(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 223 259 A1**

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
27.09.2017 Bulletin 2017/39

(51) Int Cl.:
G08G 1/14 *(2006.01)*

(21) Application number: **16162413.5**

(22) Date of filing: **24.03.2016**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

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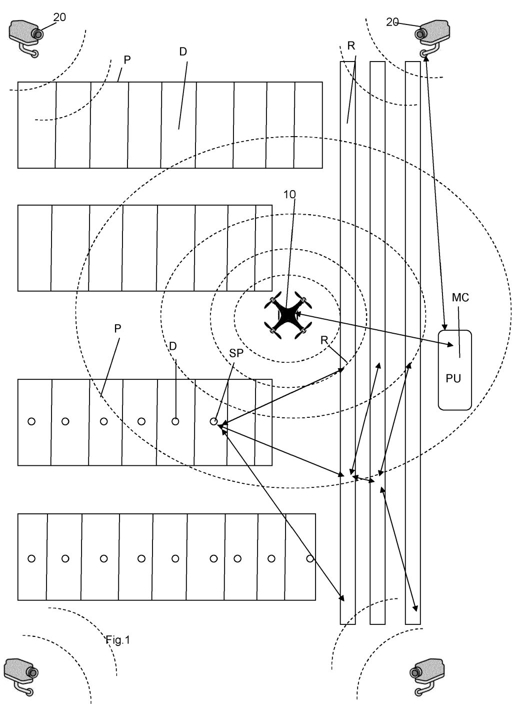
(54) **IMPROVED COMBINED SYSTEM FOR DETERMINING THE FREE OR OCCUPIED STATE OF A PARKING SPACE IN A CAR PARK**

(57) A combined system for determining the free or occupied state of a parking space in a car park is described. The system comprises: a) a first system for detecting the state of a specific parking space from among a plurality of parking spaces, comprising: * for each parking space at least one sensor intended to measure a first value of at least one parameter, said parameter being variable depending on whether a vehicle or present or not; * means for transmitting the first measured value to a processing unit comprising means for comparing the first value with a stored reference value corresponding to a known state of the specific parking space; * means for comparing the first value with a second value of the parameter, measured for at least one parking space adjacent to the specific parking space; * means for determining the state of the parking space on the basis of both the comparisons, between the first value and the reference value and between the first value and the second value; * said first system being intended to communicate the free or occupied state determined on the basis of both the comparisons to a control unit of the car park; b) a second video surveillance system comprising: * means for recording pictures and/or videos of the parking spaces in the car park, including said specific parking space; * means for comparing the acquired pictures of the specific parking space and reference pictures of said specific parking space, when no vehicles are present; * means for determining the free or occupied state of the specific parking space, on the basis of said comparison of the pictures; * said second system being intended to communicate the free or occupied state determined on the basis of said comparison of the pictures to the control unit of the car park; said control unit of the car park comprising means for determining the free or occupied state of the specific parking space on the basis of both the recordings of the free state or occupied state of said specific parking space performed by the first system and by the second system.



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Description

Technical field

[0001] The present invention relates to a method and an associated combined system for detecting the state, in particular the occupied or free state, of a specific parking space from among a plurality of parking spaces in a car park. The invention relates to a system of the aforementioned type in which each parking space is equipped with a sensor for measuring a value of at least one parameter variable depending on whether a vehicle is present or not.

Prior art

[0002] As is known, there exist various systems which may be used to detect whether a parking space in a car park is occupied or is free. In some systems, each parking space is equipped with a sensor able to measure a parameter which varies depending on whether a vehicle is present or not. One of the sensors used is of the magneto-resistive type and measures the local variations or changes in the earth's magnetic field when a metal object of a certain size, such as a motor vehicle, is situated in the vicinity of the sensor. These sensors are small in size, have a low power consumption and may be easily installed externally, preferably in combination with a waterproof and protective casing.

[0003] The sensors may comprise a radio transmitter, which transmits the value measured to a control centre of the car park, optionally via one or more repeaters. It is the control centre which determines whether the space is occupied or empty depending on the value received from the sensor and a reference value corresponding to a known state.

[0004] However, the known sensors suffer from a number of drawbacks. They are sensitive to certain conditions which are difficult to control, for example the atmospheric temperature, which influences measurement. In fact, for the same strength of the earth's magnetic field, the value measured is different at different temperatures. Similarly, the sensor is subject to wear which causes alterations, over time, of the values detected, even in the presence of an identical magnetic field. Finally, the earth's magnetic field has a very irregular behaviour which complicates the measurements, even under normal conditions.

[0005] Methods for compensating for the temperature and ageing or calibration systems are known, along with procedures for compensating for the earth's magnetic field, or systems which use the values detected by magneto-resistive sensors installed in parking spaces adjacent to a given magneto-resistive sensor. The compensation methods attempt to reduce the probability that an incorrect value detected by a given sensor is associated, by the control centre, with a parking space which is free, whereas the parking space is occupied, or vice versa.

[0006] Despite this, the known detection methods and systems currently used, even in combination with compensation methods, have a reliability equivalent to about 98% (one error every 50 measurements).

[0007] The technical problem underlying the present invention is that of increasing further the reliability of the known systems. In particular, the technical problem is that of devising a system and a method which are able to reduce further the possibility of error when detecting the free or occupied state of a parking space, substantially eliminating the possibility of error, even when there are atmospheric or meteorological conditions affecting the readings performed by all the sensors associated with the parking spaces, thereby allowing the control centre to correct possible errors in processing of the data received from the sensors and reducing the number of false positives (free spaces considered to be occupied or occupied spaces considered to be free) or uncertain situations.

Summary of the invention

[0008] The present invention aims to overcome the drawbacks of the systems and methods of the prior art by providing an improved system which offers a greater degree of reliability.

[0009] In particular, the idea forming the basis of the present invention is that of combining a first control system based on a plurality of sensors, each installed in a parking space of a car park, for example a plurality of magneto-resistive sensors able to detect the presence of a car parked in a respective parking space, and a second video surveillance system which records the pictures of the parking space and provides a second way of determining whether or not a car is present by means of processing of the pictures.

[0010] The purpose of combining the two systems in an improved system is to reduce the false positives of the first system or the second system. A further purpose of the system is that of improving the accuracy of determining the free or occupied state in those cases where one of the two systems is unable to determine with a certainty greater than a predefined threshold whether there is in reality a car parked in a given parking space, for example owing to an anomalous value detected by the magneto-resistive sensors or the impossibility of accurately processing the pictures of a parking space - whether said value is anomalous or said impossibility of processing the pictures is associated with an environmental, meteorological, wear or other condition - thereby further increasing the precision of the process for determining whether the parking space is free or empty. The purpose of the combined system is also that of being able to take decisions regarding the free or occupied state of the parking space, with a low probability of error, also in the case where one of the two systems or both the systems independently are unable to provide a certain result.

[0011] Still according to the invention, the first sensor system is combined with the second video surveillance system in an improved system comprising a centre or unit for controlling the car park. The control centre (i.e. control unit) receives the values detected by the sensors and the pictures of the video surveillance system and processes them in order to determine the state of the parking spaces with a small margin of error compared to the systems of the prior art.

[0012] It should merely be pointed out that the combination of the sensor system and the video surveillance system according to the present invention does not consist in the mere juxtapositioning of two known independent systems, but is rather a synergic combination resulting from precise considerations on the part of the Applicant, intended in particular to avoid that conflicting results provided by the two systems may result in a loss of reliability of the combined system, rather than an improvement thereof. In fact, in view of a free (or occupied) state determined with a low probability of error by the first sensor system it is evident that the same free (or occupied) state determined with another low probability of error by the second video surveillance system constitutes for the combined system a reliable confirmation that the parking space may be considered to be actually free (or occupied). However, the synergy in the case of higher probabilities of error of the first system and/or second system is not entirely evident, and the object of the method and system according to the present invention is to reduce the probability of error also in those cases of uncertainty of the two independent systems.

[0013] On the basis of the proposed idea described above, the technical problem is solved by a combined system for determining the free state or occupied state of a parking space in a car park comprising:

- a first system able to detect the state of a specific parking space from among a plurality of parking spaces, the first system comprising:

    * for each parking space at least one sensor intended to measure a first value of at least one parameter, said parameter being variable depending on whether a vehicle or present or not;

    * means for transmitting the first measured value to a processing unit comprising means for comparing the first value with a stored reference value corresponding to a known state of the specific parking space;

    * means for comparing the first value with a second value of the parameter, measured for at least one parking space adjacent to the specific parking space;

    * means for determining the state of the parking space in the first system, on the basis of both the comparisons, between the first value and the reference value and between the first value and the second value;

    * said first system being designed to communicate the free or occupied state determined on the basis of both the comparisons to a control unit (or centre) of the car park;

- a second video surveillance system comprising:

    * means for recording pictures and/or videos of the parking spaces in the car park, including said specific parking space;

    * means for comparing the acquired pictures of the specific parking space and reference pictures of said specific parking space, preferably said reference pictures being preferably associated with the parking space when no vehicles are present;

    * means for determining the free or occupied state of the specific parking space, on the basis of said comparison of the acquired pictures and the reference pictures;

    * said second system being intended to communicate the free or occupied state determined on the basis of said comparison of the pictures to the control unit of the car park;

said control unit of the car park comprising means for determining the free or occupied state of the specific parking space on the basis of both the recordings of the free or occupied state of said specific parking space performed by the first system and by the second system.

[0014] In order to determine the free state or occupied state, the combined system takes into account the so-called false positives or negative positives generated by the first system and/or by the second system.

