

[DESCRIPTION]

[TITLE OF INVENTION]

VEHICLE DETECTION DEVICE, LANE CONTROL SYSTEM, VEHICLE
DETECTION METHOD, AND PROGRAM

5 [Technical Field]

[0001]

The present invention relates to a vehicle detection device for detecting a vehicle traveling in a travel lane using an electronic toll collection system, a lane control system, a vehicle detecting method, and a program.

10 Priority is claimed on Japanese Patent Application No. 2013-220277, filed October 23, 2013, the content of which is incorporated herein by reference.

[Background Art]

[0002]

An electronic toll collection system for automatic toll collection of a toll road
15 (for example, ETC (registered trademark, Electronic Toll Collection System) has attracted attention as an application in Intelligent Transport Systems (ITS). This electronic toll collection system can collect a toll through wireless communication between a roadside device installed in a tollgate and an on-board unit mounted on a vehicle. The roadside device includes a roadside antenna provided corresponding to
20 each travel lane for performing wireless communication with the on-board unit. This roadside antenna performs transmission and reception of information necessary for collection of a toll through wireless communication with an on-board unit of a vehicle traveling in a travel lane including a corresponding communication area.

[0003]

25 When communication is performed between the roadside antenna and the

on-board unit, the roadside antenna is likely to receive radio waves from an on-board unit of a vehicle traveling in a travel lane other than the travel lane including the corresponding communication area, such as another adjacent travel lane.

There is a technology for providing a detector that detects an arrival direction of received radio waves in a roadside device, determines whether the radio waves are radio waves from a travel lane including the corresponding communication area based on the detected arrival direction of the radio waves, and limits communication with an on-board unit originating the radio waves if the radio waves are radio waves from an adjacent travel lane to avoid erroneous communication with an on-board unit that is not a target (see, for example, Patent Literature 1).

Further, there is a technology for installing a radio wave absorption panel in a structure on a road so as to prevent erroneous communication with an on-board unit which is not a target from occurring when radio waves originating from an on-board unit of a vehicle traveling in a travel lane other than the travel lane including the corresponding communication area are reflected by, for example, the structure on a road such as a ceiling of the tollgate and received by the roadside antenna (see, for example, Patent Literature 2).

[Citation List]

[Patent Literature]

[0004]

[Patent Literature 1] Japanese Unexamined Patent Application, First Publication No. 2012-247958

[Patent Literature 2] Japanese Unexamined Patent Application, First Publication No. 2003-119726

[Summary of Invention]

[Technical Problem]

[0005]

In the technology of Patent Literature 1, for example, if radio waves originating from an on-board unit of a vehicle traveling in a travel lane adjacent as described above

5 other than a travel lane including a communication area with a roadside antenna are reflected by structures on the road such as a ceiling or side walls of the travel lane, erroneous communication with an on-board unit which is not a target may occur.

Specifically, radio waves originating from an on-board unit of a vehicle traveling in a travel lane other than the travel lane including a corresponding communication area may

10 be reflected by the structures on the road, and radio waves last reflected by the travel lane including the corresponding communication area may be incident on the roadside

antenna. In this case, by detecting an arrival direction of the radio waves using a direction detector on the roadside device side, it is determined whether the radio waves are radio waves from the travel lane including the corresponding communication area.

15 Accordingly, the radio waves last reflected by the travel lane including the corresponding communication area are likely to be erroneously detected as radio waves originating from the on-board unit traveling in the travel lane including the corresponding communication area.

Further, installing the radio wave absorption panels for various structures on a road using the technology of Patent Literature 2 is considered, but enormous cost is required to install the radio wave absorption panels for all of the structures on the road which is a target, and the installation is not realistic.

[0006]

The present invention provides a vehicle detection device, a lane control system, 25 a vehicle detection method, and a program in which, when a vehicle traveling in a travel

lane including a communication area of a corresponding roadside antenna is detected, it is possible to prevent a vehicle having an on-board unit mounted thereon located in a position other than the travel lane including the communication area from being erroneously detected by the antenna.

5 [Solution to Problem]

[0007]

According to a first aspect of the present invention, a vehicle detection device is a vehicle detection device that is provided correlating with a target travel lane among a plurality of travel lanes, and detects a vehicle traveling in the target travel lane among the
10 plurality of travel lanes based on radio waves originating from an on-board unit mounted on a vehicle. The vehicle detection device includes: a position calculation unit that regards radio waves detected by a direction detection unit that detects an arrival direction of the radio waves received from the on-board unit as radio waves originating from the target travel lane based on the arrival direction of radio waves detected by the direction
15 detection unit, and obtains an estimated originating position in the target travel lane; a movement direction detection unit that detects a movement direction of a plurality of estimated originating positions obtained by the position calculation unit based on the estimated originating positions; and a travel lane determination unit that determines whether the vehicle originating the radio waves is a vehicle traveling in the target travel
20 lane based on the movement direction detected by the movement direction detection unit.

[0008]

According to a second aspect of the present invention, in the vehicle detection device of the first aspect, the travel lane determination unit determines that the vehicle travels in the target travel lane when the movement direction detected by the movement
25 direction detection unit is a direction that is along a travel direction in the target travel

lane.

[0009]

According to a third aspect of the present invention, in the vehicle detection device of the first or second aspect, the vehicle detection device further includes a position determination unit that is provided corresponding to any one target travel lane among the plurality of travel lanes, and determines whether the position obtained by the position calculation unit is in a predetermined range in the target travel lane, and the movement direction detection unit detects a movement direction of an estimated originating position based on the estimated originating position determined to be in the predetermined range by the position determination unit.

[0010]

According to a fourth aspect of the present invention, in the vehicle detection device of any one of the first to third aspects, the vehicle detection device further includes a communication control unit that limits communication with an on-board unit mounted on a vehicle determined not to travel in the target travel lane by the travel lane determination unit.

[0011]

According to a fifth aspect of the present invention, in the vehicle detection device of any one of the first to fourth aspects, the movement direction detection unit detects a movement direction of the estimated originating position based on at least three or more estimated originating positions among the plurality of estimated originating positions obtained by the position calculation unit.

[0012]

According to a sixth aspect of the present invention, a vehicle detecting device is a vehicle detection device that is provided corresponding to a target travel lane among a

plurality of travel lanes, and detects a vehicle traveling in the target travel lane among the plurality of travel lanes based on radio waves originating from an on-board unit mounted on a vehicle. The vehicle detecting device includes: a position calculation unit that regards radio waves detected by a direction detection unit that detects an arrival direction of the radio waves received from the on-board unit as radio waves originating from in the target travel lane based on the arrival direction of radio waves detected by the direction detection unit, and obtains an estimated originating position in the target travel lane; and a movement direction detection unit that detects a movement direction of the estimated originating positions based on a plurality of estimated originating positions obtained by the position calculation unit.

[0013]

According to a seventh aspect of the present invention, a lane control system includes: the vehicle detection device according to any one of the first to fifth aspects; and a lane control device that is communicably connected to the vehicle detection device and executes predetermined information processing based on information included in radio waves originating from an on-board unit determined to travel in a target travel lane by the travel lane determination unit.

[0014]

According to an eighth aspect of the present invention, a vehicle detection method is a vehicle detection method of detecting a vehicle traveling in a target travel lane among a plurality of travel lanes based on radio waves originating from an on-board unit mounted on the vehicle. The vehicle detection method includes: a position calculation step of regarding radio waves received from the on-board unit as radio waves originating from in the target travel lane based on an arrival direction of the radio waves, and obtaining an estimated originating position in the target travel lane; a movement

direction detection step of detecting a movement direction of the estimated originating positions based on a plurality of estimated originating positions obtained in the position calculation step; and a travel lane determination step of determining whether the vehicle originating the radio waves is a vehicle traveling in the target travel lane based on the movement direction detected in the movement direction detection step.

