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(71) Applicant: **MOVYON S.p.A.**
00159 Roma (IT)

(72) Inventors:
- **BOCCIARELLI, Filippo**
  00159 Roma (IT)
- **DORE, Giovanni**
  00159 Roma (IT)

(74) Representative: **Pietra, Giulia et al**
Marchi & Partners S.r.l.
Via Vittor Pisani, 13
20124 Milano (IT)

(54) APPARATUS AND METHOD FOR DETECTING THE TRANSIT OF A VEHICLE

(57) A system and a method for detecting the transit of a vehicle are described. The apparatus comprises sensors that provide data (registration number, speed, class, etc.) relative to the vehicles in transit. The apparatus also comprises a tracking device that provides information indicative of a sequence of positions of the vehicle through a tracking area, which includes the coverage areas of all the sensors of the apparatus. Each position is associated with the time at which the vehicle passed through that position. To determine whether the data detected by a sensor at a detection time tE are relative to the vehicle, at least one position is identified, in the sequence of positions, associated with a time in a range about tE and a comparison area is determined based thereon. If the comparison area overlaps the coverage area of the sensor that detected the data, it is concluded that these data relate to the vehicle.

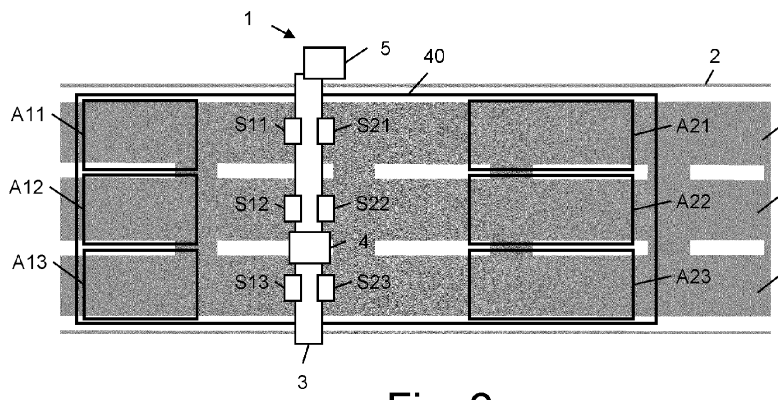

Fig. 2

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Description

Technical field

[0001] The present invention concerns in general the field of traffic control methods and systems. In particular, the present invention concerns an apparatus (for example, but not exclusively, a gate for a free-flow toll collection system) for detecting the transit of a vehicle. The present invention also concerns a method for detecting the transit of a vehicle, for example (but not exclusively) transit through a gate of a free-flow toll collection system.

State of the art

[0002] As known, free-flow toll collection systems allow collection of the toll due for the transit of vehicles along a road or motorway section, without the need for booths or barriers. A free-flow toll collection system entails the positioning of gates along the road section, each of which comprises sensors and a bridge supporting structure that supports the sensors above the carriageway. The vehicles in transit along the carriageway pass under the gate and are detected by the sensors, without having to stop or even reduce their speed. The transit data detected by the sensors are then transmitted to a server, which processes them to determine the toll due for each vehicle detected and the identity of the driver to whom to charge the toll due.

[0003] Typically, a gate comprises a set of different sensors, which detect different data for each vehicle in transit. This set of sensors generally comprises one or more sensors able to detect a unique vehicle identifier such as, for example, a camera able to provide one or more images of the vehicle from which its registration number is detected, and/or a radiofrequency transceiver able to detect the identifier of a radiofrequency on-board unit present on board the vehicle; one or more sensors able to detect the class and/or number of axles and/or weight of the vehicle; one or more sensors able to detect the speed of the vehicle and/or the lane through which the vehicle is passing; and so on.

[0004] It is particularly important that each gate is able to correlate data that are detected by different sensors and that relate to the same vehicle. This allows transit of the various vehicles through the gate to be correctly identified, avoiding for example erroneously identifying the same vehicle twice and wrongly charging it the toll twice. In general, redundancy of the data acquired by the various sensors and correct correlation of said data with one another ensures reliable detection, in which the risk of identification errors or non-identification of vehicles is minimum. Typically, the accuracy of the correlation required is no lower than 99%, namely at each gate no more than one correlation error can occur every 100 vehicles in transit.

[0005] However, the correlation between data detected by the different sensors of a gate presents some difficulties. These are due to the fact that the sensors each have their own coverage area and, in general, the coverage areas of the different sensors can have different positions along the carriageway, so that the same vehicle is detected by the gate sensors at different times.

[0006] For example, with reference to Fig. 1, a radiofrequency transceiver (schematically shown in Fig. 1 and indicated as sensor S1) generally has a coverage area A1 very near to the gate P on which it is positioned. On the other hand, a radar sensor for detecting the class and/or the number of axles and/or the speed of the vehicles (schematically shown in Fig. 1 and indicated as sensor S2) can have a coverage area A2 positioned at a distance of a few ten metres from the gate P on which it is positioned. A vehicle V will therefore pass through the area A1 (and will therefore be detected by the sensor S1) at a time t1, and will pass through the area A2 (and will therefore be detected by the sensor S2) at a subsequent time t2. If v is the speed of the vehicle V and x1 is the position of the coverage area A1 in the direction of travel of the vehicle V, the position x of the vehicle V at the detection time t2 is given by the following equation:

$$x = x1 + v\,(t2 - t1) \qquad [1]$$

[0007] If, applying the equation [1], the value of x obtained is roughly equal to the position x2 of the coverage area A2 in the direction of travel of the vehicle V, it means that the vehicle that has passed through the coverage areas A1 and A2 at times t1 and t2 respectively is actually the same vehicle V. Therefore, the data detected by the two sensors at times t1 and t2 must be correlated, since they relate to the same vehicle V.

Summary of the invention

[0008] The above correlation algorithm can be applied only in certain conditions. In particular, it is based on the assumption that the vehicles travel at a substantially constant speed between the coverage areas A1 and A2, along a substantially rectilinear trajectory. If, therefore, the vehicles do not travel at constant speed and they follow non-rectilinear trajectories (which occurs frequently if there are several lanes, and the vehicles can overtake or change lanes between the two coverage areas A1 and A2), the comparison between the result of the equation [1] and the position x2 of the area A2 no longer provides significant indications for establishing whether the data detected by the two sensors S1 and S2 at times t1 and t2 are to be correlated or not.

[0009] The drawback could be remedied if the gate sensors could be designed so as to have coverage areas as close as possible, or even coincident. In this case, it would be sufficient to correlate with one another the data detected by the gate sensors substantially at the same time, since their coverage areas would be crossed by the vehicle V substantially at the same time. However, it is not always possible to design the sensors in this way and, where technically possible, it may be necessary to provide additional works that would increase the complexity and cost of the gate. For example, with reference to the example of Figure 1 described above, the sensor S2 could be installed on a dedicated support structure that precedes the gate P by a few ten metres, so that the coverage areas A1 and A2 are substantially coincident. The provision of a separate support structure, however, may not be possible and in any case, even if possible, would increase the complexity and cost of the gate and, therefore, of the entire free-flow toll collection system.

[0010] In the light of the above, an object of the present invention (for example, but not exclusively, a gate for a free-flow toll collection system) and a method for detecting the transit of a vehicle that solves the above-mentioned drawbacks.

[0011] In particular, an object of the present invention is to provide an apparatus (for example, but not exclusively, a gate for a free-flow toll collection system) and a method for detecting the transit of a vehicle, that allows correlation of the vehicle data detected by the different sensors with a high degree of reliability, even when the sensors have coverage areas located in different positions along the carriageway and the vehicle can change speed and/or follow a non-rectilinear trajectory (for example, when there are several lanes).

[0012] According to embodiments of the present invention, this object is achieved by an apparatus (for example, but not exclusively, a gate for a free-flow toll collection system) that comprises a plurality of sensors with respective coverage areas, which detect data (for example, registration number, class or speed) relative to the vehicles that pass through their coverage areas. The apparatus also comprises a tracking device, which has a coverage area (called "tracking area") which includes all the coverage areas of the sensors of the apparatus and provides information indicative of the vehicle trajectory, where "trajectory" means the sequence of positions of the vehicle through the tracking area, each position being associated with the time at which the vehicle passed through that position. The apparatus furthermore comprises a data processing unit. To establish whether one or more data detected by a sensor of the apparatus at a certain detection time tE relate to the tracked vehicle, one or more positions of the vehicle associated with respective one or more times in a range about the time tE are identified in its trajectory. In the present description and in the claims, "in a range about the detection time tE" indicates the time interval between tE-T and tE+T (extremes included), where T is the tracking period, namely the period that elapses between times associated with consecutive tracked positions. Based on this/these position/s, a comparison area is then determined and, if the comparison area and the sensor coverage area at least partially overlap, it is concluded that the data detected by the sensor relate to the tracked vehicle.