[0015] In particular, the control unit is set so as to memorize

- the probability P^s_{FP} that the first system will determine the occupied state s=1 of the specific parking space even when the space is free (zero condition indicated by Ho), said probability being a false positive of the first detection system;
- the probability P^s_{FN} that the first system will determine the free state s=0 of the specific parking space even when the space is occupied (alternative condition indicated by H_1), said probability being a false negative of the first detection system;
- the probability P^v_{FP} that the second system will determine the occupied state v=1 of the specific parking space even when the space is free (Ho), said probability being a false positive of the second video surveillance system;
- the probability P^v_{FN} that the first system will determine the free state v=0 of the specific parking space even when the space is occupied (H_1), said probability being a false negative of the second video surveillance system;

[0016] The control unit of the combined system determines a Bayes factor

$$B = \frac{P(s|H_1)}{P(s|H_0)} \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}$$

on the basis of said stored probability values P^s_{FP} P^s_{FN} P^v_{FP} P^v_{FN} and the free state d=0 of the specific parking space, if said Bayes factor B is less than 1, or the occupied state d=1 of the specific parking space, if said Bayes factor is greater than or equal to 1.

[0017] Preferably the probability values P^s_{FP}, P^s_{FN} that the first system will determine the occupied state s=1 or free state s=0 of the specific parking space even when the space is respectively free (Ho) or occupied (H_1), and the probability values P^v_{FP}, P^v_{FN} that the second system will determine the occupied state v=1 or free state v=0 even when the space is respectively free (Ho) or occupied (H_1), are calculated on the basis of a real free or occupied state (ct), of the specific parking space, this real free or occupied state being monitored on-site, i.e. in the car park, during preliminary configuration of the combined system.

[0018] According to another aspect of the present invention, the Bayes factor B is determined by means of an alternative formulation. In particular, the control unit memorizes the probability P^v_{FP} that the second system will determine the occupied state v=1 of the specific parking space even when the space is free Ho; and the probability P^v_{FN} that the second system will determine the free state v=0 of the specific parking space even when the space is occupied H_1; and determines the Bayes factor as

$$B = \frac{P(\delta|H_1)}{P(\delta|H_0)} \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}$$

where δ is the distance between the first value of the parameter detected by the sensors of the first system and the reference value.

[0019] According to this alternative formulation, the Bayes factor B is calculated on the basis of the probability values P^v_{FP}, P^v_{FN} stored in the control unit and the state of the parking space is considered free d=0 if the Bayes factor B is less than 1 or occupied d=1 if the Bayes factor B is greater than or equal to 1. As will become clear from the description below, the first value may be a vector with three components along the axes X, Y, Z and also the reference value may be a three-dimensional vector; in this case δ_x, δ_y, δ_z they represent the distance between the components x, y, z of the first value of the parameter detected and the components x, y, z of the reference value.

[0020] For calculation of the Bayes factor according to the different variants of the system according to the invention, it is possible to apply a number of approximations to the probability values that the specific parking space will be free beforehand P(Ho) or occupied beforehand $P(H_1)$, for example assuming that $P(H_0) = P(H_1)$ for those parking spaces used substantially during the daytime.

[0021] A number of further important considerations and tests carried out by the Applicant have led to a further simplification of the formula for calculation of the Bayes formula,

$$B = \frac{P(\delta|H_1)}{P(\delta|H_0)} \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)} \quad \text{formula (30)}$$

and consequently to simplifications of the method for determining the free or occupied state in the combined system, with corresponding reductions in the error percentage.

[0022] In particular, in the case where the distance δ between the first value of the parameter detected by the sensors of the first system and the reference value corresponding to a known state is close to a threshold value θ, where the detection of the first reference system cannot be regarded as reliable, the Bayes factor in the above formula (30) is calculated only on the basis of the values alone of the second detection system ($P(v/H_i)$), i. e.:

$$B = \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}$$

[0023] Preferably, according to one aspect of the present invention, the control system further comprises sensors for detecting values indicative of the operating conditions of the first detection system and the second video surveillance system, for example rain, wind, temperature, fog or similar sensors, and the processing unit receives at its input also the values relating to the operating conditions of the systems in order to reduce further the probability of error. The sensors are for example integrated in the sensors for the parking spaces or otherwise associated with the parking spaces. Alternatively, the sensors are installed in certain predefined positions of the car park and are fewer in number than the sensors for the parking spaces.

[0024] According to a preferred embodiment, which will be described more specifically below, the detection performed by means of the first sensor system is improved using, in order to determine the free or occupied state of a given parking space SP, not only the values detected by a sensor in a parking space but also using the values detected by the sensors in the parking spaces adjacent or close to the parking space SP.

[0025] In particular, according to one aspect of the present invention, the values detected by the sensors, the pictures or the videos recorded by the video surveillance system and/or the state determined by the control centre of the car park are memorized in combination with specific operating conditions of the first and second systems, including the environmental, meteorological, wear or other conditions and a date and time when the recordings by the sensors or the video surveillance system were carried out.

[0026] The operating conditions are used as input parameters for a self-learning algorithm which determines a number of corrections to be applied for the successive values detected by the sensors or by the surveillance system and for determining a state of the parking spaces in similar operating conditions, therefore improving the process for determining the free or occupied state of the car park.

[0027] For example, the control centre may adopt corrective measures during processing or comparison of the pictures in the second video surveillance system during a given season (summer or winter) or weather conditions (snow, rain, etc.) or in a certain state of the car park (empty, night-time hours, holidays, etc.), depending on errors detected in the past during processing or comparison of the pictures in similar operating conditions, and depending on correct values detected by the first sensor system.

[0028] In fact, it is possible that operation of a system, for example the first sensor system, is more precise and reliable in certain operating conditions (for example in the case of snow), thus resulting in values with a low probability of error, and may therefore be used to correct a recording with a greater probability of error performed by the surveillance system, in said operating conditions. This correction may be applied to the video surveillance system when the operating conditions (snow) reoccur. This is particularly advantageous in the case where the same operating conditions (for example snow) occur again in combination with other operating conditions (presence of a particularly bulky mass in the vicinity of a parking space) which decrease the precision of the recording of the first detection system during a subsequent recording operation, increasing the probability of error thereof, since the correction applied to the second video surveillance system reduces its probability of error and helps improve the process for determining the free or occupied state of the parking space.

[0029] According to one aspect of the invention, the video surveillance may be performed by a drone or fixed or movable TV cameras. The use of a drone has the advantage that recordings may be made from above, from different angles and at a variable distance from the parking space.

[0030] According to another aspect of the invention, the sensors are components of a network. Each sensor measures the value of at least one parameter which is influenced by the presence or absence of a vehicle in the space considered. These values are transmitted to a processing unit which receives the values measured by other sensors. The space is considered to be empty or occupied depending not only on the value measured by the parking space sensor considered but also on the values measured by the sensors close to the space considered. Advantageously, the method increases the reliability of the combined system.

[0031] In order to ensure a precise analysis of the measurements carried out by the sensors of the first system, the measurements are performed simultaneously. A short time interval is assigned in order to carry out the measurements and transmit the values of each sensor to a repeater, where present, and if necessary from the repeater to the other repeater, until the processing unit is reached.

[0032] Each repeater is thus programmed to receive a message and send a message at a very precise moment and to save energy outside of the time intervals in which sending or receiving is performed. The sensors or repeaters may alternate from a standby mode to an operative mode, with a considerable energy savings and an increase in the autonomy of the sensors and the system.

[0033] Further characteristic features and advantages of the method according to the present invention will become clear from an example of embodiment thereof provided hereinbelow with reference to the attached drawings, solely by way of a non-limiting example.

Brief description of the figures

[0034]

Figure 1 is a schematic illustration of the combined system according to the present invention.

Figures 2a-2f show the values detected by a first detection system of the combined system, according to the present invention.

Figure 3a shows a picture of a second video surveillance system of the combined system, according to the present invention.

Figure 3b shows a graph of the values detected over time by the first system shown in Figures 2a-2f.

Figure 4 shows another graph of the values detected over time by the first system shown in Figures 2a-2f, in combination with the actual occupied state (bottom part of graph).

Figures 5a shows the graphs for determining the free or occupied state based on the first system, second system and combined system, according to the present invention, in combination with the actual occupied state (bottom part of the graph).

Figure 5b is a graph showing the improvement in performance of the combined system compared to the first and second systems.

Figures 6a is a graph showing the progression of a sigmoid function as a function of the value measured by the first system shown in Figure 2a.

Figures 6b is a graph illustrating the decisional method implemented by the combined system of the present invention, according to an embodiment thereof.

Detailed description

[0035] Figure 1 shows in schematic form a car park which may be managed by the method according to the present invention. The method is implemented by means of a combined system which comprises a first control system based on sensors D and a second video surveillance system. The video surveillance system is schematically represented in Figure 1 by means of a plurality of fixed or movable video cameras 20 which are installed in the vicinity of the car park and/or by a drone (UAV) 10 which may be kept in flight above the car park so as to obtain a broader view. Obviously it is possible to use only the video cameras or only the drone equipped with a respective video surveillance camera in order to form the video surveillance system. In any case, the video cameras and/or drones are in radio - preferably two-way - radio communication with a control centre MC equipped with a processing unit PU, as schematically shown in Figure 1.

[0036] Hereinbelow an example of embodiment of the first control system based on sensors is also provided. The car park comprises a plurality of parking spaces P, each equipped with at least one sensor D. The control system with sensors attempts to determine whether or not a vehicle is present in a given car parking space indicated by SP, namely to determine the empty or occupied state of the specific car park location corresponding to the parking space.

[0037] Different types of sensors may be used. The sensors measure a parameter which varies depending on whether or not a vehicle is present in the parking space close to the parking space associated with the sensor. Each sensor is singly associated with a parking space. For example, a sensor which measures the earth's magnetic field or its variations is used. The earth's magnetic field is disturbed, in the immediate vicinity of the parking space where the sensor is installed, by an important metallic mass, i.e. another vehicle. Moreover, the sensors may have relatively small dimensions, so that they may be inserted inside a waterproof casing mounted within the fixtures of the car park. The casings may contain radio communication means and may be preferably powered by a stand-alone battery.

[0038] In one embodiment of the invention, in addition to the sensors for each parking space, a plurality of repeaters R and a control centre MC comprising a processing unit PU are provided.