[0015]

According to a ninth aspect of the present invention, a program causes a computer operating a vehicle detection device that detects a vehicle traveling in a target travel lane among a plurality of travel lanes based on radio waves originating from an on-board unit mounted on the vehicle to function as: a position calculation means that regards radio waves detected by a direction detection unit that detects an arrival direction of the radio waves received from the on-board unit as radio waves originating from in the target travel lane based on the arrival direction of radio waves detected by the direction detection unit, and obtains an estimated originating position in the target travel lane; a movement direction detection means that detects a movement direction of a plurality of estimated originating positions obtained by the position calculation means based on the estimated originating positions; and a travel lane determination means that determines whether the vehicle originating the radio waves is a vehicle traveling in the target travel lane based on the movement direction detected by the movement direction detection means.

[Advantageous Effects of Invention]

[0016]

According to the vehicle detection device, the lane control system, the vehicle detection method, and the program described above, when a vehicle traveling in a travel lane including a communication area of a corresponding roadside antenna is detected, it

is possible to prevent a vehicle having an on-board unit mounted thereon located in a position other than the travel lane including the communication area from being erroneously detected by the antenna.

[Brief Description of Drawings]

5 [0017]

FIG. 1 is a schematic diagram illustrating an example of a lane control system available to a vehicle detection device according to an embodiment of the present invention.

FIG. 2 is a schematic diagram illustrating an example of a configuration of a lane
10 control system available to a vehicle detection device according to an embodiment of the present invention.

FIG. 3 is a block diagram illustrating an example of a configuration of a vehicle detection device according to an embodiment of the present invention.

FIG. 4 is a diagram illustrating a relationship among a horizontal angle θ_H , a
15 vertical angle θ_V , and an estimated originating position.

FIG. 5 is a flowchart illustrating an example of a vehicle detection method according to an embodiment of the present invention.

FIG. 6 is a diagram illustrating an example of an arrangement of antenna elements included in an AOA antenna.

20 FIG. 7 is a block diagram illustrating an example of a configuration of the AOA antenna.

FIG. 8 is a diagram illustrating the horizontal angle θ_H and the vertical angle θ_V .

FIG. 9 is a diagram illustrating an example of a movement path of estimated originating positions.

25 FIG. 10 is a diagram illustrating another example of the movement path of the

estimated originating positions.

[Description of Embodiments]

[0018]

Hereinafter, an example of a lane control system available to a vehicle detection
5 device according to an embodiment of the present invention will be described with
reference to the accompanying drawings. FIG. 1 is a schematic diagram illustrating an
example of a lane control system available to a vehicle detection device according to an
embodiment of the present invention.

As illustrated in FIG. 1, a plurality of travel lanes 101, 102, 103, ... are provided
10 side by side at a tollgate. In the illustrated example, the travel lanes 101, 102, and 103
are travel lanes that are toll collection targets, and toll collection is performed at each
travel lane. That is, on-board units of vehicles that travel on the travel lanes 101, 102
and 103 communicate with AOA antennas and roadside antennas provided at the
respective travel lanes, such that a toll is collected. In the illustrated example, an AOA
15 antenna 104 and a roadside antenna 105 corresponding to the travel lane 101, and an
AOA antenna 1042 and a roadside antenna 1052 corresponding to the travel lane 102 are
provided in a gantry 110. A vehicle 201 travels in the travel lane 101, a vehicle 202
travels in the travel lane 102, and a vehicle 203 travels in the travel lane 103. On-board
units 301, 302, and 303 are respectively mounted on the vehicles 201, 202, and 203.

20 [0019]

In this embodiment, a roadside device includes the gantry 110, the AOA antenna
104, the roadside antenna 105, a vehicle detection device 106 (see FIG. 2), and a relay
device 107 (see FIG. 2). In this embodiment, the roadside device is provided to
correspond to the travel lane, the gantry 110, the AOA antenna 104, the roadside antenna
25 105, the vehicle detection device 106 (see FIG. 2), and the relay device 107 (see FIG. 2)

constitute the roadside device corresponding to the travel lane 101. In the travel lane 102, although all configurations are not illustrated, a roadside device including the AOA antenna 1042, the roadside antenna 1052, a vehicle detection device, and a relay device mounted on the gantry 110 is provided. The gantry 110 has a configuration shared by
5 the roadside devices of the travel lanes 101 and 102.

In the illustrated example, the gantry 110 is provided to cross the travel lanes 101 and 102, and the angle of arrival (AOA) antennas 104 and 1042 (direction detection units) and the roadside antennas 105 and 1052 are attached to the gantry 110. Further, the AOA antenna 104 and the roadside antenna 105 correspond to the travel lane 101 and
10 are installed at a central portion in a width direction above the travel lane 101, and the AOA antenna 1042 and the roadside antenna 1052 correspond to the travel lane 102 and are installed at a central portion in a width direction above the travel lane 102.

Further, in the example of FIG. 1, the vehicle detection device 106 (see FIG. 2) and the relay device 107 (see FIG. 2) are mounted in an installation box in which the
15 AOA antenna 104 or the roadside antenna 105 is accommodated when the AOA antenna 104 or the roadside antenna 105 is provided in the gantry 110. The vehicle detection device 106 is electrically connected to the AOA antenna 104 and the roadside antenna 105 and receives an output signal based on radio waves received by the AOA antenna 104 and the roadside antenna 105 from the AOA antenna 104 and the roadside antenna
20 105. The relay device 107 is connected to the vehicle detection device 106.

[0020]

A lane control device 108 that communicates with the vehicle detection device 106 via the relay device 107 (see FIG. 2) is provided in a communication tower (not shown). Further, the lane control device 108 (see FIG. 2) is connected to a central
25 processing device 109, which is connected to a plurality of lane control devices and is

capable of information processing such as a billing process with the on-board unit of the vehicle traveling in the travel lane including an area of communication with the roadside antenna 105 based on information from the plurality of lane control devices.

[0021]

5 An area in which establishment of communication between the vehicle detection device 106 and, for example, the on-board unit 301 is permitted (hereinafter referred to as a communication area) is predetermined in the travel lane 101 in advance. In other words, an outer edge of the communication area is a boundary line that limits the establishment of communication between the vehicle detection device 106 and, for
10 example, the on-board unit 301. Accordingly, even when the vehicle detection device 106 receives radio waves from the on-board unit present in an area outside the communication area, the establishment of communication with the on-board unit is limited. In the illustrated example, the communication area is in the associated travel lane 101 and in a range of 4 (m) in a travel direction and an opposite direction of the
15 travel lane from directly under the roadside antenna 105.

[0022]

In the example of FIG. 1, the vehicle 201 (the on-board unit 301) is illustrated to be located in the communication area. Therefore, in a state illustrated in FIG. 2, the vehicle detection device 106 can establish communication with the on-board unit 301
20 mounted on the vehicle 201 via the roadside antenna 105. Further, the lane control device 108 (or a central processing device 109) can perform the billing process with respect to the on-board unit 301 with which the communication has been established.