[0013] Repeating this operation for the data detected by the various sensors of the apparatus, it is then possible to identify all those relative to the tracked vehicle, so that said data will be correctly correlated with one another.

[0014] Advantageously, the correlation process according to embodiments of the present invention does not require any particular assumption in terms of vehicle speed or trajectory. This is because the data detected by each sensor of the apparatus are compared with the actual trajectory of the vehicle, namely with the sequence of the various positions of the vehicle at the various times during the period in which the vehicle crosses the tracking area. The correlation process according to embodiments of the present invention is therefore able to provide accurate results regardless of the reciprocal distance of the coverage areas and regardless of whether the speed of the vehicle is constant or not and whether its trajectory is rectilinear or not.

[0015] According to a first aspect, an apparatus is provided to detect the transit of a vehicle, the apparatus comprising:

- a plurality of sensors that have respective coverage areas and which are suitable for providing data relating to vehicles in transit through said respective coverage areas;
- a tracking device configured to provide information indicative of a sequence of positions of the vehicle through a tracking area that includes said respective coverage areas of said plurality of sensors, each position being associated with the time at which the vehicle passed through that position; and
- a data processing unit configured to determine whether one or more data detected by a sensor of the plurality of sensors at a detection time are relative to the vehicle, said determining comprising: identifying in the sequence of positions at least one position associated with a time in a range about the detection time, determining a comparison area based on said at least one position and, if the determined comparison area is at least partially overlapping with the coverage area of said one sensor of the plurality of sensors, determining that the one or more data detected by said sensor of the plurality of sensors at the time of detection are relative to the vehicle.

[0016] Preferably, the data relative to vehicles in transit comprise two or more of the following: registration number, identification of a radiofrequency on-board unit, speed, class, number of axles, weight.

[0017] Preferably, the tracking device is suitable for providing a sequence of images of the tracking area, each image of the sequence of images showing the vehicle in a respective position of the tracking area.

[0018] Preferably, each of the positions of the vehicle through the tracking area is in the form of Cartesian coordinates in a plane substantially parallel to the roadway on which the vehicle transits.

[0019] According to one embodiment, the data processing unit is configured to identify in the sequence of positions at least two positions associated with two respective times in a range about the detection time, the comparison area being determined as the minimum convex area that contains the at least two positions.

[0020] According to a variation of this embodiment, the data processing unit is configured to identify in the sequence of positions a first position associated with a time immediately preceding or substantially coinciding with the time of detection and a second position associated with a time immediately following or substantially coinciding with the time of detection.

[0021] Preferably, a respective marker of dimensions corresponding to the dimensions of the vehicle is associated with each of the positions of the vehicle through the tracking area.

[0022] In this case, according to the above variation, the first position is associated with a first marker having dimensions corresponding to the dimensions of the vehicle, the second position is associated with a second marker having dimensions corresponding to the dimensions of the vehicle, the comparison area being determined as a minimum convex area that contains the first marker and the second marker.

[0023] Preferably, the data processing unit is furthermore configured to determine whether one or more further data detected by a further sensor of the plurality of sensors at a further detection time are correlated with said one or more data, said determining comprising: identifying in the sequence of positions at least one further position associated with a time in a range about the further detection time, determining a further comparison area based on the at least one further position and, if the further comparison area determined is at least partially overlapping the coverage area of said further sensor of the plurality of sensors, determining that the one or more further data detected by said further sensor of the plurality of sensors at the further detection time are correlated with said one or more data.

[0024] Preferably, the coverage area of the sensor and the coverage area of the further sensor are on two different lanes suitable for being travelled by the vehicles in transit.

[0025] Preferably, the apparatus is for a free-flow toll collection system.

[0026] According to a second aspect, a method is provided for detecting the transit of a vehicle, the method comprising:

- by means of a plurality of sensors having respective coverage areas, providing data relative to vehicles in transit through said respective coverage areas;
- by means of a tracking device, providing information indicative of a sequence of positions of the vehicle through a tracking area that includes said respective coverage areas of said plurality of sensors, each position being associated with the time at which the vehicle passed through that position; and
- by means of a data processing unit, upon the receipt of one or more data detected by a sensor of the plurality of sensors at a detection time, identifying in the sequence of positions at least one position associated with a time in a range about the detection time, determining a comparison area based on the at least one position and, if the comparison area determined is at least partially overlapping the coverage area of said one sensor of the plurality of sensors, determining that the one or more data detected by said sensor of the plurality of sensors at the detection time are relative to the vehicle.

Brief description of the drawings

[0027] The present invention will be clearer from the following detailed disclosure, provided by way of non-limiting example, to be read with reference to the attached drawings in which:

- Figure 1 (already described above) shows schematically a road section provided with a gate of a free-flow toll collection system, comprising two sensors with two non-overlapping coverage areas;
- Figure 2 shows an apparatus for detecting the transit of a vehicle, according to an embodiment of the present invention;
- Figures 3(a), 3(b), 3(c) show schematically three phases of determination of the trajectories of two exemplary vehicles, according to an embodiment of the present invention;
- Figures 4(a), 4(b) and 4(c) show schematically three phases of the detection of data relative to two vehicles in transit by the sensors of the apparatus of Figure 2;
- Figure 5 is a flow chart that shows the various phases of correlation between the data detected by the sensors and the trajectories of the vehicles, according to an embodiment of the present invention; and
- Figures 6(a) and 6(b) show the result of the correlation for two vehicles in transit.

Detailed disclosure of embodiments of the invention

[0028] Figure 2 shows schematically an apparatus 1 for detecting the transit of a vehicle, according to an embodiment of the present invention.

[0029] The apparatus 1 is arranged for example along a road or motorway section 2. The road or motorway section 2 can comprise a single lane or several lanes. By way of non-limiting example, the road section 2 shown in Figure 2 comprises three lanes 21, 22 and 23. Although the description below will refer only to use of the apparatus 1 for detecting the transit of vehicles along a road or motorway section, this is not limiting. The apparatus 1 can indeed be used in any context in which it is necessary to detect the transit of vehicles, for example access to a viaduct, to a parking area, to a restricted traffic area, etc.

[0030] The apparatus 1 preferably comprises a set of sensors, each of which suitable for detecting one or more data relative to each vehicle that passes through its coverage area. Said set of sensors for example can comprise two or more of the following sensors:

- a camera (for example, an RGB or infrared camera) suitable for acquiring one or more images of each vehicle in transit, from which the vehicle registration number is detected;
- a radiofrequency transceiver suitable for detecting the identifier of the radiofrequency on-board unit present on board each vehicle in transit;
- a sensor suitable for detecting the class of each vehicle in transit;
- a sensor suitable for detecting the weight of each vehicle in transit;
- a sensor (for example, a radar) suitable for detecting the speed of each vehicle in transit.

[0031] If the road section 2 has several lanes, the apparatus 1 preferably comprises a set of sensors for each lane. Assuming by way of non-limiting example that each set of sensors comprises two different sensors (for example, an RGB camera for detecting the registration number and a radar for detecting the speed), in the case of Figure 2, provided by way of example, in which there are three lanes 21, 22 and 23, the apparatus 1 comprises three sets of sensors, namely: a set of two sensors S11, S21 for lane 21, a set of two sensors S12, S22 for lane 22 and a set of two sensors S13, S23 for lane 23.

[0032] Each sensor of the apparatus 1 has a respective coverage area. Figure 2 shows schematically the coverage areas A11, A21 of the sensors S11, S21 along lane 21, the coverage areas A12, A22 of the sensors S12, S22 along lane 22, and the coverage areas A13, A23 of the sensors S13, S23 along lane 23. By way of example, the coverage areas shown in Figure 2 have a rectangular shape. This is not limiting, however, since the shape of each coverage area (and likewise its dimension and position along the carriageway) depends on the technology with which the respective sensor is made and its position relative to the carriageway.

[0033] The apparatus 1 can be for example a gate for a free-flow toll collection system. In this case, the apparatus 1 also comprises a bridge supporting structure 3, which supports the sensors of the apparatus 1 (and also other components of the apparatus 1, which will be described below) above the road section 2, so that the vehicles in transit along the road section 2 pass below the gate.

[0034] According to the present invention, the apparatus 1 also comprises a tracking device 4, which has a coverage area 40 (also called "tracking area" below) and is configured to provide information indicative of the trajectory of each vehicle in transit through the tracking area 40. The term "trajectory" of a vehicle indicates the sequence of positions through which the vehicle has passed through the tracking area 40, each position being associated with the time at which the vehicle passed through that position.

[0035] The tracking area 40 of the tracking device 4 includes all the coverage areas of the sensors of the apparatus 1. If there are several lanes and, therefore, the apparatus 1 comprises a respective set of sensors for each lane, the tracking area 40 is preferably such as to include the coverage areas of all the sets of sensors, as shown schematically in Figure 2.