[0039] Preferably, each sensor comprises means for emitting and receiving radio signals and a clock, including radio communication means with at least one repeater. The repeaters also comprise a clock and means for communication with the sensors and the control centre and with other repeaters, if present. Preferably, the repeaters are arranged in a predefined hierarchy, for example (but not exclusively) on three levels. The repeaters of the first level L1 or at least some of them are able to communicate directly with at least some of the sensors D, since they are sufficiently close to the sensors. The communication is preferably bidirectional.

[0040] The repeaters of the second level L2 are at least able to receive data from the repeaters of the first level L1 and send data to the repeaters of the third level L3. Preferably, the communication is bidirectional at every level, which for example means that the repeaters of the second level may send and receive data from the repeaters of the first level and the repeaters of the third level.

[0041] The only essential communication is that which allows data to be transmitted from the sensors D to the processing unit PU. It should be noted that it is not necessary for all the components of one level to be able to communicate will all the components of an adjacent level. Each sensor may send data to a specific repeater or to a repeater from among a series of repeaters. Similarly each repeater may be regarded as belonging to a given level in a first communication and to another level in another communication.

[0042] Therefore if the communication between two components is not possible, for example because of a malfunction, an alternative communication path may be used. Preferably, the sensors have means for emitting the signals and also means for receiving signals and may also perform the function of repeaters.

[0043] According to a preferred embodiment of the invention, each component functions during a predefined time interval of a cycle, namely a period sufficiently long to allow the sensors to perform a measurement and transmit the measurement to the processing unit.

[0044] Each sensor and each repeater have preferably a clock. Instead or in addition to the clock, each receiver may comprise means for receiving a time reference, which is common to all the components, and means for counting the time lapsed with the possibility of triggering a specific action when the counter reaches a predefined value.

[0045] During a first interval I1 of a cycle, the sensors carry out a measurement of the variable parameter, for example the earth's magnetic field. This measurement may be a scalar or a vectorial value. For example, the magnetic field may be measured along three orthogonal axes, one of which is horizontal, in a direction in which a machine may move within the car park.

[0046] When the first interval has lapsed, the sensors interrupt the measurements. Then a second interval starts 12; the intervals are separated by a relatively short period of inactivity. During the second interval, only the first level sensors and repeaters are active. The sensors have the function of sending the results of the measurements carried out during the first interval I1 and the first level repeaters are intended to receive the results of the measurements or messages which contain these results of the measurements.

[0047] At the end of the interval 12, the sensors have terminated the transmission of the measurements and are in standby mode. If a sensor is unable to terminate the transmission of measurement values, it stops sending the message at the end of the second interval.

[0048] During a third time interval 13, separate from the other intervals, the first level repeaters transmit the messages received from the sensors to the second level repeaters. Only the first and second level repeaters are active, while the other system components are in standby mode.

[0049] The messages are transmitted by the second level repeaters to the third level repeaters during a following time interval 14 and then by the third level repeaters.

[0050] This embodiment is particularly advantageous in that each component is active only during a short part of the cycle, with considerably energy savings for the entire system and increased autonomy. On the other hand the sensors may send the information directly to the processing unit, and not via the repeaters.

[0051] Figures 2a to 2f show the values which are measured for three adjacent parking spaces, based on the various occupied configurations. In the example it is assumed that one wishes to determine whether the parking space S situated in the centre is occupied or empty. Each figure shows the value of the parameter measured by the sensors for the three spaces in a given moment. The number 0 indicates that the space is empty. The number 1 indicates that the space is occupied.

[0052] In order to determine whether a specific space is empty or not, both the result of the measurements performed by the sensor in this specific parking space, and the measurements performed by the sensors close to the specific parking space, namely in a space sufficiently close to influence significantly the value of the parameter owing to the presence of another vehicle, are considered. The number and the positions of the sensors considered depends on the configuration of the parking space, the sensitivity of the sensors and the size of the vehicles (car, lorry, etc.). and may be configured in the first control system, for example by means of a graphics interface.

[0053] In the examples shown in Figures 2a, 2b and 2c, the space SP is empty. In the case of Fig. 2a, the empty space SP is situated between two empty parking spaces. In the example shown in Fig. 2b, the empty space S (parking space) is situated between an empty space and an occupied space. In the example shown in Fig. 2c, the empty space SP is surrounded by two occupied spaces. In Fig. 2a, in which all three spaces are empty, it can be seen that the value of the measured parameter is relatively low. The values for the three parking spaces are not necessarily the same. This may be due to local variations in the parameter measured, for example the earth's magnetic field, varying behaviour of the sensors (age, sensitivity, etc.). or disturbances due to closure of parking spaces for example.

[0054] In Fig. 2b, the space SP is empty as in the preceding example, but is adjacent to an occupied parking space. As can be noted, the value measured for the specific parking space is greater than that in the example shown in Fig. 2a. Therefore the vehicle in the adjacent parking space influences the measurement.

[0055] Fig. 2c shows a situation where the space SP is empty, but is situated between two occupied spaces. The value measured for the specific parking space is greater than in the two previous examples shown in Figs. 2a and 2b because the vehicles in adjacent spaces influence the value measured.

[0056] In the same way, Figs. 2d, 2e and 2f show configurations in which the specific parking space SP is occupied. The space is flanked, respectively, by two empty spaces, an empty space and an occupied space and, finally, by two occupied spaces.

[0057] In Fig. 2d the value measured by the sensor of the specific parking space is relatively low. In Fig. 2e this value is higher. This is due to the presence of a vehicle in a nearby space, which influences the value measured by the specific sensor for the parking space. In Fig. 2f the value measured for the specific space is even greater owing to the presence of another vehicle in both the adjacent spaces.

[0058] As can be seen from this data, it is possible that the value measured for an occupied space, for example the central parking space in Fig. 2d, may be lower than the value measured for an empty space, for example the central space in Fig. 2c.

[0059] In the systems of the prior art, the following is assumed: the value measured for an empty parking space is always lower than the value measured for an occupied parking space. On the other hand, it is assumed that the value measured for an occupied space is always greater than the value measured for an empty space. In such a system, the situations shown in Figures 2c and 2d would result in false measurements of the state of the parking space.

[0060] In the present invention, instead, a value of the parameter is measured using the sensor for the specific parking space SP. This value is transmitted to the processing unit, if necessary via repeaters, as explained above. A second value of the parameter is measured using the sensor for at least one parking space situated close to the specific parking space. In the example shown in Figs. 2a to2f, the second value is measured for two parking spaces adjacent to the specific parking space. The second values are sent to the processing unit, optionally via repeaters.

[0061] The control centre comprises stored values corresponding to known states of specific parking spaces. The processing unit compares the first value, i.e. the value obtained for the specific parking space, with a value stored in the control centre and corresponding to a known state of the specific parking space. It further compares the second value with the stored values corresponding to the known states of the adjacent parking spaces. Both the comparisons are used to decide whether the specific parking space must be regarded as empty or occupied.

[0062] The first and the second values may be used to create a measurement profile which may be graphically represented as shown in Figs. 2a to 2f.. This profile is compared in the processing unit with a profile corresponding to known states. The comparison with an absolute value stored in the control centre may be used to distinguish between two ambiguous situations.

[0063] As can be understood, in the present invention, not only the absolute value of the parameter measured by a sensor for a given parking space, but also the values measured for the adjacent parking spaces are taken into consideration. In the examples shown in Figs. 2a to 2f, if the measurements result in a measurement profile similar to that shown in Fig. 2a, they could indicate a configuration in which the three spaces are empty or a configuration in which the central space is empty and both the neighbouring spaces are occupied. In both cases, the central space is empty. The absolute value of the measurement may establish that this conclusion is correct. In the case where the three spaces are empty, it is also possible to obtain a measurement profile similar to that shown in Fig. 2d, which shows a central occupied space surrounded by two empty spaces. This could be due to the local disturbance of the parameter measured. In this case, using the absolute value of the measurements it is possible to distinguish between the two situations. The absolute values used to discriminate between two situations are not measured for a single space, but for different spaces.

[0064] For each parking space, at least the following elements are taken into consideration: the configuration of the car park and the occupied state of spaces around the specific parking space SP. This is possible owing to the fact that the measurements made by the sensors are performed simultaneously. The processing of these simultaneous measurements results in a greater reliability of the system. Processing measurements which have been made at different times could result in significant ambiguity of interpretation and therefore a less reliable system. In the case where the parameters measured are vectorial values, the components along each axis may be taken into consideration singly. Three different measurement profiles similar to those shown in Figs 2a to 2f may be considered along the three respective axes in order to improve the method. If three axes are used, comparisons will be carried out for each axial component as well as for the different measurements. For example, when the vehicle is in a specific parking space, the variation of the earth's magnetic field has a strong vertical component. When a vehicle occupies an adjacent space, the variation will be directed towards the vehicle and will therefore have a relatively small vertical component and a greater horizontal component. The analysis of these components increases further the reliability since it allows differentiation between the case where a vehicle is parked in the specific parking space and the case where it is parked in the adjacent space.

[0065] An example of a first parameter may be the variation of the earth's magnetic field and of the second parameter the reflection of light by the bottom of the vehicle. Similarly several sensors may be used for a parking space.

[0066] The method for determining the free state or occupied state by means of the first detection system is any case affected by an error percentage. The second video surveillance system is used to reduce the error percentage. However, carrying out decisions based on two information sources may result in conflicts.

[0067] According to the present invention, the decision regarding the free state or occupied state of the parking space is carried out on the basis of recordings made by the TV cameras and the parking sensors. The decision is reached using the method described below, with the aim of reducing the probability of error regarding the state of the parking space, while avoiding conflicts between the two information sources.

[0068] Figures 3 shows in schematic form the two information sources. In particular, in Figure 3a, the focus point of the sensors is indicated by means of a graphic symbol, i.e. a circle if the parking space is occupied, or a square if the parking space is free. Figure 3b shows the values measured by the sensor furthest to the left in Figure 3a, in relation to the axes X, Y, Z, against the time required to perform the measurement and for a measurement time period of eight days. A vertical line L indicates the moment in which the photograph shown in Figure 3a was taken.