[0023]

Meanwhile, the vehicle 202 travels behind the vehicle 201 in the travel lane 102.
25 However, in this state, it is assumed that radio waves originating from the on-board unit

302 are reflected by, for example, the vehicle 201 located in the communication area, and then are incident on the AOA antenna 104, as illustrated in FIG. 1. In this case, the vehicle detection device 106 detects that the radio waves originating from the on-board unit 302 originate from a reflection position of the radio waves reflected by the vehicle 201 (that is, a position at which the vehicle 201 travels) since the vehicle detection device 106 obtains a position of the on-board unit based on an arrival direction of the radio waves detected by the AOA antenna 104. Accordingly, the vehicle detection device 106 is likely to erroneously detect that the reflection position at which the vehicle 201 reflects the radio waves is a position at which the on-board unit 302 originates the radio waves.

In this case, a case in which the on-board unit 302 of the vehicle 202 that does not travel on the travel lane 101 establishes communication with the roadside antenna 105 of the travel lane 101 may occur. In this case, since the on-board unit 302 also establishes communication with the roadside antenna 1052 provided in the travel lane 102, a duplicate toll is likely to be charged.

[0024]

Further, the vehicle 203 travels in the travel lane 103 that is an adjacent lane in which the roadside antennas 105 and 1052 are not installed, and is a vehicle that is not originally a target of the communication with the vehicle detection device 106.

However, in this state, as illustrated in FIG. 1, radio waves originating from the on-board unit 303 are reflected by the vehicle 202, and then are incident on the AOA antenna 1042.

In this case, a vehicle detection device (not shown) corresponding to the travel lane 102 detects that the radio waves originating from the on-board unit 303 originate from a reflection position of the radio waves reflected by the vehicle 202 (that is, a position at which the vehicle 202 travels) since the vehicle detection device obtains a position of the on-board unit based on an arrival direction of the radio waves detected by the AOA

antenna 1042. Accordingly, the vehicle detection device is likely to erroneously detect that the reflection position at which the vehicle 202 reflects the radio waves is a position at which the on-board unit 303 originates the radio waves. In this case, a case in which the on-board unit 303 of the vehicle 203 that does not travel on the travel lane 102

5 establishes communication with the roadside antenna 1052 of the travel lane 102 may occur.

[0025]

Further, the radio waves emitted from the on-board units 302 and 303 may be reflected by, for example, ceilings, road surfaces, or roadside wall surfaces of the travel lanes 101, 102, and 103, reflected by a road surface in the communication area of the travel lane 101, and then be incident on the AOA antenna 104. In such a case, since the vehicle detection device 106 obtains the position of the on-board unit based on the arrival direction of the radio waves detected by the AOA antenna 104, the vehicle detection device 106 detects that the radio waves originating from the on-board units 302 and 303 originate from a reflection position of the radio waves reflected by the road surface of the travel lane 101 (that is, a position in the communication area of the travel lane 101).

Accordingly, the vehicle detection device 106 is likely to erroneously detect that the reflection position at which the road surface in the communication area of the travel lane 101 reflects the radio waves is a position at which the on-board units 302 and 303

20 originate radio waves.

In this case, a case in which the on-board units 302 and 303 of the vehicles 202 and 203 that do not travel on the travel lane 101 establish the communication with the roadside antenna 105 of the travel lane 101 may occur.

[0026]

25 The vehicle detection device according to the present invention has the

following configuration as one aspect of solving the above problem.

FIG. 2 is a schematic diagram illustrating an example of a configuration of a lane control system according to this embodiment.

As illustrated in FIG. 2, the lane control system according to this embodiment includes the AOA antenna 104, the roadside antenna 105, the vehicle detection device 106, the relay device 107, the lane control device 108, and the central processing device 109. These configurations correspond to the travel lane 101. The lane control system may include the AOA antenna 1042, the roadside antenna 1052, a vehicle detection device, a relay device, and a lane control device corresponding to the other travel lane 102. Further, the vehicle detection device 106, the relay device 107, and the lane control device 108 may be configurations corresponding to both of the travel lanes 101 and 102.

[0027]

This vehicle detection device 106 is provided, for example, to correspond to a target travel lane among a plurality of travel lanes in which a vehicle travels, and detects the vehicle traveling in the travel lane based on the radio waves originating from the on-board unit mounted on the vehicle. In this embodiment, an example in which the vehicle detection device 106 detects a vehicle traveling in the travel lane 101 that is one target travel lane in which the communication area of the roadside antenna 105 has been predetermined on a road surface among the plurality of travel lanes will be described, but the embodiment of the present invention is not limited thereto. For example, a configuration in which the vehicle detection device 106 is associated with a plurality of travel lanes 101 and 102 and detects a vehicle traveling in the plurality of travel lanes 101 and 102 may be adopted.

[0028]

The AOA antenna 104 is a direction detection unit that detects an arrival direction of received radio waves. In this embodiment, the AOA antenna 104 calculates an angle at which the radio waves originating from the on-board unit are incident on a light reception surface (hereinafter referred to as a radio wave arrival angle) based on a phase difference between the radio waves received from the on-board unit. In this embodiment, the AOA antenna 104 calculates a horizontal angle θ_H that is the radio wave arrival angle on a horizontal plane and a vertical angle θ_V that is the radio wave arrival angle on a vertical plane. The AOA antenna 104 outputs information indicating the horizontal angle θ_H and the vertical angle θ_V (hereinafter referred to as radio wave arrival angle information) calculated as information indicating the arrival direction of the received radio waves to the vehicle detection device 106.

This AOA antenna 104 includes a plurality of antenna elements so that the AOA antenna 104 can perform wireless communication with the on-board unit mounted on the vehicle and perform measurement of the radio wave arrival angle so as to detect an estimated originating position of the on-board unit. As this AOA antenna 104, for example, a microstrip array antenna having a configuration in which microstrip antenna elements are arranged in an array form may be used. This microstrip array antenna can form any directivity relatively easily by manipulating an amplitude and a phase of a radio wave signal incident on each array antenna element.

[0029]

The roadside antenna 105 performs dedicated short range communications (DSRC) with the on-board unit, acquires on-board unit data including, for example, an on-board unit ID or vehicle type information based on a radio wave signal transmitted from the on-board unit, and outputs the on-board unit data to the vehicle detection device 106. The on-board unit ID is identification information for identifying each on-board

unit. The vehicle type information includes, for example, a type of vehicle (small car, midsize car, large car, ...) or information indicating whether there is a toll discount target.

[0030]

The vehicle detection device 106 originates radio waves including transmission data for toll collection from the roadside antenna 105, and detects (demodulates) the radio waves from the on-board unit, which is received by the roadside antenna 105, to acquire on-board unit data (for example, on-board unit ID or vehicle type information) for toll collection included in the same radio waves. Further, the vehicle detection device 106 executes a vehicle detection process of detecting a vehicle in a target travel lane. Details of the vehicle detection process will be described below with reference to FIG. 3.

[0031]

The relay device 107 executes a communication process between the vehicle detection device 106 and the lane control device 108 and, for example, connects the vehicle detection device 106 and the lane control device 108 through optical communication.

[0032]

The lane control device 108 receives information from the vehicle detection device 106 via the relay device 107, and performs a process for toll collection, such as a billing process for a toll based on the on-board unit data received from the on-board unit with which the communication has been established.

Further, the lane control device 108 associates information indicating that the billing process has been executed, the on-board unit data, position information indicating the estimated originating positions detected by the vehicle detection device 106, the information indicating the horizontal angle θ_H and the vertical angle θ_V , and the

information indicating the arrival time of the radio waves with the on-board unit ID of the on-board unit that has performed the billing process or the like, and stores the information in its storage unit.