[0036] The tracking device 4 can for example comprise a camera or RGB or infrared camera, which provides a sequence of colour or infrared images of a portion of the road section 2 comprising the coverage areas of all the sets of sensors of the apparatus 1. In this case, the tracking area 40 substantially coincides with the field of view of the camera and has a substantially rectangular shape, as shown schematically in Figure 2.

[0037] The apparatus 1 also comprises a data processing unit 5. This can be supported by the supporting structure 3, or can be located at the foot of or near to the latter.

[0038] The operation of the apparatus 1, according to an embodiment of the present invention, will now be described.

[0039] As the vehicles travel along the road or motorway section 2, the tracking device 4 provides information indicative of their trajectories through the tracking area 40.

[0040] In the embodiment in which the tracking device 4 detects a sequence of colour or infrared images, said sequence of images is subject (by the device 4 itself and/or the data processing unit 5) to a tracking algorithm, which allows identification of each vehicle that can be seen in the sequence of images and identification of the trajectory through the tracking area 40. For this purpose it is possible to use tracking algorithms known per se. Known tracking algorithms that can be used are for example described by W. Luo et al: "Multiple Object Tracking: A Literature Review", arXiv:1409.7618v4 [cs.CV] 22 May 2017, or by J. Redmon et al.: "You Only Look Once: Unified, Real-time Object Detection", arXiv:1506.02640v5 [cs.CV] 9 May 2016, or by S. Sivaraman et al.: "Looking at Vehicles on the Road: A Survey of Vision-Based Vehicle Detection, Tracking, and Behavior Analysis", IEEE Transactions On Intelligent Transportation Systems, Vol. 14, No. 4, December 2013, page 1773.

[0041] For sufficiently accurate tracking to be obtained (taking account of the average speed of the vehicles along the road or motorway section 2), the acquisition period of the images by the tracking device 4 is preferably between 50 ms and 100 ms, for example 80 ms.

[0042] Regardless of the specific tracking algorithm applied to the sequence of images provided by the tracking device 4, the output of the tracking algorithm preferably comprises, for each vehicle in transit through the tracking area 40, a sequence of the positions through which the vehicle has passed within the tracking area 40 (below also called "tracked positions" for the sake of brevity).

[0043] Each tracked position is preferably expressed in the form of Cartesian coordinates in a plane parallel to the roadway. The reference system relative to which the Cartesian coordinates of each position tracked are determined can, for example, originate in one of the vertexes of the tracking area 40, for example in the vertex between the entry side of the vehicles into the tracking area 40 and the side parallel to the right-hand edge of the carriageway.

[0044] According to an advantageous embodiment, each vehicle in transit through the tracking area 40 is preferably associated with a marker having shape and dimensions corresponding to said vehicle, namely such as to contain it. According to an advantageous embodiment, said marker has the shape of a rectangle with width and length substantially equal to the width and length of the vehicle. Each tracked position is therefore preferably expressed in terms of Cartesian coordinates of one or more predefined points of the marker (for example its centre of gravity and/or one or more of its vertexes) in the above-mentioned plane parallel to the roadway. According to an advantageous variation, if the marker is rectangular, each position tracked is preferably expressed in terms of Cartesian coordinates of two opposite vertexes of the rectangular marker, in particular the one with minimum x and y coordinates and the one with maximum x and y coordinates.

[0045] Preferably, each tracked position is furthermore associated with a timestamp that indicates the time when the vehicle passed through that tracked position.

[0046] Each tracked position with the respective timestamp can therefore be expressed in the following form:

$$Tj = \{t_j; x_{mj}, y_{mj}; x_{Mj}, y_{Mj}\} \qquad [2]$$

in which tj is the timestamp associated with the position, x_{mj}, y_{mj} are the coordinates of the vertex of the rectangular marker with minimum x and y and x_{Mj}, y_{Mj} are the coordinates of the vertex of the rectangular marker with maximum x and y. The index j is an integer that varies between 1 and N, where j=1 indicates the initial position and time of the tracking (corresponding to the complete entry of the vehicle into the tracking area 40) and j=N indicates the final position and time of the tracking (corresponding to the complete exit of the vehicle from the tracking area 40).

[0047] According to an advantageous embodiment, when the entry of a new vehicle into the tracking area 40 is detected, it is associated with a respective identifier, which will continue to identify the vehicle until it exits the tracking area 40. All the tracked positions, from entry of the vehicle into the tracking area 40 onwards, will therefore be associated with the same identifier. It is to be noted that said identifier has no relation with the vehicle registration number or with the identifier of the vehicle on-board unit, since these data relative to the vehicle - detected by the other sensors of the apparatus 1 - have not yet been related to the tracking performed on the basis of the information provided by the tracking device 4.

[0048] For example, with reference to Figure 3(a), it is assumed that two vehicles VA and VB enter the tracking area 40 substantially simultaneously, in lanes 22 and 23 respectively of the road section 2. For greater clarity of the drawings, Figure 3(a) (and also the following Figures 3(b) and 3(c)) only show the tracking area 40, while the apparatus 1, its components and the coverage areas of the other sensors of the apparatus 1 have been omitted.

[0049] As shown in Figure 3(b), at the time tj = t1 tracking of the vehicles VA and VB begins, namely their first tracked position is determined. The first tracked position for each vehicle VA, VB is detected when it is determined that the vehicle VA, VB has completely entered the tracking area 40. According to an advantageous embodiment, for each vehicle VA and VB, the respective rectangular marker RA, RB that contains it is determined and the position thereof is determined. This first tracked position with the respective timestamp can therefore be expressed, for each vehicle VA, VB, in the following form:

$$T1^A = \{t1; x_{m1}^A, y_{m1}^A; x_{M1}^A, y_{M1}^A\} \quad [3a]$$

$$T1^B = \{t1; x_{m1}^B, y_{m1}^B; x_{M1}^B, y_{M1}^B\} \quad [3b]$$

in which x_{m1}^A, y_{m1}^A are the coordinates of the vertex Vm^A of the rectangular marker RA with minimum x and y, x_{M1}^A, y_{M1}^A are the coordinates of the vertex Vm^A of the rectangular marker RA with maximum x and y, x_{m1}^B, y_{m1}^B are the coordinates of the vertex Vm^B of the rectangular marker RB with minimum x and y, and x_{M1}^B, y_{M1}^B are the coordinates of the vertex Vm^B of the rectangular marker RB with maximum x and y.

[0050] From this moment onwards, tracking of the two vehicles VA and VB continues, until they completely exit the tracking area 40. This can occur at the same time if the two vehicles VA and VB proceed substantially at the same speed, or at different times if the two vehicles proceed at different speeds.

[0051] It is assumed that the vehicle VA proceeds at a higher speed than the vehicle VB and overtakes it within the tracking area 40. At a time tn subsequent to t1 the tracked positions will therefore be those shown in Figure 3(c), namely both vehicles will be in lane 23, with the vehicle VA in a more advanced position than vehicle VB. This tracked position with the respective timestamp can therefore be expressed, for each vehicle VA, VB, in the following form:

$$Tn^A = \{tn; x_{mn}^A, y_{mn}^A; x_{Mn}^A, y_{Mn}^A\} \quad [4a]$$

$$Tn^B = \{tn; x_{mn}^B, y_{mn}^B; x_{Mn}^B, y_{Mn}^B\} \quad [4b]$$

in which x_{mn}^A, y_{mn}^A are the coordinates of the vertex Vm^A of the rectangular marker RA with minimum x and y, x_{Mn}^A, y_{Mn}^A are the coordinates of the vertex VM^A of the rectangular marker RA with maximum x and y, x_{mn}^B, y_{mn}^B are the coordinates of the vertex Vm^B of the rectangular marker RB with minimum x and y, and x_{Mn}^B, y_{Mn}^B are the coordinates of the vertex VM^B of the rectangular marker RB with maximum x and y.

[0052] While the vehicles in transit are tracked on the basis of the information provided by the tracking device 4 as described above, the other sensors of the apparatus 1 detect data relative to said vehicles such as, for example, as described above, their registration numbers and/or the identifiers of their radiofrequency on-board units and/or their speed and/or their class and/or their weight.

[0053] The data detected by each sensor of the apparatus 1 are preferably accompanied by a timestamp tE that indicates the detection time. The sensors of the apparatus 1 are preferably synchronized with one another and with the tracking device 4, so that the timestamps tE that generate, and the timestamps tj generated by the tracking device 4, all substantially refer to the same time base and can therefore be compared with one another.

[0054] The data detected by each sensor of the apparatus 1 are furthermore preferably associated with the position of the sensor coverage area. The position of each coverage area is preferably expressed in the form of Cartesian coordinates of one or more points of the coverage area in a plane parallel to the roadway. The reference system relative to which the Cartesian coordinates of the positions of the sensor coverage areas are determined is preferably the same as the one relative to which the Cartesian coordinates of the tracked positions of the vehicles in transit through the tracking area 40 are determined. In this way, the Cartesian coordinates of the tracked positions and the Cartesian coordinates of the positions of the coverage areas are comparable with one another.