[0069] The Applicant has adopted a decisional approach based on the Bayes theory, for determining the free state or occupied state on the basis of the two systems. If s indicates the information supplied by the parking space sensor and v indicates the information sent back by the video surveillance system, there are two hypothetical situations Ho, H_1, in particular:

$$H_0\text{: the parking space is free} \qquad (1)$$

$$H_1\text{ : the parking space is occupied} \qquad (2)$$

[0070] Determination of the free state or occupied state is based on the calculation of the following Bayes factor:

$$B = \frac{P(H_1|s,v)}{P(H_0|s,v)} = \frac{P(s,v|H_1)}{P(s,v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}$$

[0071] The information derived from the two sources, s and v, is considered to be conditionally independent, since the two systems do not influence each other, in which case the Bayes factor may be rewritten as:

$$B = \frac{P(s|H_1)}{P(s|H_0)} \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)} \qquad (3)$$

[0072] The decisional rule of the combined system according to the present invention consists in selection of the most probable situation

$$d = \begin{cases} 1 & \text{if } B \geqslant 1, \\ 0 & \text{else.} \end{cases} \qquad (4)$$

namely in regarding the specific parking space as occupied (d=1), if the Bayes factor is greater than or equal to 1, and as free (d=0) if the Bayes factor is less than 1.

[0073] In order to measure the performance of the combined system, the average probability of error $P^d err$ was calculated as:

$$P^d_{\text{err}} = P(H_0)\,P(d=1|H_0) + P(H_1)\,P(d=0|H_1).$$

[0074] In the formula (5), the probability *P(d|Hi)* was calculated marginalizing s and v as indicated below:

$$P(d|H_i) = \sum_{s,v} P(d|s,v)\,P(s,v|H_i)$$

$$= \sum_{s,v} H\left((2\,d-1)\cdot(B-1)\right)\,P(s|H_i)\,P(v|H_i)$$

where *i* = 0,1 and $H(x) = \begin{cases} 1 & \text{if } x \geqslant 0 \\ 0 & \text{else} \end{cases}$, is the step function.

[0075] With this formulation it is possible to evaluate the effectiveness or precision of the combined system.

[0076] An example of implementation of the method and the system according to the present invention is provided below, with a number of examples which, however, may be adapted depending on the specific characteristics of the car park which is to be monitored.

[0077] For example, in the case of a car park used only during the night-time hours, it is possible to assume that the probability of finding the parking space empty beforehand (P(Ho)) is the same as the probability of finding the parking space occupied beforehand ($P(H_1)$), i.e. $P(H_0) = P(H_1) = ½$.. Obviously, other preliminary considerations may be made for parking spaces which are used differently during different hourly time intervals and consequently adapting the probability of finding the parking space free or occupied beforehand.

[0078] In order to calculate the Bayes factor B in the formula (3), the performance of the sensors s and the TV cameras v was calculated. The frequency of the false positives P^S_{FP} and the false negatives P^S_{FN} of the parking space sensors was assessed on the basis of real data acquired, for example in a predetermined time period of fifteen days, detecting the following false positives and false negatives for the sensors of the first system:

$$P^s_{FP} = P(s=1|H_0) \approx 4.20\%$$

$$P^s_{FN} = P(s=0|H_1) \approx 7.32\%$$

[0079] Similarly, the frequency of the false positives P^v_{FP} and false negatives P^V_{FN} of the video surveillance system may be calculated on the basis of real data acquired, obtaining respective error percentages.

[0080] By adopting the combined system according to the invention, i.e. by taking the decision as to the free state or occupied state based on integration of the information supplied by the two sources, it is possible to reduce the percentage of false positives and false negatives and therefore reduce the probability of error of the combined system.

[0081] The bottom graph shown in Figure 4 shows the effective free state or occupied state of a parking space over two days from 8 a.m. on 28.10 to 4 p.m. on 29.10. The continuous line c_t indicates the real occupied state, the points s_t and v_t indicate the recordings made by the first system and the second system in relation to the time t; in some time instants, the system based on the video cameras and/or the system based on the parking sensors are affected by errors, as indicated by the presence of points along the abscissa 0 (parking space free) between 8 a.m. and 4 p.m. on 28.10, when instead the parking space was actually occupied (c_t=1).

[0082] The graph immediately above shows the result of the measurements carried out by the parking space sensors, i.e. obtained from the combined measurements performed along the three axes X, Y, Z. The three lines X, Y and Z in the top part of Figure 4 show the measurements along the single axes and the respective reference values.

[0083] The window B in Figure 4 shows the blown-up view of the graph between 8 a.m. and 4 p.m. on 28.10. During this time interval, processing of the free state or occupied state based on the parking space sensors alone proved to be difficult since the data detected by the sensors fluctuated around a threshold value (160). Differently, between 8 a.m. and 4 p.m. on 29.10 the recording made by the parking space sensors allowed more precise processing of the occupied state of the parking space.

[0084] Assuming that the variables s and v are binary variables, each individually representing the decision taken by the sensor system and the video surveillance system independently, the formula (4) may be applied in order to obtain a decision based on the combination of the two systems. The reduction in the error when determining the state of the parking space based on the combined system according to the present invention is clearly indicated by the data shown in the table below, obtained from a real installation.

sensor	P_{FP}	P_{FN}	P_{err}
s	4,2%	7.32%	5.76%
v	3.0%	10.%	6.5%
d	7.07%	0.73%	3.90%

[0085] In this example, the error percentage of the sensor system used separately was 5.76%, the error percentage of the video camera system was 6.5%, while the error percentage of the combined system (calculated using Formula 5) was substantially lower, i.e. 3.9%.

[0086] This improvement can be clearly seen in Figures 5a, which shows the variables, s and v, the variable d (decision taken by the combined system) and the real occupied or free state of the parking space ct.

[0087] In order to investigate further the performance of the combined system, the Applicant considered that the probability of false positives and false negatives of the video surveillance system might be the same. In this case, the combined system has a probability of error better than that of the two separate systems. In particular, the graph in Figure 5b shows the probability of error of the combined system P^d_{err} as a function of the probability of error of the video surveillance system P^v_{err}; so long as P^v_{err} is less than P^s_{err}, $P^d_{err} = P^v_{err}$; when instead P^v_{err} is greater than P^s_{err} (5.76%), $P^d_{err} = P^s_{err}$. The grey area represents the improvement achieved by the combined system. Advantageously the simultaneous use of the two systems is not conflictual and does not adversely affect the performance of the combined system.

[0088] By way of a further improvement to the system and method according to the present invention, a number of advanced decisions were carried out, in particular to remedy malfunctioning or lack of reliability of the sensor system.

[0089] As already mentioned, this system, measures the distance between one vector $u = (u_x; u_y; u_z)$ and a reference point or centre $\mu = (\mu_x; \mu_y; \mu_z)$, $\delta=||u-\mu||$. In the first system, if δ is greater than a threshold value e, the parking space is considered to be occupied, namely:

$$s = \begin{cases} 1 & \text{if } \underbrace{\|\boldsymbol{u} - \boldsymbol{\mu}_0\|}_{=\delta} > \theta, \\ 0 & \text{else.} \end{cases}$$

$$s = 1 \text{ if } || u-\mu || > 0$$

otherwise s=0.

[0090] The closer δ is to the threshold θ (as in the window B in Figure 4), the more the reliability of the sensors diminishes.

[0091] According to one aspect of the present invention, in order to incorporate more information in the chosen method based on the combined system, δ instead of s was considered in the decision rule.

[0092] The Bayes factor of the formula (3) was therefore rewritten as:

$$B = \frac{P(\delta|H_1)}{P(\delta|H_0)} \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}$$

[0093] In order to calculate $P(\delta|H_i)$, according to the present invention a function $\sigma(\delta)$ was defined:

$$P(H_1|\delta) = \underbrace{\frac{1}{1+\exp\left(\frac{\theta-\delta}{\beta}\right)}}_{\sigma(\delta):=}$$

where $\beta > 0$ is a parameter which takes account of the uncertainty close to the threshold θ, as schematically shown in Figure 6a. In a preferred embodiment $\beta = 8$; this value is associated with half of the standard deviation of the sensor signal in the case where said signal is stationary.

[0094] The Bayes factor may therefore be rewritten as:

$$B = P(H_1|\delta)/P(H_0|\delta) \,.\, P(v|H_1)/P(v|H_0) \qquad (7)$$

$$B = \frac{\sigma(\delta)}{1-\sigma(\delta)} \cdot \frac{P(v|H_1)}{P(v|H_0)}$$

and the decision rule may be always based on the preceding formula (4).

[0095] The fraction $\frac{\sigma(\delta)}{1-\sigma(\delta)}$ is equivalent to the numerical value 1 for values of δ very close to a value θ, in which case the Bayes factor, and therefore the entire decision, may be based on v.

[0096] The decisional rule based on the formula (7) determines a further reduction of the probability of error, which is graphically represented in Figure 6b, with reference to a time interval of two days, between 28 and 29 October. In this case, the following values were recorded: P^v_{err} = 6.68%; P^s_{err} = 6.96%; P^d_{err} = 1.9%.

[0097] The Applicant has, lastly, envisaged a further improvement to the system and decision method intended to combine the vector u and the value v. The idea is to use a model for u, for each hypothetical situation Ho, H_1:

$$\boldsymbol{u} = \boldsymbol{\mu} + \boldsymbol{\varepsilon}$$

under H_0

$$\boldsymbol{u} = \boldsymbol{\mu} + \xi + \boldsymbol{\varepsilon}$$

under H_1 where $\varepsilon \sim \mathcal{N}(0, \Sigma^\varepsilon)$ has a normal distribution and the covariance matrix Σ^ε is known (signal noise). the parameter μ is preferably set during a system set-up phase by means of a calibration procedure; ξ is a random variable.