Further, the lane control device 108 sets a threshold value of the radio wave arrival angle indicating the communication area, and transmits the set threshold value information of the radio wave arrival angle to the vehicle detection device 106. This lane control device 108, for example, may receive information indicating a height from the road surface at which the AOA antenna 104 has been installed, an average height of the on-board unit, a width of the relevant travel lane, a width of an island, or the like, and calculate and set the threshold value of the radio wave arrival angle indicating the communication area. As the height of the on-board unit, an average height determined for each vehicle type in advance based on the vehicle type information received from the roadside antenna 105 as described below may be used.

While an example in which the billing process is executed by the lane control device 108 will be described in this embodiment, this embodiment is not limited thereto, and the billing process may be executed by the central processing device 109 that is connected to a plurality of lane control devices and generally controls the plurality of lane control devices.

[0033]

Next, an example of a configuration of the vehicle detection device 106 will be described with reference to FIG. 3. FIG 3 is a block diagram illustrating an example of a configuration of the vehicle detection device 106 according to this embodiment.

As illustrated in FIG. 3, the vehicle detection device 106 includes an association unit 160, a position calculation unit 161, a position determination unit 162, a movement direction detection unit 163, a travel lane determination unit 164, a communication

control unit 165, a storage unit 166, and a received data analysis unit 167, and executes a vehicle detection process.

The association unit 160 associates the radio wave arrival angle information and the on-board unit data that are based on the same radio waves with each other based on time information indicating a time at which the radio waves are incident on the AOA antenna 104 and time information indicating a time at which the radio waves are incident on the roadside antenna 105, and stores the radio wave arrival angle information and the on-board unit data in the storage unit 166. The time at which the radio waves are incident can be measured by a timer unit provided in the AOA antenna 104 or the roadside antenna 105. Further, if a time at which the radio wave arrival angle information and the on-board unit data are input to the vehicle detection device 106 is in an error range, the association unit 160 may determine that the radio wave arrival angle information and the on-board unit data are based on the same radio waves. Further, a sequential number indicating an order of emission is included as the on-board unit data in the radio waves originating from the on-board unit. Accordingly, the association unit 160 can identify the on-board unit data input from the roadside antenna 105 for each sequential number.

[0034]

The position calculation unit 161 regards the radio waves detected by the AOA antenna 104 as radio waves originating from the corresponding travel lane 101 based on the arrival direction of the radio waves detected by the AOA antenna 104, and obtains an estimated originating position on the corresponding travel lane 101. In this embodiment, the position calculation unit 161 obtains the estimated originating position based on the radio wave arrival angle information output from the AOA antenna 104, and outputs position information indicating the obtained estimated originating position to the position

determination unit 162 and the movement direction detection unit 163.

[0035]

Now, an example of the horizontal angle θ_H and the vertical angle θ_V according to this embodiment will be described with reference to FIG. 4. FIG. 4 is a diagram illustrating a relationship among the horizontal angle θ_H , the vertical angle θ_V , and the estimated originating position.

As illustrated in FIG. 4, the AOA antenna 104 is located in a reference position. In the illustrated example, the position of the AOA antenna 104 is determined as an origin (the reference position) of an XYZ coordinate system.

In the XYZ coordinate system, an X-axis is set in a direction parallel to a travel direction of the travel lane, in which a direction opposite to the travel direction from the reference position is a positive direction. Further, a Y-axis is set in a direction perpendicular to the travel direction of the travel lane. Further, a Z-axis is set in a vertical direction, in which a downward direction from the reference position is a positive direction. In this embodiment, the vertical angle θ_V is set to an angle with respect to the Z-axis as a reference line, in which a direction directed in the direction opposite to the travel direction within a vertical plane is a positive vertical angle. Further, in this embodiment, the horizontal angle θ_H is set to an angle with respect to the X-axis as a reference line, in which a direction directed to one side in a width direction of the travel lane including the communication area in a horizontal plane is a positive horizontal angle.

[0036]

The AOA antenna 104 detects the arrival direction of the radio waves by obtaining the vertical angle θ_V and the horizontal angle θ_H of the detected radio waves.

The arrival direction of the radio waves is not limited thereto. For example, the arrival direction may be expressed by other angular components rather than the vertical angle θ_v and the horizontal angle θ_H as angles. Further, the arrival direction may be expressed by, for example, three coordinates (XYZ coordinate values) as well as the angle components.

5 The position calculation unit 161 obtains a point P_i in a plane set on the target travel lane indicated by the arrival direction expressed by the horizontal angle θ_H and the vertical angle θ_v , and sets the point as the estimated originating position. Since the on-board unit is mounted inside the vehicle, it is preferable for the point P_i in a plane at the same height as the height of the on-board unit in a direction expressed by the

10 horizontal angle θ_H and the vertical angle θ_v , rather than a position P_0 on a road surface of the travel lane present in a direction expressed by the horizontal angle θ_H and the vertical angle θ_v , to be set as the estimated originating position, as illustrated in FIG. 4. This position calculation unit 161 may use an average height of the on-board unit as a default value, or may calculate the same estimated originating position point P_i as the

15 height of the on-board unit according to the vehicle type using information indicating the height of the on-board unit determined for each vehicle type based on the vehicle type information received by the roadside antenna 105.

[0037]

 The position determination unit 162 executes a vehicle position determination to

20 determine whether the estimated originating position of the on-board unit is in the communication area based on the position information obtained by the position calculation unit 161 or the horizontal angle θ_H and the vertical angle θ_v from the AOA antenna 104. This position determination unit 162 outputs a result of the determination to the travel lane determination unit 164.

For example, a threshold value of the radio wave arrival angle indicating the communication area is stored in the storage unit 166. This threshold value of the radio wave arrival angle is defined by the horizontal angle θ_H and the vertical angle θ_V .

Further, the threshold value of the radio wave arrival angle is set to correspond
 5 to each of the horizontal angle θ_H and the vertical angle θ_V . If the horizontal angle θ_H and the vertical angle θ_V exceed the threshold value of the radio wave arrival angle, the position determination unit 162 determines that the estimated originating position of the on-board unit is outside the range of the communication area. More specifically, the threshold value of the radio wave arrival angle is an angle indicating a position of an
 10 outer edge of the communication area, which is a threshold value expressed by the horizontal angle θ_H and the vertical angle θ_V . That is, the threshold value of the radio wave arrival angle is a threshold value for determining whether the estimated originating position is outside the communication area in a case in which the horizontal angle θ_H and the vertical angle θ_V detected by the AOA antenna 104 is converted into the estimated
 15 originating position.

Position information corresponding to the position of the outer edge of the communication area, such as a threshold value of the position obtained by the position calculation unit 161, may be stored in the storage unit 166. In this case, if the estimated originating position calculated by the position calculation unit 161 exceeds the threshold
 20 value, that is, if the estimated originating position obtained by the position calculation unit 161 is outside the communication area, the position determination unit 162 determines that the estimated originating position of the on-board unit is outside the range of the communication area.

[0038]

The movement direction detection unit 163 calculates the movement direction of the estimated originating positions of the on-board unit based on the position information calculated by the position calculation unit 161, which is a plurality of position information indicating the estimated originating positions of the same on-board unit, and
5 outputs movement direction information indicating the calculated movement direction to the travel lane determination unit 164.

This movement direction detection unit 163 detects a direction indicated by a line segment connecting a plurality of estimated originating positions of the same on-board unit in an order of reception of the radio waves. For example, the movement
10 direction detection unit 163 can calculate a direction vector between the estimated originating positions of the line segment connecting the estimated originating positions in an order of reception of the radio waves of the same on-board unit as movement direction information. Further, the movement direction detection unit 163 can calculate an
15 average value of the direction vector between the plurality of estimated originating positions of the line segment connecting the estimated originating positions in the order of reception of the radio waves of the same on-board unit as the movement direction information.