[0055] If, as shown in the drawings, the coverage areas have a rectangular shape, the position of each coverage area is preferably expressed in terms of Cartesian coordinates of one or more predefined points of the rectangle (for example its centre of gravity and/or one or more of its vertexes) in the above-mentioned plane parallel to the roadway. According to an advantageous variation, the position of each coverage area is preferably expressed in terms of Cartesian coordinates of two opposite vertexes of the rectangle, in particular the one with minimum x and y coordinates and the one with maximum x and y coordinates.

[0056] Each detection event of one or more data by a sensor with the respective timestamp tE can therefore be expressed in the following form:

$$E = \{data;\ tE; x_d, y_d; x_D, y_D\} \quad [5]$$

in which data are the one or more data detected by the sensor, x_d, y_d are the coordinates of the vertex of the rectangle that represents the sensor coverage area with minimum x and y, and x_D, y_D are the coordinates of the vertex of the rectangle that represents the sensor coverage area with maximum x and y.

[0057] For example, with reference to Figure 4(a), at a time tE1 the vehicle VA in transit along the lane 22 crosses the coverage area A12 and, therefore, the sensor S12 detects one or more data relative to said vehicle (for example, its registration number). For greater clarity of the drawings, Figure 4(a) (and also the subsequent Figures 4(b) and 4(c)) show only the sensor coverage areas of the apparatus 1 and the tracking area 40, while the apparatus 1 and its components have been omitted. Substantially at the same time (namely at time tEl), the vehicle VB in transit along the lane 23 crosses the coverage area A13 and, therefore, the sensor S13 detects one or more data relative to said vehicle (for example, its registration number).

[0058] These two detection events can therefore be expressed in the following form:

$$E1^A = \{data\_A; tE1; x_{d12}, y_{d12}; x_{D12}, y_{D12}\} \qquad [6a]$$

$$E1^B = \{data\_B; tE1; x_{d13}, y_{d13}; x_{D13}, y_{D13}\} \qquad [6b]$$

in which data_A are the one or more data detected by the sensor S12 at time tE1, x_{d12}, y_{d12} are the coordinates of the vertex of the coverage area A12 with minimum x and y, x_{D12}, y_{D12} are the coordinates of the vertex of the coverage area A12 with maximum x and y, data_B are the one or more data detected by the sensor S13 at time tEl, x_{d13}, y_{d13} are the coordinates of the vertex of the coverage area A13 with minimum x and y, and x_{D13}, y_{Dl3} are the coordinates of the vertex of the coverage area A13 with maximum x and y.

[0059] As shown in Figure 4(b), at time tE2 subsequent to time tEl, after overtaking the vehicle VB and moving to lane 23, the vehicle VA crosses the coverage area A23 and, therefore, the sensor S23 detects further one or more data relative to said vehicle (for example its speed). This detection event can therefore be expressed in the following form:

$$E2^A = \{data\_A'; tE2; x_{d23}, y_{d23}; x_{D23}, y_{D23}\} \qquad [7]$$

in which data_A' are the one or more data detected by the sensor S23 at time tE2, x_{d23}, y_{d23} are the coordinates of the vertex of the coverage area A23 with minimum x and y, and x_{D23}, y_{D23} are the coordinates of the vertex of the coverage area A23 with maximum x and y.

[0060] As shown in Figure 4(c), at time tE3 subsequent to time tE2, after being overtaken by vehicle VA, vehicle VB also crosses the coverage area A23 and, therefore, the sensor S23 detects further one or more data relative to said vehicle (for example, its speed). This detection event can therefore be expressed in the following form:

$$E2^B = \{data\_B'; tE3; x_{d23}, y_{d23}; x_{D23}, y_{D23}\} \qquad [8]$$

in which data_B' are the one or more data detected by the sensor S23 at time tE3, x_{d23}, y_{d23} are the coordinates of the vertex of the coverage area A23 with minimum x and y, and x_{D23}, y_{D23} are the coordinates of the vertex of the coverage area A23 with maximum x and y.

[0061] Correct correlation of the data detected by the sensors as described above should allow reciprocal correlation of the data data_A and data_A' detected respectively by the sensors S12 and S23 at times tE1 and tE2 as they relate to the same vehicle (namely the vehicle VA) and, analogously, reciprocal correlation of the data data_B and data_B' detected respectively by the sensors S13 and S23 at times tE1 and tE3 since they relate to the same vehicle (namely vehicle VB).

[0062] The procedure for carrying out this correlation according to embodiments of the present invention will be described in detail below, with reference to the flow chart of Figure 5. The procedure described below is preferably performed by the data processing unit 5 of the apparatus 1.

[0063] The data processing unit 5 receives in input the various sequences of tracked positions for the vehicles in transit (preferably, expressed according to the equation [2] shown above) and the detection events of data relative to the vehicles in transit by the sensors of the apparatus 1 (preferably, expressed according to the equation [5] shown above).

[0064] For each detection event E received from one of the sensors of the apparatus 1 (step 500), the data processing unit 5 preferably reads its timestamp tE (step 501).

[0065] Then, amongst the sequences of tracked positions Tj (with j integer index varying between 1 and N, where j=1 indicates the position and initial time of the tracking and j=N indicates the position and final time of the tracking) in input, the data processing unit 5 preferably selects those such that tE is between their tracking start time t1 and their tracking end time tN, namely with $t1 \leq tE \leq tN$ (step 502). The other sequences of tracked positions are preferably ignored.

[0066] Then, for each sequence Tj selected, the data processing unit 5 preferably identifies in the sequence one or more tracked positions which are associated with one or more respective times tj in a range about tE (step 503). In the present description and in the claims, the expression "range about tE" indicates the time interval between tE-T and tE+T (including extremes), where T is the tracking period, namely the time that elapses between times associated with consecutive tracked positions. Therefore, the data processing unit 5 preferably determines a comparison area, based on the tracked position(s) identified in the preceding step 503 (step 504). The comparison area is such as to contain the tracked position(s) identified in the preceding step 503. If several tracked positions associated with respective times tj are identified, the comparison area is preferably the minimum convex area that contains all the identified positions.

[0067] According to an advantageous embodiment of steps 503 and 504, at step 503 the data processing unit 5 identifies, in each sequence Tj selected, the tracked position associated with time tj immediately preceding (or coinciding with) tE and the tracked position associated with time tj+1 immediately subsequent to (or coinciding with) tE, namely $tj \leq tE \leq tj+1$. Then, in the subsequent step 504, the data processing unit 5 preferably determines, as a comparison area for that sequence Tj, the minimum area comprising the two markers that represent the position of the vehicle at time tj and at time tj+1. If the markers have a rectangular shape, said minimum area (also rectangular) can therefore be expressed in the following form:

$$A=\{\min(x_{mj},x_{mj+1}),\min(y_{mj},y_{mj+1});\ \max(x_{Mj},x_{Mj+1}),\max(y_{Mj},y_{Mj+1})\} \quad [9]$$

in which x_{mj}, y_{mj} are the coordinates of the vertex with minimum x and y of the rectangular marker that indicates the position of the vehicle at time tj, x_{Mj}, y_{Mj} are the coordinates of the vertex with maximum x and y of the rectangular marker that indicates the position of the vehicle at time tj, x_{mj+1}, y_{mj+1} are the coordinates of the vertex with minimum x and y of the rectangular marker that indicates the position of the vehicle at time tj+1 and x_{Mj+1}, y_{Mj+1} are the coordinates of the vertex with maximum x and y of the rectangular marker that indicates the position of the vehicle at time tj+1.

[0068] For example, with reference to the detection event $E2^A$ shown in Figure 4(b) described above, the data processing unit 5 considers both the sequences of tracked positions Tj^A and Tj^B relative to the vehicles VA and VB, since the time tE2 of the detection event $E2^A$ is between the tracking start time and the tracking end time of both the sequences (step 502).

[0069] Therefore, in the sequence Tj^A the data processing unit 5 identifies the tracked positions associated with times tj and tj+1, respectively immediately preceding and immediately subsequent to time tE2 (step 503). Figure 6(a) shows the two rectangular markers RAj and RAj+1 that represent these two tracked positions identified in the sequence Tj^A. For greater clarity of the drawings, Figure 6(a) (and also the following Figure 6(b)) shows only the coverage area A23 of the sensor S23 that generated the detection event $E2^A$ considered, while the apparatus 1, its components, the coverage areas of the other sensors and the tracking area 40 have been omitted. Then, the data processing unit 5 preferably determines a comparison area AA as the minimum rectangular area that comprises the two rectangular markers RAj and RAj+1, by applying the above equation [9] (step 504).