In one variation of embodiment ξ is considered to be a variable with normal distribution. In this case $\xi \sim \mathcal{N}(0, \Sigma^\xi)$, where the covariance matrix Σ^ξ takes into consideration the ample variation of the signals (change-over points). According to this further embodiment of the invention, the Bayes factor may be expressed as:

$$B = \frac{P(\boldsymbol{u}|H_1)}{P(\boldsymbol{u}|H_0)} \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}$$

formula (50)

with

$$\frac{P(u|H1)}{P(u|H0)} = \frac{\int d\xi\, f(u,\mu+\xi,\Sigma^{\varepsilon})\ f(\xi,0,\Sigma^{\varepsilon})}{f(u,0,\Sigma^{\varepsilon})}$$

where $f(u,\mu,\Sigma)$ is the density function of a Gaussian random variable with average μ and covariance matrix Σ.

[0098] According to one aspect of the invention, the control unit determines the free or occupied state of the parking space on the basis of the values detected by the first system, according to an estimate of the parameters described hereinbelow, taking into account possible fluctuations of the signal. In fact, the signal may be influenced, for example, by the vicinity of other cars or by the position in which the vehicle is parked in the parking space and in relation to the sensors, or by other factors.

[0099] In particular, during a step for calibration and configuration of the first system, a value μ representing the absence of a vehicle in a parking space is estimated. The value μ is estimated on the basis of a plurality of measurements performed by the sensors when the parking space is empty, during calibration of the system. During operation of the first system, the sensors detect a value **u** in the absence of a vehicle, which may vary from the predefined value μ, minus a value ε, representing the noise during operating conditions.

[0100] In short, when no vehicle is present

$$(H_0)\ \mathbf{u} = \boldsymbol{\mu} + \boldsymbol{\varepsilon}.$$

u may be a vector having, for example, three components $\mathbf{u}_x$, $\mathbf{u}_y$, $\mathbf{u}_z$ along the three axial directions x, y, z, each of which has an associated value. Similarly, the reference value μ may be a vector having three components μ_x, μ_y, μ_z along the axial directions x, y, z, each with its predefined value set during configuration of the first system. The value ε representing the noise may also be a vector with three components ε_x, ε_y, ε_z.

[0101] According to the system of the present invention, the noise ε is described by a Gaussian distribution

$$\varepsilon \sim N(0, \Sigma^{\varepsilon})$$

where Σ^{ε} is a covariance matrix and 0 indicates the ideal situation in the absence of noise.

[0102] The distribution of the noise may be considered to be the same whether the vehicle is present or not.

[0103] In the case H_1 where a vehicle is parked in the parking space, the value **u** detected by the first system varies from the value μ by an amount ξ, not known beforehand, since dependent on the vehicle which occupies the parking space (for example dependent on the size of the vehicle) less the noise ε.

[0104] Therefore, when a vehicle is present in the parking space (H_1), $\mathbf{u} = \mu + \xi + \varepsilon$.

[0105] To summarise:

$$u_k = \{\mu_k + \varepsilon_k \qquad \text{if } H_0 \qquad (100)$$

$$u_k = \{\mu_k + \xi_k + \varepsilon_k \quad \text{se } H_1 \qquad (101)$$

where μ is a known value (or a vector with known components μ_x, μ_y, μ_z), since set during configuration of the system, ξ (or the vector ξ, i.e. its components ξx, ξy, ξz) is a value not known beforehand, since dependent, for example, on the vehicle occupying the parking space and its position with respect to the signal sensors.

[0106] Essentially ξ is a random vector

$$\xi = (\xi_x, \xi_y, \xi_z)$$

where

$\xi_k \sim N\left(0, \sigma_k^{\xi}\right)$ is a random variable with Gaussian distribution centred on 0 and with standard deviation σ_k^{ξ} and

$\varepsilon_k \sim N(0, \sigma_k^\varepsilon)$ is a random variable with Gaussian distribution centred on 0 and with standard deviation σ_k^ε.

[0107] The noise ε on the components x, y, z is considered to be independent.

[0108] Based on the above premises, the Bayes factor B^s for the first sensor system may be derived from the following formula

$$B^s = \frac{P(\boldsymbol{u}|H_1)}{P(\boldsymbol{u}|H_0)} \cdot \frac{P(H_1)}{P(H_0)} = \left(\prod_{k \in \{x,y,z\}} \frac{P(u_k|H_1)}{P(u_k|H_0)} \right) \cdot \frac{P(H_1)}{P(H_0)} \quad \text{(formula 120)}$$

where k indicates the axes x, y, z and $\underline{\mathbf{u}}_k$ is the component along the axis k of the signal detected.

[0109] The components of the vector $\underline{\mathbf{u}}$ on the three axes x, y, z may be regarded as being independent of each other.

[0110] In the formula (120) the following equivalence may be used:

$$\frac{P(u_k|H1)}{P(u_k|H0)} = \frac{\int d\xi_k \; f\left(u_k ; \mu_k + \xi_k , \sigma_k^\varepsilon\right) \, f\left(\xi_k ; 0, \sigma_k^\xi\right)}{f\left(u_k ; \mu_k , \sigma_k^\varepsilon\right)} \quad \text{(formula 140)}$$

where

$$f(x;\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

is a Gaussian function by definition.

[0111] The right-hand component of the formula (140) shown above may be rewritten as:

$$\frac{P(u_k|H_1)}{P(u_k|H_0)} = \left(1 + \frac{1}{\rho^2}\right)^{-1/2} \exp\left[\frac{1}{2}\frac{t^2}{1+\rho^2}\right]$$

where

$$t = (u_k - \mu_k)/\sigma_k^\varepsilon, \; \rho = \sigma_k^\varepsilon/\sigma_k^\xi. \quad \text{(formula 150)}$$

[0112] In the formula (150) $\boldsymbol{\mu}_{\mathbf{k}}$_$\mathbf{u}_k$ are known in that they are, as mentioned, the predetermined value $\boldsymbol{\mu}_{\mathbf{k}}$_(estimated and stored) in the system and the value detected by the sensors $\underline{\mathbf{u}}_k$ during the operating conditions.

[0113] In order to calculate the values t and p in the formula (150) the values of σ_k^ε and σ_k^ξ were estimated, as described below.

[0114] In particular, in order to estimate σ_k^ε where $\varepsilon_k = u_k - \mu_k$, the following equivalence is used:

$$\sigma_k^\varepsilon = \sqrt{var(\varepsilon_k)} = \sqrt{var(u_k - \mu_k)} \quad \text{formula (400)}$$

[0115] Therefore, the value σ_k^ε is determined on the basis of the variance of $u_k - \mu_k$, these latter values being known assuming the situation Ho, namely where there is no car in the parking space.

[0116] Instead, in order to estimate σ_k^{ξ} where $\xi_k + \varepsilon_k = u_k - \mu_k$, the following equivalence is used

$$var(u_k - \mu_k) = var(\xi_k) + var(\varepsilon_k)$$

taking into account that ξ_k is independent of ε_k

[0117] Moreover, since

$$\left(\sigma_k^{\xi}\right)^2 = var(\xi_k) = var(u_k - \mu_k) - var(\varepsilon_k) = var(u_k - \mu_k) - \left(\sigma_k^{\varepsilon}\right)^2$$

σ_k^{ξ} may be obtained from the formula

$$\sigma_k^{\xi} = \sqrt{var(u_k - \mu_k) - \left(\sigma_k^{\varepsilon}\right)^2} \qquad \text{formula (401)}$$

namely depending on the known values $u_k - \mu_k$.

[0118] In the above formula σ_{ξ} is estimated during configuration of the system assuming the situation H_1, namely that there are vehicles parked in the parking space.

[0119] During this configuration step, the values u_k are detected when a vehicle is present and, via the estimates of μ_k and σ_k^{ε} (formula 400), said estimates having been already obtained during the preceding system configuration step when there were no vehicles present in the parking space, σ_k^{ξ} is calculated using the formula 401. Advantageously, according to this embodiment, the Bayes factor Bs of the formula (120) relating to the first sensor system may be calculated on the basis of the sole values of $u_k - \mu_k$.

[0120] Consequently, the free or occupied state based on the first system is determined as:

$$s = \begin{cases} 1 & \text{if } B^s \geqslant 1, \\ 0 & \text{else.} \end{cases}$$

where the parking space is considered occupied, by the first system, if s=1 and free if s=0.

[0121] In order to take into account also the value obtained from the second video surveillance system, the following formula, derived in accordance with that already indicated in relation to the formula (50), is used:

$$B = \left(\prod_{k \in \{x,y,z\}} \frac{P(u_k|H_1)}{P(u_k|H_0)} \right) \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}. \qquad \text{formula (250)}$$

[0122] The Bayes factor B allows a decision to be taken on the free state or occupied state, based on both the values u and v.

Claims

1. Combined system for determining the free or occupied state of a parking space in a car park, comprising

- a first system for detecting the state of a specific parking space from among a plurality of parking spaces, comprising:

* for each parking space at least one sensor intended to measure a first value of at least one parameter, said parameter being variable depending on whether a vehicle or present or not;
* means for transmitting the first measured value to a processing unit comprising means for comparing the first value with a stored reference value corresponding to a known state of the specific parking space;
* means for comparing the first value with a second value of the parameter, measured for at least one parking space adjacent to the specific parking space;
* means for determining the state of the parking space on the basis of both the comparisons, between the first value and the reference value and between the first value and the second value;
* said first system being designed to communicate the free or occupied state determined on the basis of both the comparisons to a control unit of the car park;

- a second video surveillance system comprising:

* means for recording pictures and/or videos of the parking spaces in the car park, including said specific parking space;
* means for comparing the acquired pictures of the specific parking space and reference pictures of said specific parking space, when no vehicles are present;
* means for determining the free or occupied state of the specific parking space, on the basis of said comparison of the pictures;
* said second system being intended to communicate the free or occupied state determined on the basis of said comparison of the pictures to the control unit of the car park;

said control unit of the car park comprising means for determining the free or occupied state of the specific parking space on the basis of both the recordings of the free state or occupied state of said specific parking space performed by the first system and by the second system.