The movement direction detection unit 163 may calculate information indicating how much the direction indicated by the line segment connecting the estimated
20 originating positions of the same on-board unit in an order of reception of the radio waves deviates from the travel direction in the target travel lane including the communication area, such as a dispersion value (or a sample dispersion) of the estimated originating positions of the same on-board unit, or acquire the information as the movement direction information. Specifically, when the determined travel direction in
25 the target travel lane including the communication area is set to an expected value, the

movement direction detection unit 163 can calculate a value indicating how much the plurality of estimated originating positions disperses from the expected value as the dispersion value (or the sample dispersion).

[0039]

5 The travel lane determination unit 164 determines whether the vehicle travels in the corresponding target travel lane based on the movement direction calculated by the movement direction detection unit 163. For example, the travel lane determination unit 164 executes a vehicle movement direction determination to determine whether the movement direction follows a movement locus of the on-board unit mounted on the
10 vehicle traveling in the target travel lane including the corresponding communication area based on the input direction information. This travel lane determination unit 164 outputs a result of the determination to the communication control unit 165.

For example, the travel lane determination unit 164 determines whether the movement direction calculated by the movement direction detection unit 163 is a
15 direction along the travel direction in the corresponding travel lane 101. If the direction indicated by the line segment connecting the estimated originating positions of the same on-board unit in an order of the reception of the radio waves is not in a predetermined range, the travel lane determination unit 164 determines that the movement direction is not a direction along the travel direction of the corresponding travel lane 101.

20 Specifically, if a direction vector between the estimated originating positions of the line segment connecting the estimated originating positions at two points of the same on-board unit in an order of reception of the radio waves deviates by a predetermined threshold value (an angle) or more from the travel direction on the corresponding travel lane 101, the travel lane determination unit 164 determines that the movement direction
25 is not the direction along the travel direction of the corresponding travel lane 101.

Further, if an average of the direction vector between the estimated originating positions of the line segment connecting the estimated originating positions at three or more points of the same on-board unit in the order of reception of the radio waves deviates by the predetermined threshold value (angle) or more from the travel direction on the

5 corresponding travel lane 101, the travel lane determination unit 164 determines that the movement direction is not the direction along the travel direction of the corresponding travel lane 101.

[0040]

Further, when it is determined that there is a dispersion by the predetermined
10 threshold value or more based on a dispersion value (a sample dispersion) of three or more estimated originating positions of the same on-board unit, the travel lane determination unit 164 determines that the movement direction calculated by the movement direction detection unit 163 is not a direction that is along the travel direction of the corresponding travel lane 101. The travel lane determination unit 164 can
15 increase the accuracy of the determination as to whether the movement direction is along the travel direction by combining a determination based on an average of the direction vectors between three or more estimated originating positions of the same on-board unit and a determination based on a dispersion value (a sample dispersion) of the three or more estimated originating positions of the same on-board unit. That is, in the case of
20 the former determination, when a plurality of estimated originating positions vary to a left and right of the travel direction, it may be difficult to detect this variation due to the average. However, it is possible to detect such a variation through a combination with the latter determination.

In this embodiment, the travel lane determination unit 164 executes the vehicle
25 movement direction determination for only the on-board unit of which the estimated

originating position is determined to be in the range of the communication area by the position determination unit 162.

[0041]

When the travel lane determination unit 164 determines that the vehicle (the
5 on-board unit) does not travel in the target travel lane including the communication area, the communication control unit 165 limits the establishment of communication with the on-board unit. Specifically, the communication control unit 165 does not transmit the on-board unit data from the on-board unit with which the establishment of the communication has been limited to the lane control device 108, and does not transfer
10 information from the lane control device 108 to the on-board unit with which the establishment of the communication has been limited. That is, the communication control unit 165 transmits the on-board unit data from the on-board unit with which the establishment of the communication has been permitted to the lane control device 108 via the relay device 107, and transfers information from the lane control device 108 to
15 only the on-board unit with which the establishment of the communication has been permitted.

The embodiment of the present invention is not limited thereto, and the communication control unit 165 transmits all of the on-board unit data received from the roadside antenna 105 to the lane control device 108. The communication control unit
20 165 may transmit a result of the determination to the lane control device 108 only when the travel lane determination unit 164 determines that the received radio waves are radio waves from a vehicle (an on-board unit) that does not travel in the target travel lane including the communication area. For example, the communication control unit 165 transmits information indicating the on-board unit ID included in the on-board unit data
25 corresponding to the radio waves determined to be the radio waves from the vehicle (the

on-board unit) that does not travel in the target travel lane including the communication area to the lane control device 108.

The lane control device 108 limits the establishment of communication with the on-board unit based on the determination result of the travel lane determination unit 164
5 and the on-board unit ID received from the communication control unit 165.

[0042]

Next, an example of a vehicle detection method according to this embodiment will be described with reference to FIG. 5. FIG 5 is a flowchart illustrating an example of a vehicle detection method according to this embodiment.

10 For example, the on-board unit 301 is assumed to originate radio waves W1 including on-board unit data. The on-board unit 301 continuously originates a plurality of radio waves at predetermined time intervals.

(Step ST101)

Then, the AOA antenna 104 receives the radio waves W1, calculates information
15 indicating a horizontal angle θ_H and a vertical angle θ_V indicating an arrival direction of the radio waves W1, and outputs the information to the vehicle detection device 106.

(Step ST102)

Further, the roadside antenna 105 receives the radio waves W1 and outputs a reception signal including on-board unit data included in the radio waves W1 to the
20 vehicle detection device 106. At least an on-board unit ID of the on-board unit 301 is included in the on-board unit data included in the radio waves W1.

[0043]

(Step ST103)

The association unit 160 of the vehicle detection device 106 writes information
25 indicating the horizontal angle θ_H and the vertical angle θ_V based on the same radio

waves W1, and the on-board unit ID to the storage unit 166 in association with each other based on a timing at which the AOA antenna 104 receives the radio waves W1 and a timing at which the roadside antenna 105 receives the radio waves W1. Further, the association unit 160 outputs the information indicating the horizontal angle θ_H and the vertical angle θ_V indicating the arrival direction of the radio waves W1, and the on-board unit ID to the position calculation unit 161 in association with each other.

When the AOA antenna 104 then receives radio waves W2 different from the radio waves W1, the AOA antenna 104 calculates information indicating a horizontal angle θ_H and a vertical angle θ_V indicating an arrival direction of the radio waves W2, and outputs the information to the vehicle detection device 106. Further, the association unit 160 of the vehicle detection device 106 acquires on-board unit data from a reception signal received by the roadside antenna 105 at the same timing as a timing at which the radio waves W2 are received (simultaneously or substantially simultaneously). The association unit 160 writes information indicating the horizontal angle θ_H and the vertical angle θ_V indicating the arrival direction of the radio waves W2, and the on-board unit ID to the storage unit 166 in association with each other. The association unit 160 can identify each radio wave W1, W2, ... based on a sequential number included in the radio waves.

Thus, the association unit 160 writes the information indicating the horizontal angle θ_H and the vertical angle θ_V , and the on-board unit ID obtained from a plurality of radio waves W1, W2, ... to the storage unit 166 in association with each other.