[0070] The data processing unit 5 then repeats the same procedure also for the sequence Tj^B, namely it identifies the tracked positions associated with times tj and tj+1, respectively immediately preceding and immediately following time tE2 (step 503). Figure 6(b) shows the two rectangular markers RBj and RBj+1 that represent these two tracked positions identified in the sequence Tj^B. Therefore, the data processing unit 5 preferably determines a comparison area AB as the minimum rectangular area that comprises the two rectangular markers RBj and RBj+1 (step 504), by applying the above equation [9] (step 504).

[0071] Returning to the flow chart of Figure 5, for each of the sequences Tj selected, the data processing unit 5 preferably compares the comparison area with the coverage area of the sensor that generated the detection event E considered (step 505).

[0072] If the intersection of the two areas is empty (namely if the two areas do not have any overlapping), the data processing unit 5 concludes that the detection event E is not correlated with the sequence of tracked positions Tj, namely the data detected do not relate to the vehicle that has followed the sequence of tracked positions Tj (step 506).

[0073] If, on the other hand, the intersection of the two areas is not empty (namely if the two areas are at least partially overlapping), the data processing unit 5 concludes that the detection event E is correlated with the sequence of tracked positions Tj, namely the data detected relate to the vehicle that has followed the sequence of tracked positions Tj (step 507).

[0074] For example, with reference again to Figures 6(a) and 6(b), the intersection of the comparison area AA obtained from the sequence Tj^A with the tracking area A23 of the sensor S23 that generated the tracking event $E2^A$ is not empty, while the intersection of the comparison area AB obtained from the sequence Tj^B with the tracking area A23 is empty. The data processing unit 5 therefore concludes that the event $E2^A$ is correlated with the sequence of tracked positions Tj^A, and not with the sequence of tracked positions Tj^B. In other words, the data processing unit 5 concludes that the data data_A' detected by the sensor S23 at time tE2 relate to the vehicle that has followed the sequence of tracked positions Tj^A, and not to the vehicle that has followed the sequence of tracked positions Tj^B.

[0075] The above procedure is repeated for all the detection events generated by the sensors of the apparatus 1. In this way, each detection event will be correlated with one of the sequences of tracked positions and, therefore, detection events correlated with the same sequence of tracked positions will be correlated with one another.

[0076] For example, with reference to Figures 4(a) and 4(c) described above, by repeating the procedure described above also for the events $E1^A$ and $E1^B$ shown in Figure 4(a) and for the event $E2^B$ shown in Figure 4(c), the data processing unit 5 will determine that the events $E1^A$ and $E1^B$ are correlated respectively with the sequences of tracked positions Tj^A and Tj^B, while the event $E2^B$ is correlated with the sequence of tracked positions Tj^B. The events $E1^A$ and $E2^A$, both correlated with the sequence of tracked positions Tj^A, are therefore correlated with each other and, analogously, the events $E1^B$ and $E2^B$, both correlated with the sequence of tracked positions Tj^B, are therefore correlated with each other. The data processing unit 5 thus concludes that the data data_A detected by the sensor S12 at time tE1 and the data_A' detected by the sensor S23 at time tE2 are relative to the same vehicle (namely the vehicle VA), while the data data_B detected by the sensor S13 at time tE1 and the data_B' detected by the sensor S23 at time tE3 are relative to the same vehicle (namely the vehicle VB).

[0077] Advantageously, the correlation procedure described above has no particular requirements in terms of speed and trajectory of the vehicles VA and VB. This is because the data detected by each sensor of the apparatus 1 (in particular, the detection time and the position of the sensor coverage area) are compared with the actual trajectory of the vehicles VA and VB, namely with the sequence of the various positions of the vehicles VA and VB at the various times during the period of crossing of the tracking area 40. The correlation procedure is therefore able to provide accurate results regardless of the reciprocal distance of the coverage areas and regardless of whether the speed of the vehicles VA and VB is constant or not and whether their trajectory is rectilinear or not.

Claims

1. An apparatus (1) for detecting the transit of a vehicle (VA), said apparatus (1) comprising:

   - a plurality of sensors (S12, S23) having respective coverage areas (A12, A23) and being suitable for providing data relating to vehicles in transit through said respective coverage areas (A12, A23);
   - a tracking device (4) configured to provide information indicative of a sequence of positions (Tj^A) of said vehicle (VA) through a tracking area (40) which includes said respective coverage areas (A12, A23) of said plurality of sensors (S12, S23), each position being associated with the time at which said vehicle (VA) passed through said position; and
   - a data processing unit (5) configured to determine whether one or more data detected by a sensor (S23) of said plurality of sensors (S12, S23) at a detection time (tE2) relate to said vehicle (VA), said determining comprising: identifying in said sequence of positions (Tj^A) at least one position associated with a time (tj) in a range about said detection time (tE2), determining a comparison area (AA) on the basis of said at least one position and, if said determined comparison area (AA) is at least partially overlapping with the coverage area (A23) of said sensor (S23) of said plurality of sensors (S12, S23), determining that said one or more data detected by said sensor (S23) of said plurality of sensors (S12, S23) at said detection time (tE2) relate to said vehicle (VA).

2. The apparatus (1) according to claim 1, wherein said data relating to vehicles in transit include two or more of: registration number, identifier of a radio frequency on-board unit, speed, class, number of axles, weight.

3. The apparatus (1) according to claim 1 or 2, wherein said tracking device (4) is suitable for providing a sequence of images of said tracking area (40), each image of said sequence of images showing said vehicle (VA) in a respective position (Tj^A) of said tracking area (40).

4. The apparatus (1) according to any one of the preceding claims, wherein each of said positions (Tj^A) of said vehicle (VA) through said tracking area (40) is in the form of Cartesian coordinates in a plane substantially parallel to the roadway on which said vehicle (VA) transits.

5. The apparatus (1) according to any one of the preceding claims, wherein said data processing unit (5) is configured to identify in said sequence of positions (Tj^A) at least two positions associated with two respective times (tj , tj + 1) in a range about said detection time (tE2), said comparison area (AA) being determined as minimum convex area that contains said at least two positions.

6. The apparatus (1) according to claim 5, wherein said data processing unit (5) is configured to identify in said sequence of positions (Tj^A) a first position associated with a time immediately preceding or substantially coincident (tj) with said detection time (tE2) and a second position associated with a time immediately subsequent to or substantially coincident (tj + 1) with said detection time (tE2).

7. The apparatus (1) according to any one of the preceding claims, wherein each one of said positions (Tj^A) of said vehicle (VA) through said tracking area (40) is associated with a respective marker (RAj, RAj+1) whose size corresponds to the size of said vehicle (VA).

8. The apparatus (1) according to claims 6 and 7, wherein said first position is associated with a first marker (RAj) whose size corresponds to the size of said vehicle (VA) and said second position is associated with a second marker (Raj+1) whose size corresponds to the size of said vehicle (VA), said comparison area (AA) being determined as the minimum convex area which contains said first marker (RAj) and said second marker (RAj+1).

9. The apparatus according to any one of the preceding claims, wherein said data processing unit (5) is further configured to determine whether one or more further data detected by a further sensor (S12) of said plurality of sensors (S12, S23) at a further detection time (tE1) are correlated with said one or more data, said determining comprising: identifying in said sequence of positions (Tj^A) at least one further position associated with a time (tj) in a range about said further detection time (tE1), determining a further comparison area on the basis of said at least one further position and, if said further determined comparison area is at least partially overlapping with the coverage area (A12) of said further sensor (S12) of said plurality of sensors (S12, S23), determining that said one or more further data detected by said further sensor (S12) of said plurality of sensors (S12, S23) at said further detection time (tE1) are correlated with said one or more data.

10. The apparatus (1) according to claim 9, wherein said coverage area (A23) of said sensor (S23) and said coverage area (A21) of said further sensor (S21) are on two different lanes which can be travelled by said vehicles in transit.

11. The apparatus (1) according to any one of the preceding claims, wherein said apparatus (1) is for a free-flow toll collection system.

12. A method for detecting the transit of a vehicle (VA), said method comprising:

- by means of a plurality of sensors (S12, S23) having respective coverage areas (A12, A23), providing data relating to vehicles in transit through said respective coverage areas (A12, A23);
- by means of a tracking device (4), providing information indicative of a sequence of positions (Tj^A) of said vehicle (VA) through a tracking area (40) which includes said respective coverage areas (A12, A23) of said plurality of sensors (S12, S23), each position being associated with the time at which said vehicle (VA) passed through said position; and
- by means of a data processing unit (5), determining whether one or more data detected by a sensor (S23) of said plurality of sensors (S12, S23) at a detection time (tE2) relate to said vehicle (VA), said determining comprising: identifying in said sequence of positions (Tj^A) at least one position associated with a time (tj) in a range about said detection time (tE2), determining a comparison area (AA) on the basis of said at least one position and, if said determined comparison area (AA) is at least partially overlapping with the coverage area (A23) of said sensor (S23) of said plurality of sensors (S12, S23), determining that said one or more data detected by said sensor (S23) of said plurality of sensors (S12, S23) at said detection time (tE2) relate to said vehicle (VA).

