking spot are the triggers for detection procedure to start, while the selected criterion K is between the boundary value K_r (the boundary criterion value is the value of consideration that vehicle is at the parking lot) and doubled boundary value $2 \cdot K_r$. The parking lot state detection procedure, during which the decision based on additional information (in this case – CP) is made, is started only when the criterion value is less than the boundary. The simulation results in Fig. 4.13b show that, unfortunately, for one constructional model of vehicle when the sensor is turned at the angle of 135° with regards to the car it operated incorrectly, because the exit of the car from the parking lot was not registered. In other cases, the algorithm operated correctly: cars were detected both when entering and leaving and, most importantly, the critical point was recognised.

If separate car parking identification methods would not be precise and effective enough, the combined method might be used. It is characterised by using multiple aforementioned methods at once. The final decision of the algorithm can be quite diverse because it might be dependent on the hierarchy of reliability or using the "majority" principle or based on the identification importance and so on.

CONCLUSION

1. Technologies for transportation detection were analysed and their advantages and drawbacks were highlighted. It was determined that intellectual transportation control systems are installed to exploit the existing infrastructure and control transport flow in optimal ways. The biggest part of the car trip in the city centre is devoted to the search of parking place, which can be reduced by monitoring the states of parking spots and informing drivers about empty places. The existing methods for parking slot detection are narrowly applied and usually dedicated only for enclosed parking lots.
2. Vector magnetic field sensors with acceptable technical and economical parameters (both small size and price) were introduced, which can precisely measure the alteration of every magnetic field component and, therefore, can be used in open-air parking lots. A magnetic field distortion measurement method is proposed, which can be adapted for car detection and parking place state definition almost at every type of parking lot. Experimental research applying the mentioned method was held in a developed and produced three-axes magnetic field measurement system for vehicle detection.
3. Algorithms were created and detection criteria were formulated based on the simulation and practical research results, which allow to estimate and determine the state of a parking slot. Research suggests that the most precise parking place state detection can be carried out using a complex detection criterion.
4. The data was collected at real car parking lots using the developed means and magnetic field distortion dependency on the type of a car and its constructional features were determined. An analysis of surrounding temperature allowed to evaluate and compensate for the impact of temperature. The installed calibration procedure allowed to eliminate the inequality of the local magnetic field and the impact of surroundings.
5. It was identified by the research of long-lasting efficiency of the algorithms that the magnetic field distortion measurement method is suitable for transportation detection and can be exploited at any type of parking lots, while its versatility would allow to replace the currently used ultrasonic sensors and inductive loops.
6. A simulation and experimental research were carried out, which allowed to estimate the influence of strong extrinsic magnetic fields to the AMR sensors. It was determined that the sensitivity of AMR sensor is not dependent on the magnetisation of nearly placed items, therefore static or dynamic field measurements can be performed without additional calibration of the sensor. If during exploitation there are strong magnetic fields (above 2mT) near the sensor,

calibration before measurement of static magnetic field or demagnetisation with a fading alternating magnetic field should be applied to the sensor.

ĮVADAS

Daugėjant transporto priemonių, transporto srautų valdymo sistemoms tenka spręsti vis sudėtingesnius uždavinius. Pastaraisiais metais plėtojamos ir elektroninės eismo valdymo sistemos, tačiau lieka neišspręstų problemų, susijusių su eismo valdymu, automobilių grūstimis, automobilių statymu ir daug kitų specifinių atvejų. Tikslus transporto srautų aptikimas ir prognozavimas yra vienas iš svarbiausių eismo valdymo uždavinių siekiant pagerinti eismo sąlygas miesto gatvėse. Transporto srautų prognozavimas yra svarbus eismo infrastruktūrai planuoti, projektuoti, vystyti ir transportui valdyti. Be to, visos masinio susibūrimo vietos siejamos ir su didesne ekstremalių situacijų rizika, o šiose situacijose gali būti naudingos eismo srautų valdymo sistemos. Todėl sklandžiam ir sparčiam eismo srautų judėjimui užtikrinti reikalingos efektyvios, integruotos intelektualiosios transporto valdymo sistemos.

Šiuolaikinių elektronikos technologijų vystymasis ir galimybė tas technologijas pritaikyti miesto eismui valdyti atveria naujų būdų spręsti eismo saugumo, eismo srautų valdymo, kuro sąnaudų mažinimo, aplinkos teršimo ir kitas su eismu susijusias problemas. Pažangių transporto valdymo sistemų įdiegimas reikalauja daug mažiau išteklių nei kitų transporto infrastruktūros dalių atnaujinimas, pavyzdžiui, kelių tiesimas ar platinimas.

Automobilių aptikimo sistema – viena iš pagrindinių eismo valdymo sistemos dalių. Nesant pigesnių ir patikimesnių alternatyvų, automobiliams aptikti ir sekti vis dažniau naudojamos vaizdų analizės technologijos, kurios yra brangios, ne visada patikimos ir reikalauja daug skaičiavimo išteklių. Eismo valdymo sistemose taikant įprastinius automobilių atpažinimo vaizde metodus ir naudojant paprastas vaizdo kameras, ne visada įmanoma užtikrinti tikslų automobilių aptikimą, ypač nakties metu ar esant blogoms oro sąlygoms. Naudojant kameras surinkti ir realiuoju laiku apdoroti transporto srautų duomenis iš kiekvienos vietos beveik neįmanoma, sistemai įdiegti prireiktų labai daug įrangos, didelio pralaidumo ryšio linijų ir lėšų. Todėl labai aktualu kurti alternatyvius transporto priemonių aptikimo metodus panaudojant kitų tipų jutiklius.