[0044]

(Step ST104)

Then, the position calculation unit 161 of the vehicle detection device 106

obtains a point P_1 on a plane indicated by the arrival direction expressed by the horizontal angle θ_H and the vertical angle θ_V , and sets the point to be an estimated originating position. The position calculation unit 161 outputs position information indicating the obtained estimated originating position P_1 to the position determination unit 162 and the movement direction detection unit 163. In this case, the position calculation unit 161 may obtain the estimated originating position point P_1 according to the height of the on-board unit based on information indicating the height of the on-board unit obtained by the received data analysis unit 167.

Subsequently, the position calculation unit 161 obtains estimated originating positions $P_2, P_3, \dots$ obtained using the arrival direction of the radio waves based on a plurality of information (information indicating the horizontal angle θ_H and the vertical angle θ_V , and the on-board unit ID) stored in the storage unit 166. The position calculation unit 161 associates information indicating an order of reception of the radio waves (for example, i : a sequential number) and the on-board unit ID with the estimated originating position.

[0045]

(Step ST105)

The position determination unit 162 of the vehicle detection device 106 compares the horizontal angle θ_H and the vertical angle θ_V associated with the on-board unit ID with a threshold value of the radio wave arrival angle by referring to the storage unit 166 to determine whether the estimated originating position P_1 is in the range of the communication area. The position determination unit 162 outputs a result of the determination to the travel lane determination unit 164.

The position determination unit 162 of the vehicle detection device 106 may determine whether the estimated originating position P_1 is in the range of the

communication area based on the position information obtained by the position calculation unit 161. The position determination unit 162 outputs a result of the determination to the travel lane determination unit 164.

[0046]

5 (Step ST106)

If it is determined in step ST105 that the estimated originating position P_1 of the on-board unit is in the range of the communication area (for example, the horizontal angle θ_H and the vertical angle θ_V do not exceed the threshold values of the radio wave arrival angle determined to correspond to the horizontal angle θ_H and the vertical angle

10 θ_V), the movement direction detection unit 163 calculates the movement direction indicated by the estimated originating positions $P_1, P_2, P_3, \dots$ of the on-board unit based on the position determined to be in the range of the communication area, which is the position information (for example, $P_1, P_2, P_3, \dots$) with which the same on-board unit ID is associated, among a plurality of position information obtained by the position
15 calculation unit 161, and outputs information indicating the movement direction to the travel lane determination unit 164.

[0047]

(Step ST107)

If it is determined in step ST105 that the estimated originating position P_1 is in
20 the range of the communication area, the travel lane determination unit 164 determines whether the movement direction indicated by the estimated originating positions $P_1, P_2, P_3, \dots$ of the same on-board unit is a direction along the travel direction in the travel lane based on the information indicating the movement direction input from the movement direction detection unit 163. If the movement direction indicated by the estimated
25 originating positions $P_1, P_2, P_3, \dots$ of the same on-board unit is a direction along the

travel direction in the travel lane, the travel lane determination unit 164 determines that the vehicle travels in the travel lane 101 based on the calculated movement direction. If the travel lane determination unit 164 determines that the vehicle travels in the travel lane 101, the travel lane determination unit 164 outputs information indicating the on-board unit ID associated with the estimated originating positions P_1 , P_2 , P_3 , ... of the same on-board unit to the communication control unit 165.

[0048]

(Step ST108)

The communication control unit 165 transmits a result of the determination of the travel lane determination unit 164 determining that the vehicle travels in the travel lane 101 together with the estimated originating positions P_1 , P_2 , and P_3 , ... of the same on-board unit and information indicating the on-board unit ID to the lane control device 108. The lane control device 108 writes the received information to the storage unit in association with one another. The lane control device 108 establishes communication with the on-board unit indicated by the on-board unit ID.

(Step ST109)

On the other hand, if it is determined in step ST105 that the estimated originating position P_1 is not in the range of the communication area or if it is determined in step ST107 that the vehicle does not travel in the travel lane based on the calculated movement direction, the communication control unit 165 transmits a result of the determination of the travel lane determination unit 164 determining that the vehicle does not travel in the travel lane 101 together with information indicating a corresponding on-board unit ID to the lane control device 108. The lane control device 108 stops the communication with the on-board unit having the on-board unit ID that is determined not to travel in the travel lane 101 based on the information received from the vehicle

detection device 106.

[0049]

(Step ST110)

Meanwhile, the received data analysis unit 167 analyzes received data input
5 from the roadside antenna 105, and acquires the on-board unit ID and the vehicle type
information included in the on-board unit data. This received data analysis unit 167
also acquires the sequential number from the received data.

This received data analysis unit 167 determines a predetermined height of the
on-board unit according to the vehicle type based on the acquired vehicle type
10 information, and outputs information indicating the determined height of the on-board
unit to the association unit 160 and the position calculation unit 161.

(Step ST111)

Further, although detailed description is omitted, the received data analysis unit
167 analyzes the received data received from the on-board unit and acquires information
15 used for the billing process. The information analyzed by the received data analysis
unit 167 is transmitted to the lane control device 108 via the relay device 107.

The lane control device 108 executes the billing process for only the on-board
unit of the vehicle determined to travel in the travel lane including the communication
area based on the received information.

20 [0050]

Next, the AOA antenna 104 according to this embodiment will be described with
reference to FIGS. 6 and 7.

FIG 6 is a diagram illustrating an example of an arrangement of antenna
elements included in the AOA antenna 104. As illustrated in FIG. 5, the AOA antenna
25 104 includes AOA antenna elements 104A, 104B, 104C, and 104D. The AOA antenna

elements 104A and 104B are arranged at the same height position and arranged in a horizontal direction. A distance between the AOA antenna elements 104A and 104B is d_1 . On the other hand, the AOA antenna element 104C is arranged at a position higher than the AOA antenna elements 104A and 104B, and the AOA antenna element 104D is arranged at a position lower than the AOA antenna elements 104A and 104B. The AOA antenna elements 104C and 104D are arranged in a vertical direction, and a distance between the AOA antenna elements 104C and 104D is d_2 .

[0051]

FIG. 7 is a block diagram illustrating an example of a configuration of the AOA antenna 104. As illustrated in FIG. 7, the AOA antenna 104 includes the AOA antenna elements 104A to 104D, a horizontal phase processing unit 141 that receives outputs of AOA antennas 104A and 104B, a vertical phase processing unit 142 that receives outputs of the AOA antennas 104C and 104D, heterodyne conversion units 143A to 143D connected to the AOA antenna elements 104A to 104D, and local oscillators 144 and 145.

The local oscillator 144 outputs a local oscillation signal at a predetermined frequency to the heterodyne conversion units 143A and 143B, and the local oscillator 145 outputs a local oscillation signal at a predetermined frequency to the heterodyne conversion units 143C and 143D.

The heterodyne conversion units 143A and 143B obtain a difference between a frequency of radio waves received by the AOA antenna elements 104A and 104B inclined at a predetermined depression angle ψ and disposed with a predetermined distance d_1 and the frequency of the local oscillation signal output from the local oscillator 144, convert the respective received radio waves into signals at a low frequency (an intermediate frequency), and output the signal to the horizontal phase processing unit 141. Information indicating a phase ϕ_A is included in a signal output by

the heterodyne conversion unit 143A, and information indicating a phase ϕ_B is included in a signal output by the heterodyne conversion unit 143B.

The heterodyne conversion units 143C and 143D obtain a difference between a frequency of radio waves received by the AOA antenna elements 104C and 104D inclined at a predetermined depression angle ψ and disposed with a predetermined distance d_2 and the frequency of the local oscillation signal output from the local oscillator 145, convert the respective received radio waves into signals at a low frequency (an intermediate frequency), and output the signals to the vertical phase processing unit 142. Information indicating a phase ϕ_C is included in a signal output by the heterodyne conversion unit 143C, and information indicating a phase ϕ_D is included in a signal output by the heterodyne conversion unit 143D.