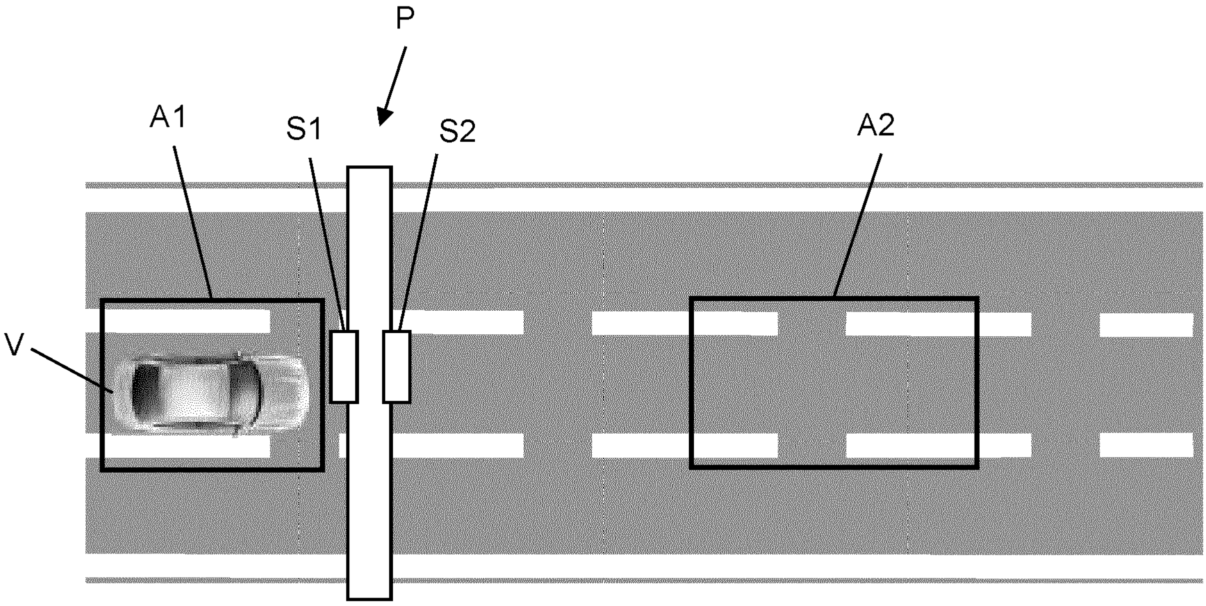

Fig. 1(a) (prior art)

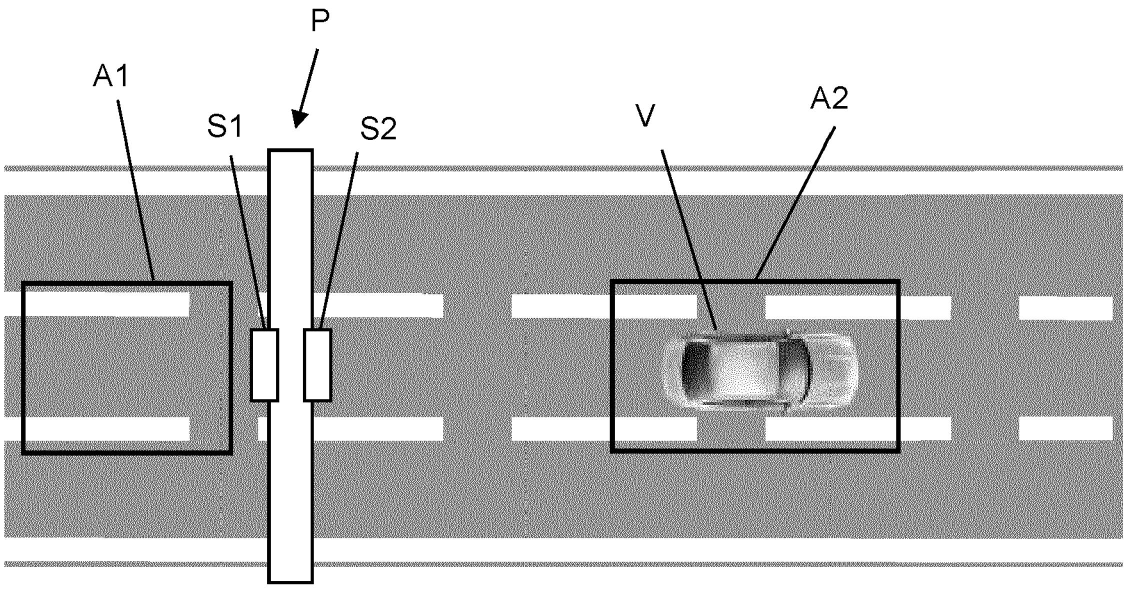

Fig. 1(b) (prior art)

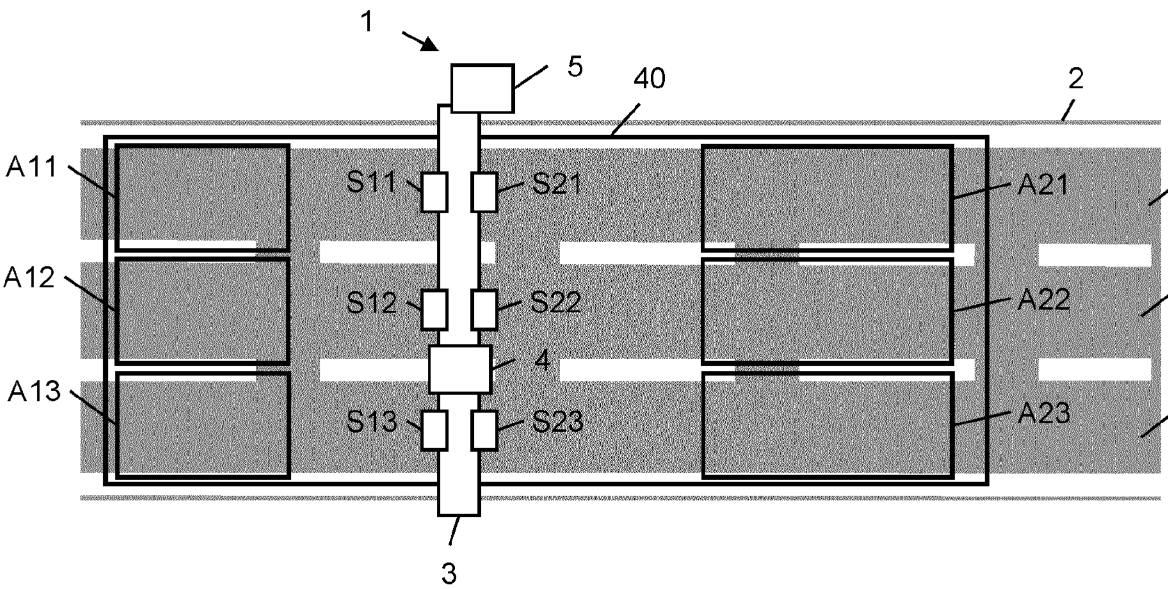

Fig. 2

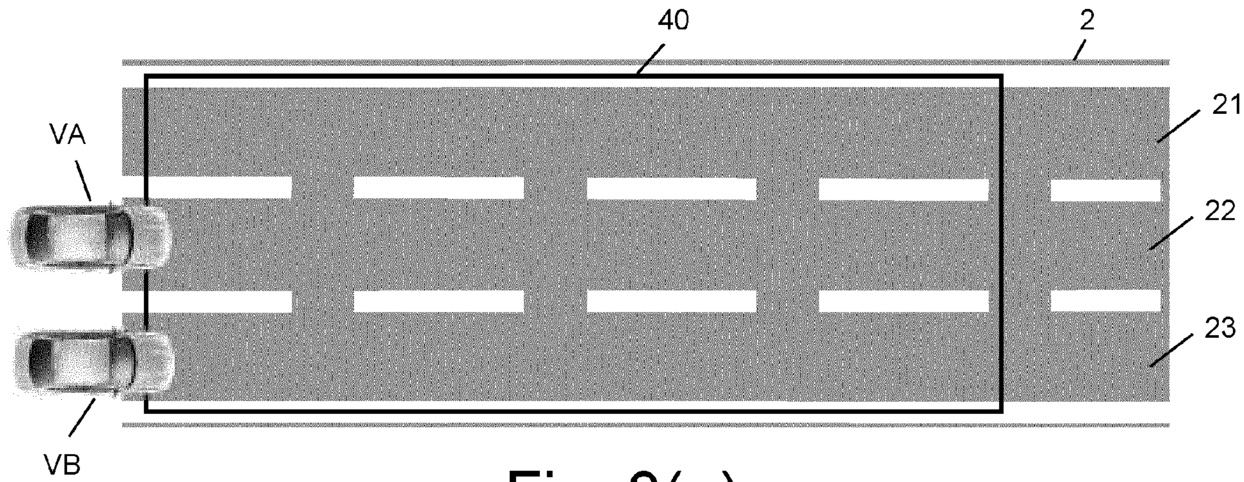

Fig. 3(a)