2. System according to claim 1, **characterized in that** said control unit calculates a factor

$$B = \left(\prod_{k\in\{x,y,z\}} \frac{P(u_k|H_1)}{P(u_k|H_0)} \right) \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)},$$

where

$$\frac{P(u_k|H_1)}{P(u_k|H_0)} = \left(1 + \frac{1}{\rho^2}\right)^{-1/2} \exp\left[\frac{1}{2}\frac{t^2}{1+\rho^2}\right]$$

and

$$t = (u_k - \mu_k)/\sigma_k^{\varepsilon},\ \rho = \sigma_k^{\varepsilon}/\sigma_k^{\xi}$$

and where

$\mathbf{u_k}$ is an axial component along an axis k of the first value of the parameter measured by the sensor of the first system;
$\mathbf{\mu_k}$ is an axial component along the axis k of a value μ representing the value of the first parameter when there is no vehicle present in the parking space, said representative value μ being estimated and stored in the control unit during configuration of the first system;

σ_k^{ε} being the standard deviation along the axis k of the component $\varepsilon_{\mathbf{k}}$ of the noise ε during measurement of the first value of the parameter performed by the sensor of the first system in the parking space;

σ_k^{ξ} being the standard deviation along the axis k of a component ξ_k of the first value of the parameter when a vehicle is present in the parking space;
$P(H_0)$ being the probability of finding the parking space empty,
$P(H_1)$ being the probability of finding the parking space occupied,
$P(v|H_0)$ being the probability that the video surveillance system will determine the free or occupied state, in the free condition of the parking space,
$P(v|H_1)$ being the probability that the surveillance system will determine the free or occupied state, in the occupied condition of the parking space,
said probabilities $P(H_0)$, $P(H_1)$, $P(v|H_0)$, $P(v|H_1)$ being memorized in the control unit, and **characterized in that** said means for determining the free state or occupied state provide as output
the free state of the parking space if B<1 or
the occupied state of the parking space if B>=1.

3. System according to claim 2, **characterized in that** said means for determining the free or occupied state estimate σ_k^{ε} and σ_k^{ξ} according to the formulas

$$\sigma_k^{\varepsilon} = \sqrt{var(\varepsilon_k)} = \sqrt{var(u_k - \mu_k)}$$

$$\sigma_k^{\xi} = \sqrt{var\left(u_k - \mu_k\right) - (\sigma_k^{\varepsilon})^2},$$

4. System according to claim 3, **characterized in that** σ_k^{ε} is estimated on the basis of the representative value μ stored during said configuration of the first system and on the basis of the value of u measured when there is no vehicle present in the parking space (H_0), and N is calculated during a second step for configuration of the system in which the value u is measured when a vehicle is present in the parking space (H_1).

5. System according to claim 1, **characterized in that** said control unit is set so as to memorize

- the probability (P^s_{FP}) that the first system will determine the occupied state (s=1) of the specific parking space even when the parking space is free (Ho);
- the probability (P^s_{FN}) that the first system will determine the free state (s=0) of the specific parking space even when the parking space is occupied (H_1);
- the probability (P^v_{FP}) that the second system will determine the occupied state (v=1) of the specific parking space even when the parking space is free (Ho);
- the probability (P^v_{FN}) that the first system will determine the free state (v=0) of the specific parking space even when the parking space is occupied (H_1);

and **in that**
The control unit determines a Bayes factor

$$\mathrm{B} = \frac{P(v|H_1)}{P(v|H_0)}\frac{P(v|H_1)}{P(v|H_0)}\frac{P(H_1)}{P(H_0)}$$

on the basis of said stored probability values (P^s_{FP} P^s_{FN} P^v_{FP} P^v_{FN}) and determines the free state (d=0) if said Bayes factor B is less than 1 or the occupied state (d=1) if said Bayes factor is greater than or equal to 1.

6. System according to claim 5, **characterized in that** said probability values (P^s_{FP}, P^s_{FN}) that the first system will determine the occupied state (s=1) or free state (s=0) of the specific parking space even when the space is respec-

tively free (Ho) or occupied (H_1), and said probability values (P^v_{FP}, P^v_{FN}) that the second system will determine the occupied state (v=1) or free state (v=0) even when the space is respectively free (Ho) or occupied (H_1), are calculated on the basis of a real free or occupied state (ct) of the specific parking space, said real free or occupied state being monitored on-site during preliminary configuration of the combined system.

7. System according to claim 1, **characterized in that** said control unit is set so as to memorize

- the probability (P^v_{FP}) that the second system will determine the occupied state (v=1) of the specific parking space even when the parking space is free (Ho);
- the probability (P^v_{FN}) that the first system will determine the free state (v=0) of the specific parking space even when the parking space is occupied (H_1);

and **in that** the control unit determines a Bayes factor on the basis of said stored probability values (P^v_{FP}, P^v_{FN}) and determines the free state (d=0) if said Bayes factor B is less than 1 or the occupied state (d=1) if said Bayes factor is greater than or equal to 1, where δ is the distance between the first value of the parameter and the reference value.

8. System according to claims 4 or 7, **characterized in that** the control unit memorizes a same probability value (1/2) that the specific parking space will be free beforehand (P(Ho)) or occupied beforehand ($P(H_1)$).

9. System according to claim 8, **characterized in that** said Bayes factor

$$B = \frac{P(\delta|H_1)}{P(\delta|H_0)} \cdot \frac{P(v|H_1)}{P(v|H_0)} \cdot \frac{P(H_1)}{P(H_0)}$$

is calculated on the basis of only the values of the second detection system ($P(v/H_i)$) for predetermined values of δ close to a value θ, where θ is a threshold value close to which the recording of the first system is not considered to be reliable.

10. System according to claim 1, **characterized in that** said first system comprises means for creating a measurement profile, said measurement profile comprising at least the first and the second value, and means for comparing the measurement profile with a set of pre-memorized measurement profiles corresponding to a set of states of the specific parking space and of said at least one adjacent space.

11. System according to claim 1, **characterized in that** the first and second values comprise at least two axial components and said comparison means compare the axial components of the first value and the axial components of the second value.

12. Method for determining the free or occupied state of a parking space in a car park, comprising

- a first step for detecting the state of a specific parking space from among a plurality of parking spaces by means of a first system, comprising:

  * for each parking space at least one sensor intended to measure a first value of at least one parameter, said parameter being variable depending on whether a vehicle or present or not;
  * means for transmitting the first measured value to a processing unit comprising means for comparing the first value with a stored reference value corresponding to a known state of the specific parking space;
  * means for comparing the first value with a second value of the parameter, measured for at least one parking space adjacent to the specific parking space;
  * means for determining the state of the parking space on the basis of both the comparisons, between the first value and the reference value and between the first value and the second value;
  * said first system communicating the free or occupied state determined on the basis of both the comparisons to a control unit of the car park;

- a second step for determining the free or occupied state of said specific parking space by means of a second video surveillance system comprising:

* means for recording pictures and/or videos of the parking spaces in the car park, including said specific parking space;
* means for comparing the acquired pictures of the specific parking space and reference pictures of said specific parking space, when no vehicles are present;
* means for determining the free or occupied state of the specific parking space, on the basis of said comparison of the pictures;
* said second system communicating the free or occupied state determined on the basis of said comparison of the pictures to the control unit of the car park;

- a third step during which the control unit of the car park determines the free or occupied state of the specific parking space on the basis of both the recordings of the free state or occupied state of said specific parking space performed by the first system and by the second system during the first two steps.