[0052]

The horizontal phase processing unit 141 calculates an angle (that is, the horizontal angle θ_H) at which the radio waves arrive at the AOA antennas 104A and 104B based on a phase difference ($\phi_A - \phi_B$) between the signals input from the heterodyne conversion units 143A and 143B, and outputs information indicating the horizontal angle θ_H to the vehicle detection device 106. This horizontal phase processing unit 141 calculates the horizontal angle θ_H according to Equation (1) below.

The vertical phase processing unit 142 calculates an angle (that is, the vertical angle θ_V) at which the radio waves arrive at the AOA antennas 104C and 104D based on a phase difference ($\phi_C - \phi_D$) between the signals input from the heterodyne conversion units 143C and 143D, and outputs information indicating the vertical angle θ_V to the vehicle detection device 106. This vertical phase processing unit 142 calculates the vertical angle θ_V according to Equation (2) below.

[0053]

$$\theta_H = \sin^{-1} \{(\phi_A - \phi_B)\lambda / (2\pi \cdot d1)\} \cdots \text{Equation (1)}$$

$$\theta_V = \sin^{-1} \{(\phi_C - \phi_D)\lambda / (2\pi \cdot d2)\} \cdots \text{Equation (2)}$$

$(\phi_A - \phi_B)$ is a phase difference due to a deviation between a timing of incidence of the radio waves on the AOA antenna element 104A and a timing of incidence of the radio waves on the AOA antenna element 104B, and $(\phi_C - \phi_D)$ is a phase difference due to a deviation between a timing of incidence of the radio waves on the AOA antenna element 104C and a timing of incidence of the radio waves on the AOA antenna element 104D. λ is a wavelength of the radio waves from the on-board unit.

10 [0054]

Here, a principle of obtaining the horizontal angle θ_H and the vertical angle θ_V using Equations (1) and (2) will be briefly described.

As illustrated in FIG. 8, for example, if the depression angle of the AOA antenna elements 104C and 104D is ψ_v , the horizontal angle θ_v at which the radio waves originating from the on-board unit 301 of the vehicle 201 to the AOA antenna 104 arrive at the AOA antenna elements 104C and 104D can be obtained as follows.

[0055]

As illustrated in FIG. 8, since the AOA antenna elements 104C and 104D are inclined at the depression angle ψ_v , a distance L_D from the on-board unit 301 to the AOA antenna element 104D is longer than a distance L_C from the on-board unit 301 to the AOA antenna element 104C. Accordingly, in the AOA antenna elements 104C and the AOA antenna element 104D, timings of reception of the radio waves deviate, and a phase difference is generated between the radio waves received by the AOA antenna element 104C and the AOA antenna element 104D. If this phase difference is $(\phi_C - \phi_D)$ and the

wavelength of the radio waves is λ , a difference η_2 between the distance L_C from the on-board unit 301 to the AOA antenna element 104C and the distance L_D from the on-board unit 301 to the AOA antenna element 104D is expressed by Equation (3).

[0056]

$$\eta_2 = (\phi_C - \phi_D)\lambda / (2\pi) \cdots \text{Equation (3)}$$

[0057]

Therefore, if an element interval between the AOA antenna element 104C and the AOA antenna element 104D is d_2 , Equation (4) is obtained from a geometric relationship in FIG. 7. Equation (5) is obtained from Equation (4). Therefore, from

10 this Equation (5), a radio wave arrival angle θ_v is expressed as in Equation (2). As illustrated in FIG. 8, the radio waves arrive at the AOA antenna elements 104C and 104D in parallel with each other, and the radio wave arrival angles at the AOA antenna elements 104C and 104D are assumed to be the same θ_v .

[0058]

$$15 \quad \sin\theta_v = \eta_2 / d_2 = (\phi_C - \phi_D)\lambda / (2\pi) / d_2 \cdots \text{Equation (4)}$$

$$(\phi_C - \phi_D) = (2\pi \cdot d_2 \cdot \sin\theta_v) / \lambda \cdots \text{Equation (5)}$$

[0059]

Similarly, when there is no on-board unit 301 on a straight line parallel to the travel direction of the travel lane 101, which is a straight line intersecting a center point
20 of the AOA antenna 104, a distance L_A from the on-board unit 301 to the AOA antenna element 104A is different from a distance L_B from the on-board unit 301 to the AOA antenna element 104B. Accordingly, timings of reception of the radio waves deviate in the AOA antenna element 104A and the AOA antenna element 104B, and a phase difference is generated between the radio waves received by the both of the AOA antenna

elements. This phase difference is $(\phi_A - \phi_B)$ and a wavelength of the radio waves is λ . In this case, a difference $\eta 1$ between the distance L_A from the on-board unit 301 to the AOA antenna element 104A and the distance L_B from the on-board unit 301 to the AOA antenna element 104B is expressed by Equation (6).

5 [0060]

$$\eta 1 = (\phi_A - \phi_B)\lambda / (2\pi) \cdots \text{Equation (6)}$$

[0061]

Therefore, if the element interval between the AOA antenna element 104A and the AOA antenna element 104B is $d1$, Equation (7) is obtained from the geometric relationship of FIG. 8. Equation (8) is obtained from Equation (7). Therefore, a radio wave arrival angle θ_H is expressed as shown in Equation (1) from Equation (8). It is assumed that the radio waves arrive at the AOA antenna elements 104A and 104B in parallel with each other, and the radio wave arrival angles at the AOA antenna elements 104A and 104B are both the same θ_H .

15 [0062]

$$\sin\theta_H = \eta 1 / d1 = (\phi_A - \phi_B)\lambda / (2\pi) / d1 \cdots \text{Equation (7)}$$

$$(\phi_A - \phi_B) = (2\pi \cdot d1 \cdot \sin\theta_H) / \lambda \cdots \text{Equation (8)}$$

[0063]

Next, an example of a movement path of the estimated originating position of the on-board unit 301 mounted on the vehicle 201 traveling on the corresponding travel lane 101 will be described with reference to FIG. 9. As illustrated in FIG. 9, the estimated originating position P_1 of the on-board unit 301 is present in the communication area. In this case, the travel lane determination unit 164 determines whether the movement direction calculated by the movement direction detection unit 163

is along the travel direction of the corresponding target travel lane. As illustrated in FIG. 9, an angle from $+\alpha$ to $-\alpha$ with respect to the travel direction of the corresponding travel lane 101 is assumed to be determined as a threshold value (an angle) corresponding to the direction vector. In this case, the travel lane determination unit 164 may determine whether each of a direction vector directed from the estimated originating positions P_1 to P_2 , a direction vector directed from the estimated originating position P_2 to P_3 , $\cdots$ is in a range of the threshold value (the angle) based on the movement direction indicated by the estimated originating positions $P_1, P_2, P_3, \cdots$ of the on-board unit 301. Further, the travel lane determination unit 164 may determine whether an average of the direction vectors indicated by estimated originating positions P_1, P_2, P_3, P_4 , and P_5 of the on-board unit 301 is in a range of the threshold value (the angle). In the illustrated example, the travel lane determination unit 164 may determine that the direction vector directed from the estimated originating positions P_1 to P_2 , the direction vector directed from the estimated originating position P_2 to P_3 , $\cdots$ are all in the range of the threshold value (the angle), and the average of the direction vectors indicated by the estimated originating positions P_1, P_2, P_3, P_4 , and P_5 of the on-board unit 301 are in the range of the threshold value (the angle).