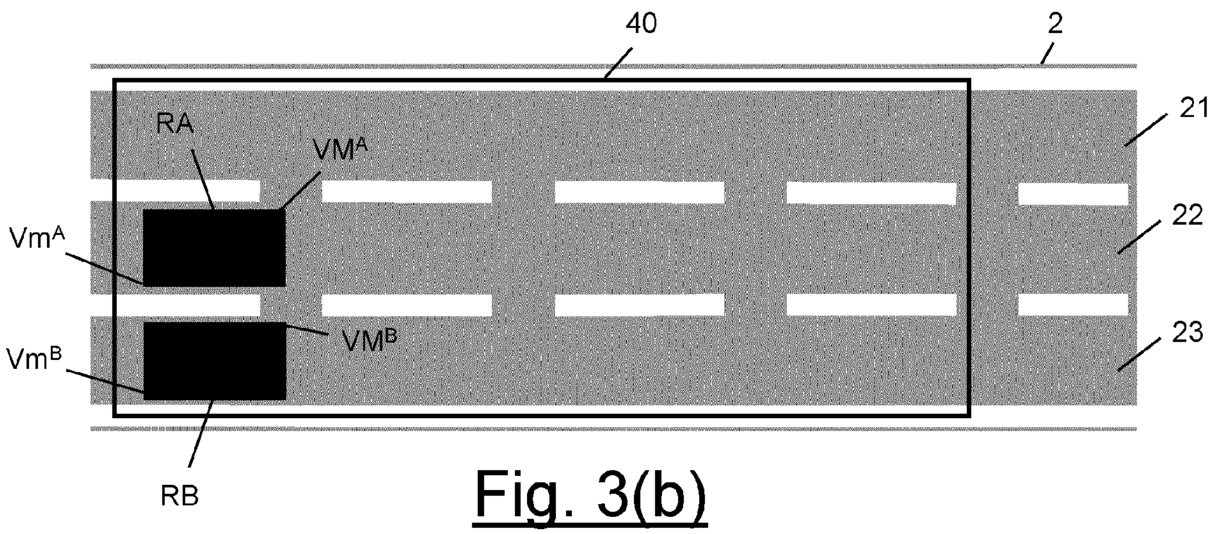

Fig. 3(b)

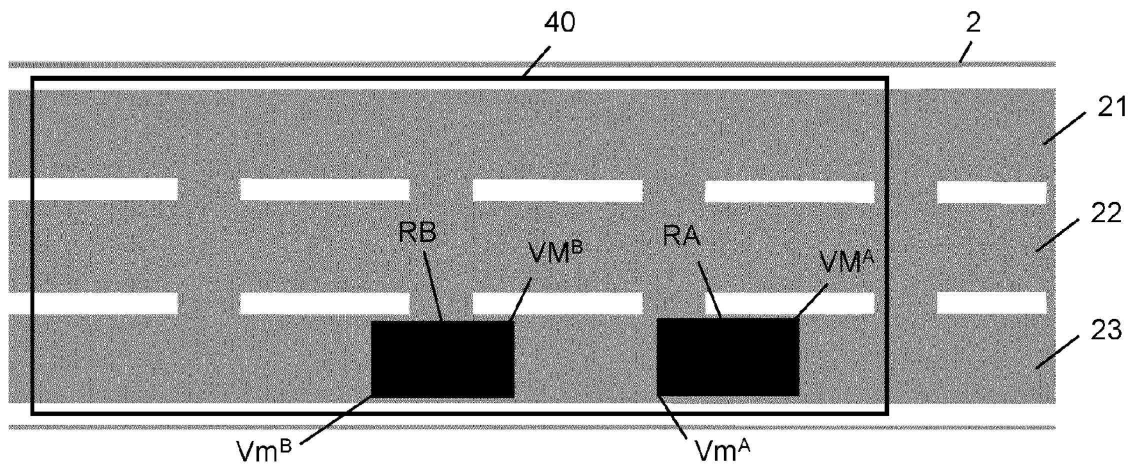

Fig. 3(c)

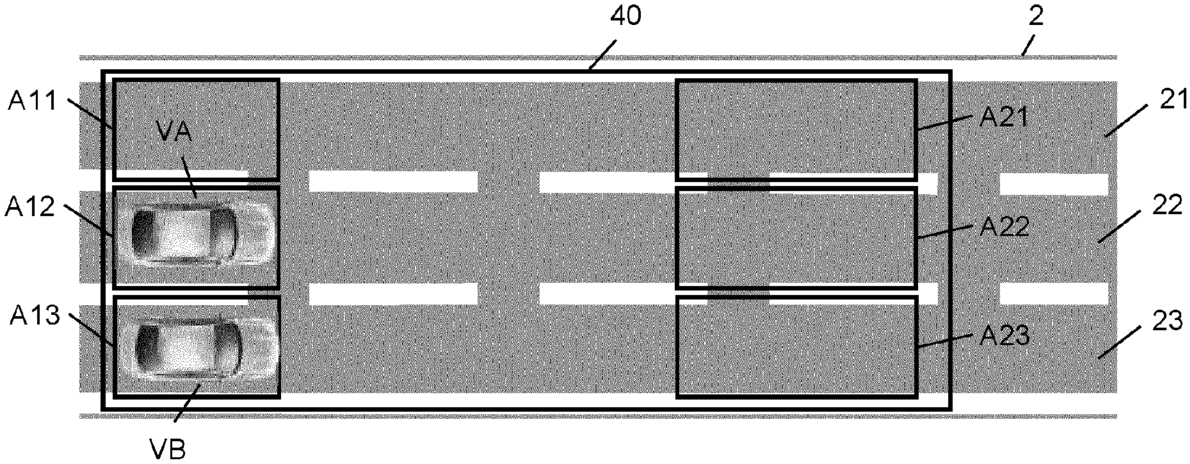

Fig. 4(a)

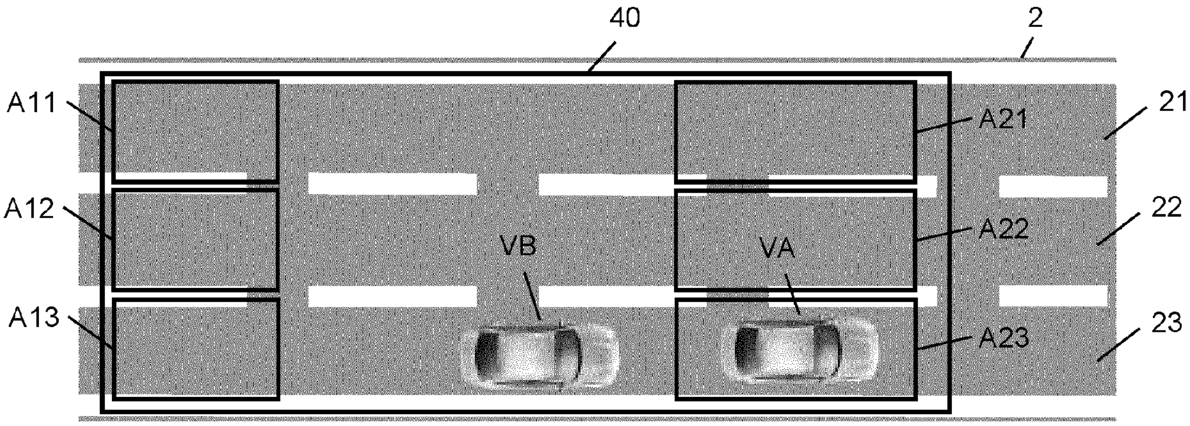

Fig. 4(b)