Darbo tikslas ir uždaviniai

Darbo tikslas – sukurti ir ištirti alternatyvius jau esantiems transporto priemonių aptikimo jutiklius ir pasiūlyti priemonių bei metodų efektyviam jų darbui užtikrinti. Tikslui pasiekti buvo suformuluoti šie uždaviniai:

- Išanalizuoti įvairias technologijas, naudojamas transporto aptikimo jutikliuose, ir išryškinti šiuo metu dažniausiai naudojamų jutiklių technologijų privalumus ir trūkumus.
- Pasiūlyti priimtinų techninių parametrų jutiklius, skirtus transporto priemonėms aptikti.

- Sukurti transporto priemonių aptikimo algoritmus, ištirti jų ir aparatinės bei programinės įrangos atsparumą trikdžiams ir klimato veiksniams.
- Įvertinti transporto priemonių aptikimo metodų ir algoritmų patikimumą, optimizuoti pasiūlytus metodus ir algoritmus, pritaikant juos konkrečioms eksploatacijos sąlygoms.
- Aprobuoti aptikimo jutiklius realiose transporto valdymo sistemose.
- Įvertinti ir ištirti išorinio poveikio (trikdžių) įtaką.

Darbo praktinis taikymas

Disertacijoje sukurti metodai pritaikyti kuriant ir gaminant transporto valdymo sistemų transporto priemonių aptikimo jutiklius su adaptyviąja klimato poveikio kompensacija ir kompleksiniu aptikimo algoritmu.

Mokslinis naujumas

Pasiūlytas transporto priemonių aptikimo metodas, pagrįstas Žemės magnetinio lauko homogeniškumo pokyčio fiksavimu lauko stiprį matuojant magnetorezistyviniais jutikliais. Sukurtas kompleksinis aptikimo kriterijaus ir jo skaičiavimo algoritmas.

Tyrimų metodika ir priemonės

Vykstantys procesai modeliuoti pasinaudojus sukurtais matematiniais modeliais programavimo aplinkoje „Matlab“. Aptikimo įrenginiai kurti naudojant įterptines mikrovaldiklių sistemas, kurių programinė įranga kurta naudojant C programavimo kalbą ir „IAR“ programavimo aplinką. Eksperimentai atlikti su magnetorezistyviniais magnetinio lauko jutikliais automobilių stovėjimo aikštelėse įvairiomis klimato sąlygomis. Eksperimentų rezultatai apdoroti naudojant programų paketą „Matlab“. Fizikiniai procesai modeliuoti modeliavimo aplinkoje „Comsol Multiphysics“.

Praktinė darbo vertė

Rinkoje taikomų aptikimo metodų trūkumai lėmė tai, kad šiuo metu beveik nėra atvirojo tipo transporto stovėjimo aikštelių, kuriose įdiegti automobilių aptikimo jutikliai. Darbe pasiūlytas magnetinio lauko matavimo naudojant magnetorezistyvinius jutiklius metodas yra universalus ir gali būti taikomas tiek atvirojo, tiek uždarojo tipo automobilių stovėjimo aikštelėse, taip gerokai padidinant reguliuojamų stovėjimo vietų skaičių. Darbas turi praktinę vertę ir dėl to, kad buvo ištirti ir pasiūlyti geresnių techninių parametrų jutikliai, palyginti su dabar esančiais rinkoje. Aptikimo sistemoms su šiais jutikliais buvo sukurti funkcionavimo algoritmai ir programos, ištirtas jų atsparumas trikdžiams, klimato veiksniams ir pateiktos praktinio sistemų diegimo rekomendacijos. Pateikti praktiniai magnetinio lauko metodo bandymų duomenys leidžia įvertinti aptikimo sistemos, kurios veikimas paremtas šiuo metodu, efektyvumą. Rengiant darbą buvo sukurti nauji „Matlab" ir „Comsol Multiphysics" elektromagnetinių trikdžių ir transporto priemonių aptikimo modeliai, kurie gali būti pritaikomi projektuojant ir tobulinant kitas transporto priemonių aptikimo sistemas su magnetiniais jutikliais.

Suprojektuotas ir pagamintas transporto priemonių valdymo sistemos transporto priemonių aptikimo jutiklio prototipas ir sukurti modeliai panaudoti mokymo procese.

Tyrimo rezultatų aprobavimas

Disertacijos tyrimo rezultatai pristatyti keturiose tarptautinėse mokslinėse konferencijose. Keturi straipsniai disertacijos tema publikuoti mokslo žurnaluose, referuojamuose Mokslinės informacijos instituto (ISI) pagrindiniame sąraše.

Ginti pateikiami darbo rezultatai

1. Žemės magnetinio lauko pokyčio matavimu paremtas automobilių aptikimo stovėjimo vietoje metodas ir algoritmai.
2. Aptikimo kriterijai, leidžiantys nustatyti automobilių stovėjimo vietos būseną ir sekti jos užimtumą.
3. Žemės magnetinio lauko pokyčio matavimu paremti automobilių greičio nustatymo metodai.
4. Praktinių tyrimų rezultatai, leidžiantys apibūdinti galimybes aptikti automobilius ir susidarančius kritinius taškus esant nepalankioms sąlygoms.
5. Magnetinių trikdžių ir klimato veiksnių eliminavimo ir jutiklių kalibravimo algoritmai.

Disertacijos struktūra ir apimtis

Disertaciją sudaro įvadas, keturi skyriai, išvados, literatūros sąrašas. Darbo apimtis – 90 puslapiai. Disertacijoje pateiktos 8 lentelės, 96 paveikslai. Literatūros sąrašą sudaro 70 šaltinių.

UDK 681.586.785+656.11.021](043.3)

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