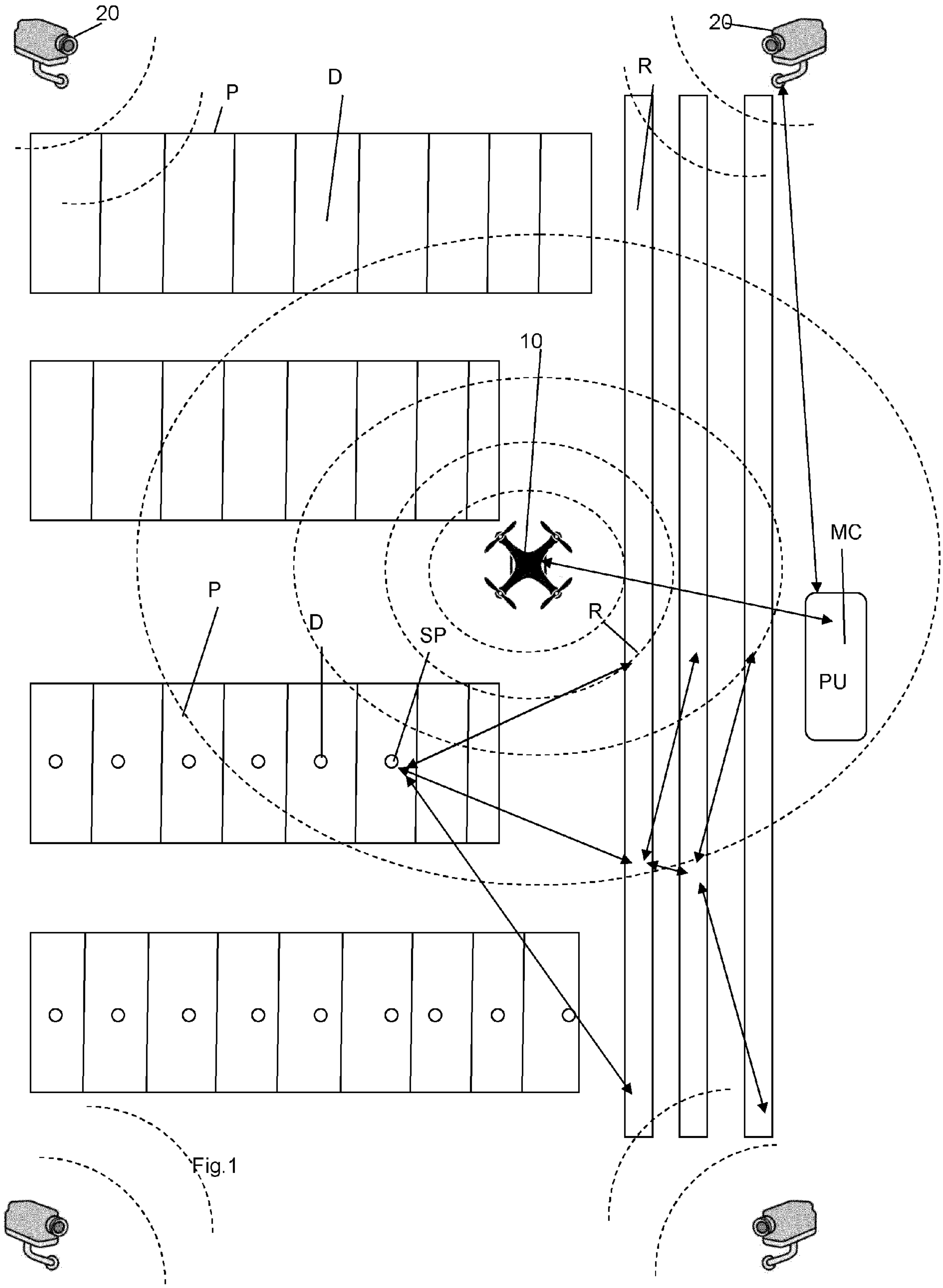


Fig.1

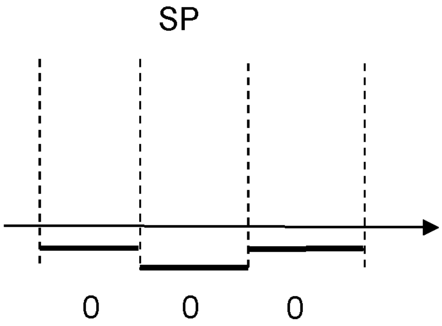


Fig.2a

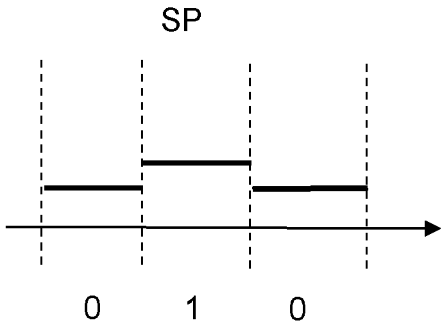


Fig.2d

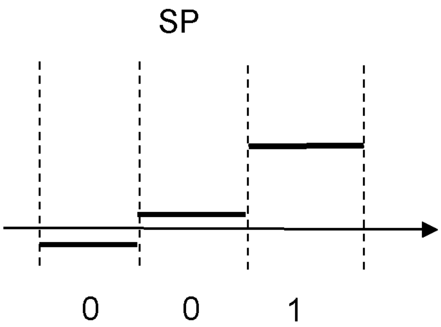


Fig.2b

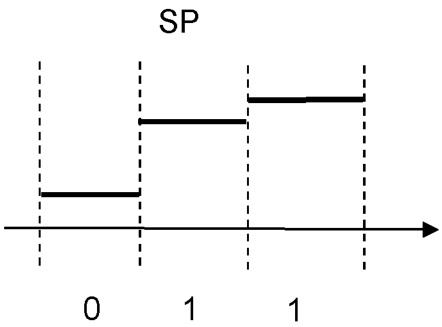


Fig.2e

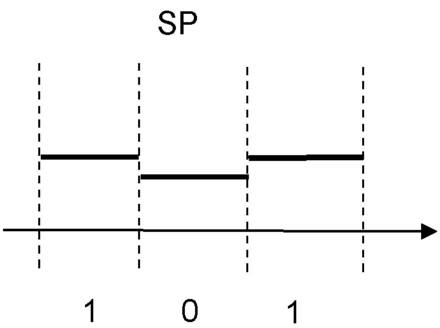


Fig.2c

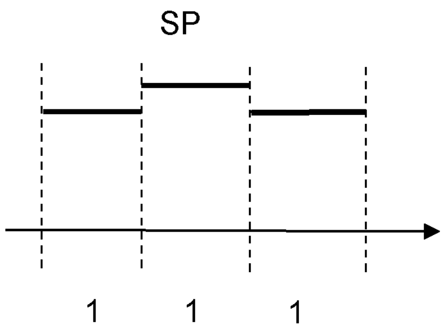


Fig.2f

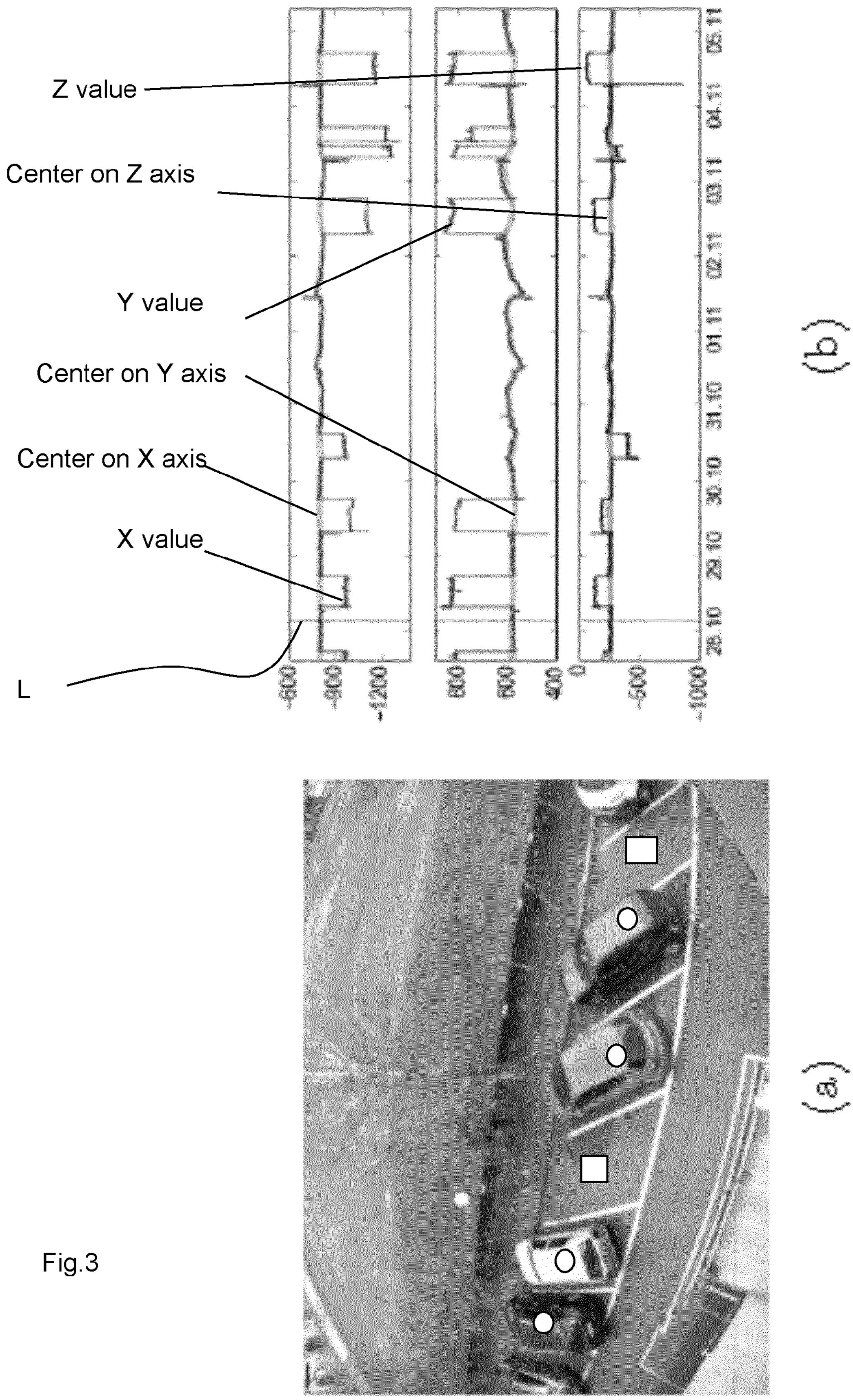
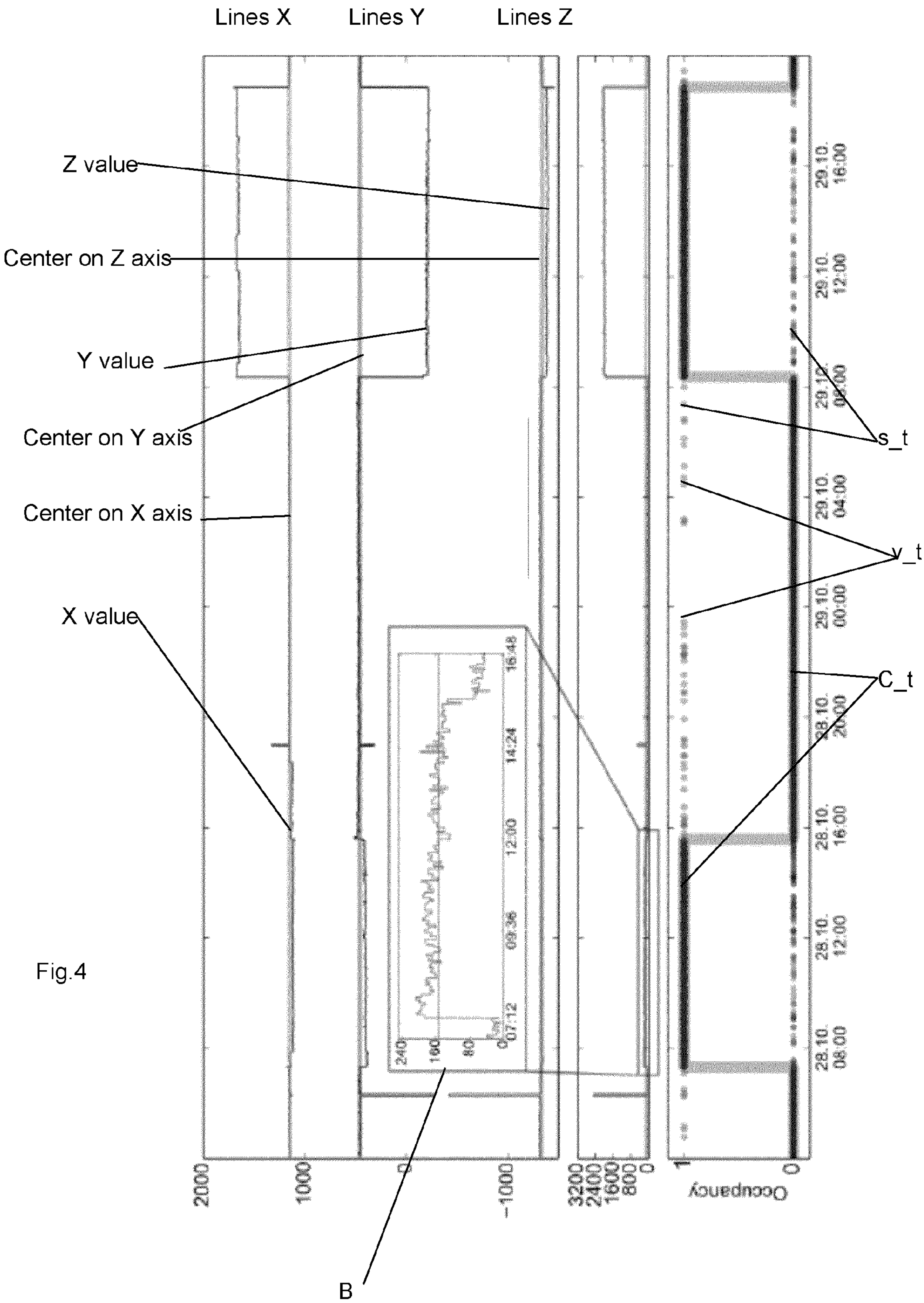