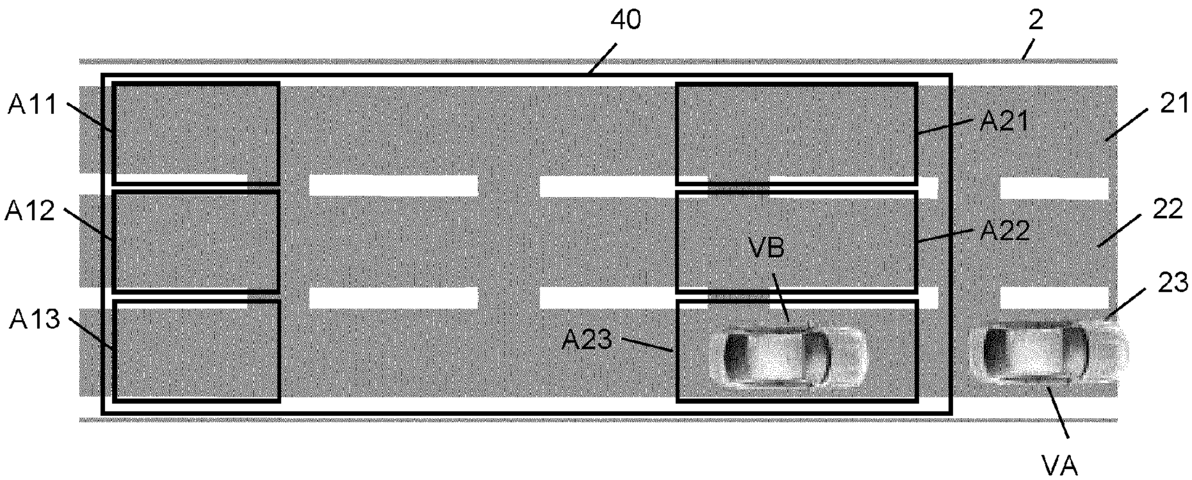

Fig. 4(c)

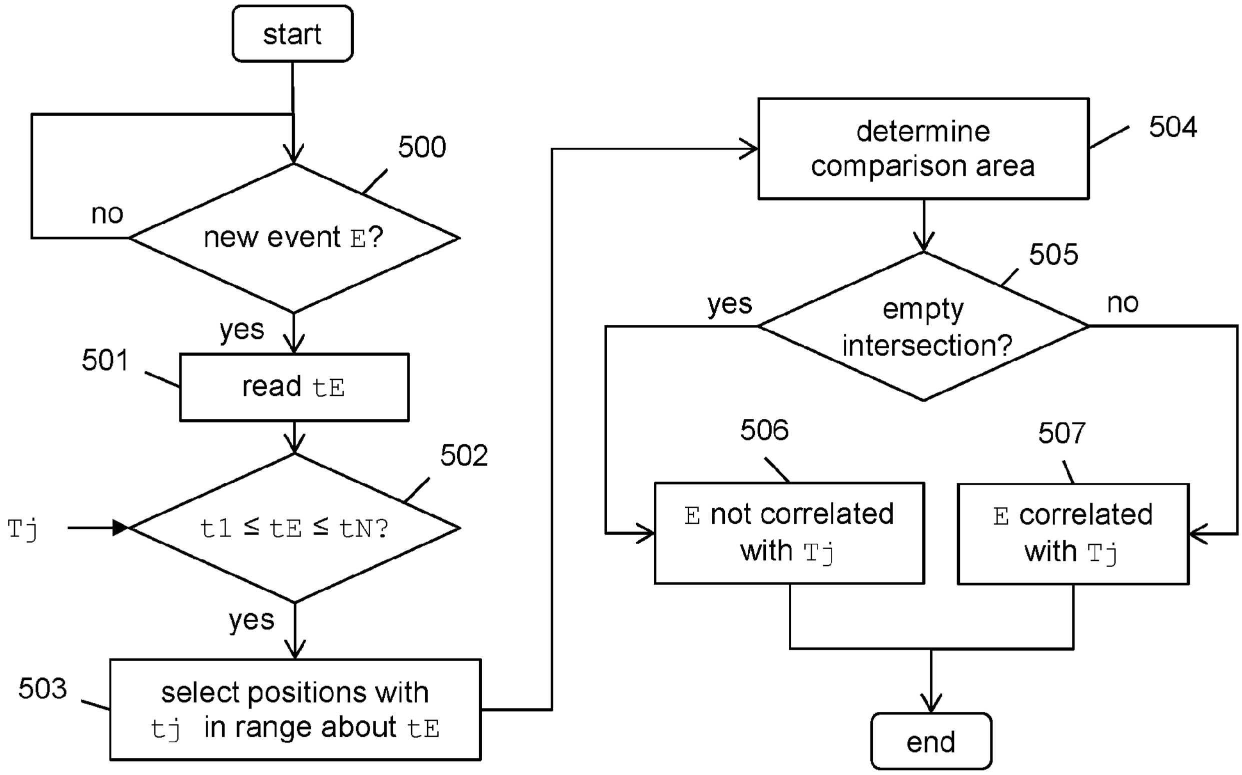
start
500
no
new event E?
yes
501
read tE
502
Tj
t1 ≤ tE ≤ tN?
yes
503
select positions with
tj in range about tE
determine
comparison area
504
505
yes
empty
intersection?
no
506
507
E not correlated
with Tj
E correlated
with Tj
end

Fig. 5

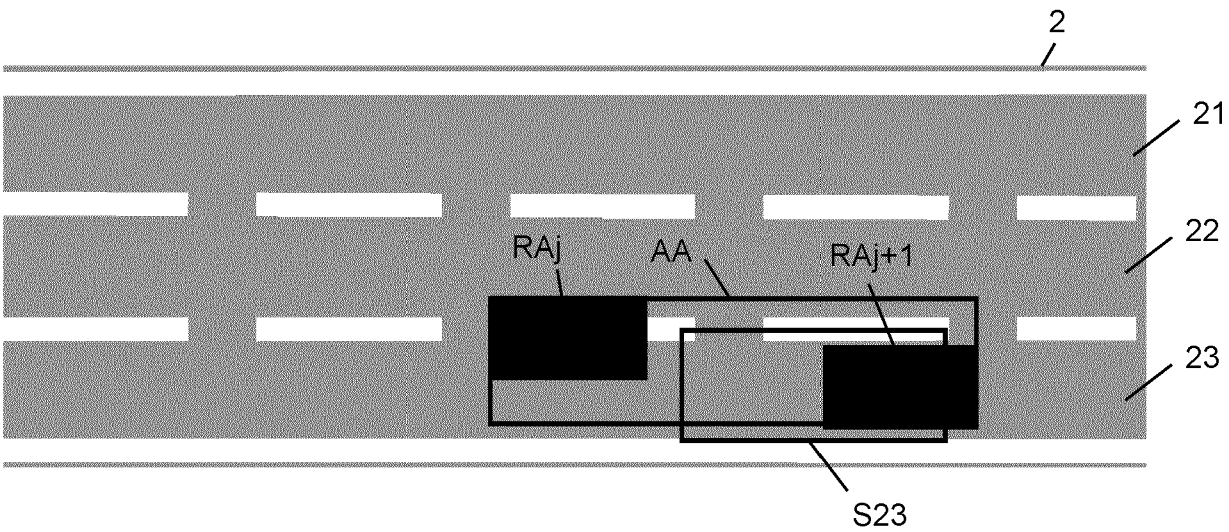

Fig. 6(a)

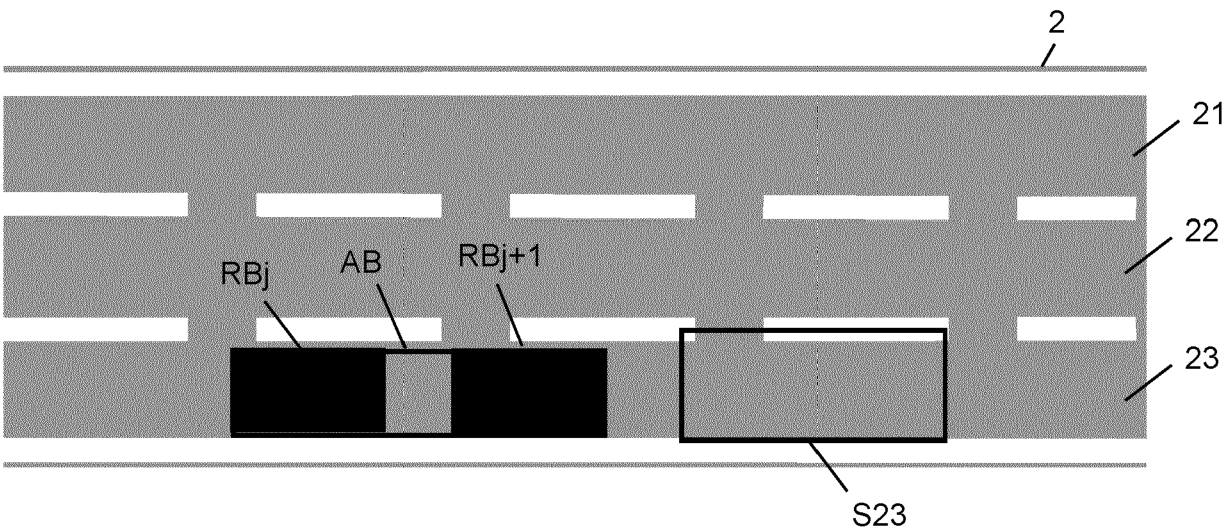

Fig. 6(b)

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EUROPEAN SEARCH REPORT

Application Number
EP 23 15 4279

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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	17 May 2023	Quartier, Frank

CATEGORY OF CITED DOCUMENTS

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17-05-2023

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