Z value
Center on Z axis
Y value
Center on Y axis
Center on X axis
X value
L
(b)
(a)

Fig.3


Lines X
Lines Y
Lines Z
Z value
Center on Z axis
Y value
Center on Y axis
Center on X axis
X value
s_t
y_t
C_t
B
2000
1000
0
-1000
3200
2400
1600
800
0
1
0
Occupancy
28.10. 08:00
28.10. 12:00
28.10. 16:00
28.10. 20:00
29.10. 00:00
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29.10. 08:00
29.10. 12:00
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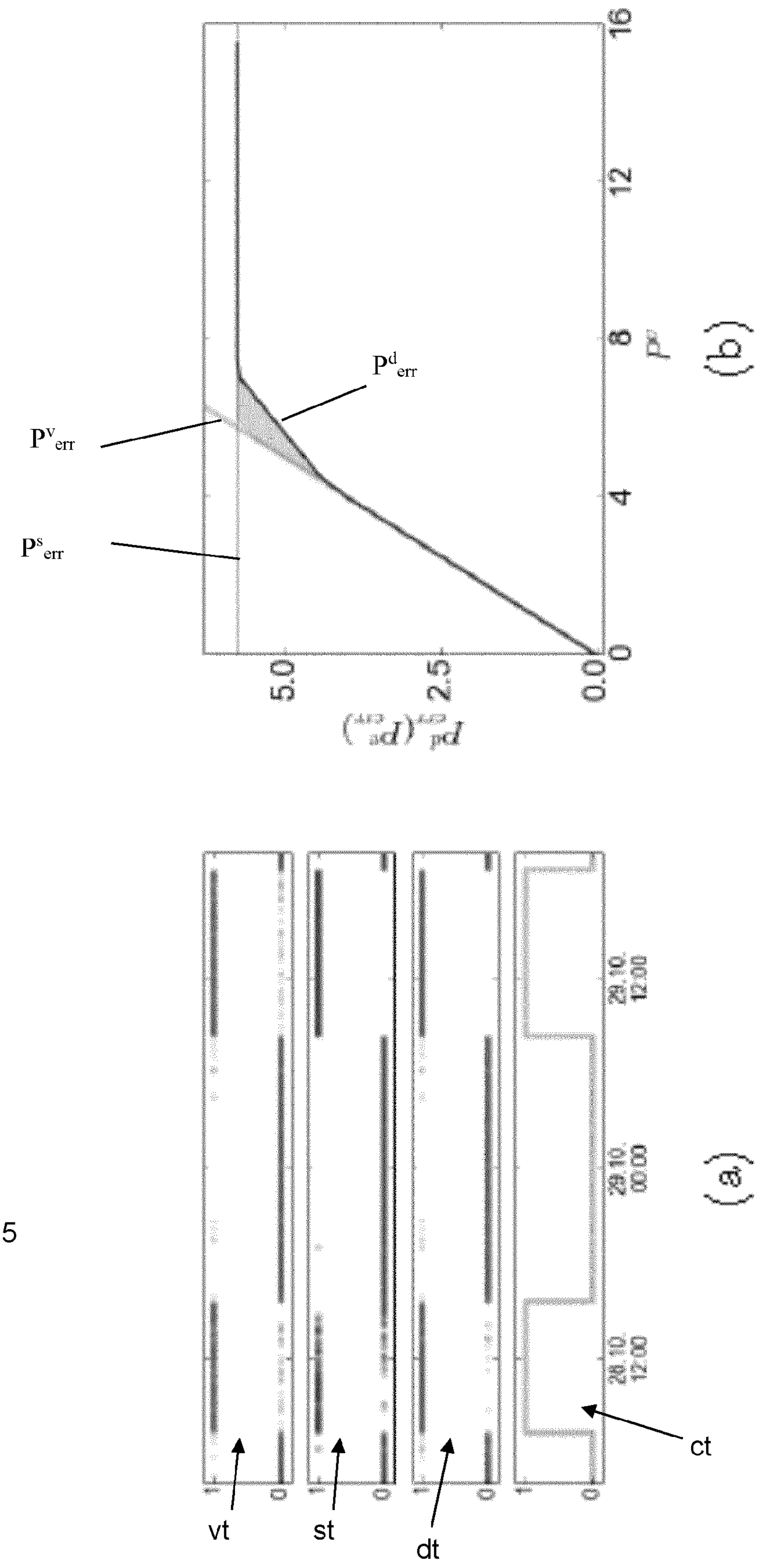
07:12
09:36
12:00
14:24
16:48

Fig.4

Fig.5



P^v_err
P^s_err
P^d_err
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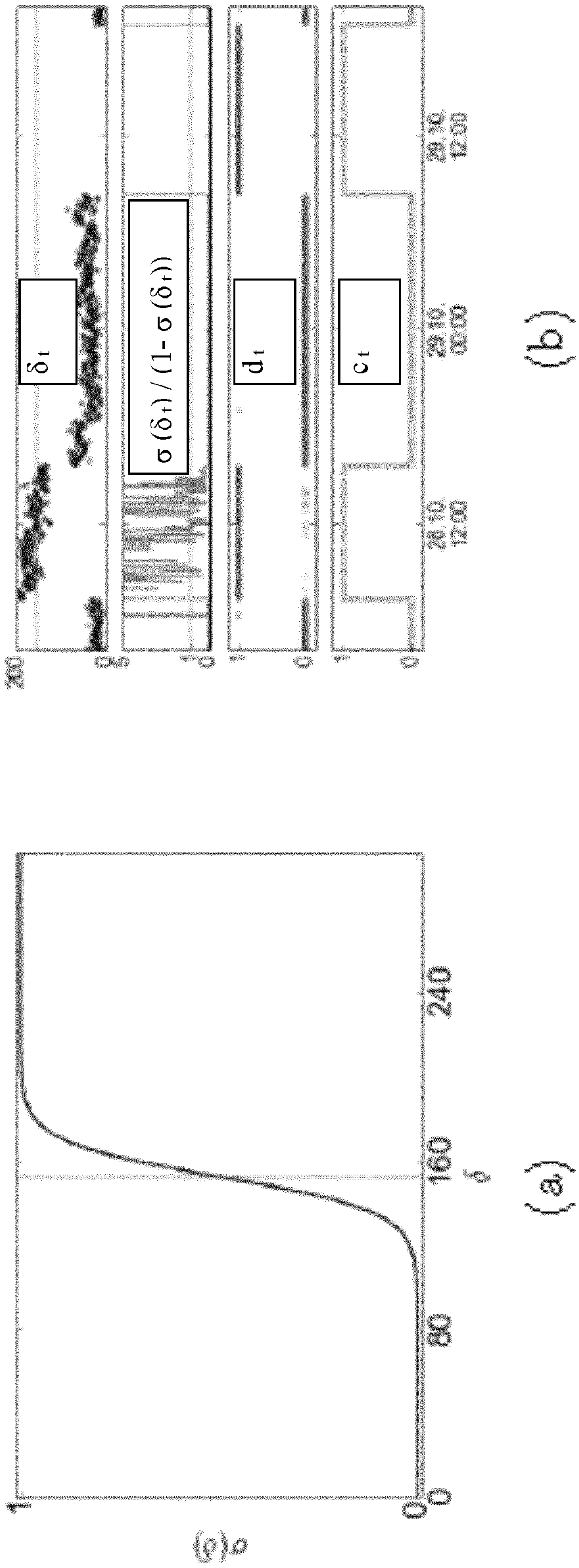
2.5
5.0
0
4
8
12
16
(b)
28.10.
12:00
29.10.
00:00
29.10.
12:00
(a)
vt
st
dt
ct
1
0

Fig.6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σ(δt) / (1- σ(δt))
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ct
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(b)
σ(δ)
0
80
160
240
δ
(a)

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EUROPEAN SEARCH REPORT

Application Number
EP 16 16 2413

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	28 September 2016	Fagundes-Peters, D

CATEGORY OF CITED DOCUMENTS

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