Therefore, the travel lane determination unit 164 determines that the movement direction indicated by the estimated originating positions $P_1, P_2, P_3, \cdots$ of the on-board unit 301 is a direction that is along the travel direction. Therefore, the travel lane determination unit 164 determines that the vehicle 201 (the on-board unit 301) travels in the travel lane 101, and the lane control device 108 establishes the communication with the on-board unit 301.

[0064]

Next, an example of the movement path of the estimated originating positions of

the on-board unit 302 mounted on the vehicle 202 traveling in the travel lane 102 other than the target travel lane including the communication area of the roadside antenna 105 will be described with reference to FIG. 10. As illustrated in FIG. 10, radio waves originating when the vehicle 202 travels at a point R_{101} in the travel lane 102, for example, are assumed to be reflected by a ceiling, be further reflected by the vehicle 201 traveling in the communication area of the travel lane 101, and be incident on the AOA antenna 104 attached to the travel lane 101. In this case, the position calculation unit 161 detects the position at which the vehicle 201 reflects the radio waves (that is, the position at which the vehicle 201 travels) as an estimated originating position P_{101} of the on-board unit 302.

In this case, the position determination unit 162 outputs a result of the determination that the estimated originating position P_{101} of the on-board unit 302 is in a range of the communication area to the travel lane determination unit 164.

[0065]

Further, the radio waves originating when the vehicle travels at a point R_{102} in the travel lane 102, for example, are assumed to be reflected by the ceiling, be further reflected by the vehicle 201 traveling in the communication area of the travel lane 101, and be incident on the AOA antenna 104 attached to the travel lane 101. In this case, the position calculation unit 161 detects the position at which the vehicle 201 reflects the radio waves (that is, the position at which the vehicle 201 travels) as an estimated originating position P_{102} of the on-board unit 302. Then, the radio waves originating from the on-board unit 302 are assumed not to be reflected by the ceiling and be incident on the AOA antenna 104. The on-board unit 302 is assumed to move at positions R_{103} , R_{104} , and R_{105} in the travel lane 102.

In this case, the travel lane determination unit 164 determines whether the

movement direction calculated by the movement direction detection unit 163 is along the travel direction of the corresponding travel lane. In the illustrated example, a direction vector directed from the estimated originating position P_{101} of the on-board unit 302 to P_{102} exceeds a range of an angle from $+\alpha$ to $-\alpha$ with respect to the travel direction of the
5 corresponding travel lane 101.

Accordingly, the travel lane determination unit 164 determines that the movement direction indicated by the estimated originating positions P_{101} and P_{102} of the on-board unit 302 is not a direction along the travel direction. Therefore, the travel lane determination unit 164 determines that the vehicle 202 (the on-board unit 302) does not
10 travel in the travel lane 101, and the lane control device 108 stops the communication with the on-board unit 302.

[0066]

Thus, the vehicle detection device 106 according to this embodiment can determine that the movement direction indicated by the estimated originating positions
15 P_{101} and P_{102} as illustrated in FIG. 10 is not along the travel direction and determine that the vehicle 202 (the on-board unit 302) does not travel in the travel lane 101. Thus, since the estimated originating positions P_{101} and P_{102} are in the communication area, the vehicle detection device 106 can detect the vehicle to be a vehicle that is likely to travel in the travel lane 101 that is a target.

20 However, the vehicle detection device 106 according to this embodiment can suppress detection of a vehicle that does not travel in the travel lane 101 by determining that the movement direction indicated by the estimated originating positions P_{101} and P_{102} is not along the travel direction and determining that the vehicle 202 (the on-board unit 302) does not travel in the travel lane 101.

25 The vehicle detection device 106 according to this embodiment detects the

movement direction based on at least three or more estimated originating positions P_1 to P_3 . Accordingly, it is possible to improve the detection accuracy of the movement direction to be detected.

Further, when the movement direction based on the at least three or more estimated originating position P_1 to P_5 cannot be detected by the movement direction detection unit 163, the travel lane determination unit 164 of the vehicle detection device 106 according to this embodiment may determine that a vehicle does not travel in the corresponding target travel lane.

[0067]

Further, when the estimated originating position is not included in the communication area, the vehicle detection device 106 according to this embodiment does not execute a determination as to whether the vehicle travels in the travel lane 101 based on the movement direction. Accordingly, since the vehicle detection device 106 does not need to execute a movement direction determination process for a vehicle that is less likely to travel in the travel lane 101 which is a target, a processing load is reduced.

Further, when the estimated originating position is included in the communication area, the vehicle detection device 106 according to this embodiment executes the determination as to whether the vehicle travels on the travel lane 101 based on the movement direction. Accordingly, the vehicle detection device 106 can determine whether the vehicle that is highly likely not to travel in the travel lane 101 is included among vehicles that are likely to travel in the travel lane 101 that is the target, and prevent the vehicle that is highly likely not to travel in the travel lane 101 from being detected.

[0068]

Further, the vehicle detection device 106 according to this embodiment permits

the establishment of communication only for the on-board unit determined to travel in the travel lane 101. That is, even when it is erroneously determined that a vehicle is present in a communication range due to the influence of reflection or the like, it is determined that the vehicle does not travel in the travel lane 101 through the movement direction determination. Accordingly, it is possible to prevent communication with the on-board unit that does not travel in the travel lane 101 from being established, and to avoid a situation in which the billing process is erroneously performed.

Further, the vehicle detection device 106 according to this embodiment may have a configuration in which the position determination unit 162 illustrated in FIG. 3 is not included.

Further, the vehicle detection device 106 according to this embodiment may have a configuration in which at least the position calculation unit 161 and the movement direction detection unit 163 are included. With this configuration, the vehicle detection device 106 can detect the movement direction of the vehicle traveling on the travel lane.

[0069]

In toll roads or the like, a plurality of travel lanes may often be provided side by side. Further, there is a place at which a space between travel lanes cannot be sufficiently ensured or a place at which a space between an upward travel lane and a downward travel lane cannot be sufficiently ensured. Further, there is a place at which the vicinity of an exit of the toll road is very narrow, and a width of the travel lane, that is, a width of the communication area is narrow. At this place, an installation space of a radio wave absorption panel cannot often be sufficiently ensured. Accordingly, it is particularly effective in an environment where the vehicle detection device according to this embodiment is used.

Further, although the example in which the vehicle detection device 106 is

installed at a tollgate has been described in the above embodiment, the embodiment of the present invention is not limited thereto. For example, the embodiment of the present invention can be applied to a travel lane in which the communication area is set on a normal travel lane. Further, the travel lane is not limited to the toll road.

5 [0070]

A program for realizing functions of the processing unit in this embodiment may be recorded in a computer-readable recording medium, and the program recorded on the recording medium may be loaded to a computer system and executed to perform the process. The “computer system” stated herein includes an OS or hardware such as a
10 peripheral device. Further, the “computer system” also includes a WWW system including a homepage providing environment (or a display environment). Further, the “computer-readable recording medium” includes a flexible disk, a magneto-optical disc, a ROM, or a portable medium such as a CD-ROM, or a hard disk built in the computer system. Further, the “computer-readable recording medium” also includes a recording
15 medium that holds a program for a predetermined time, such as a volatile memory (DRAM) inside a computer system including a server or a client when a program is transmitted over a network such as the Internet or a communication line such as a telephone line.

[0071]

20 Further, the program may be transmitted from a computer system in which this program is stored in a storage device or the like to other computer systems via a transmission medium or by transfer waves in the transfer medium. Here, the “transfer medium” for transferring the program refers to a medium having a function of transferring information, such as a network (a communication network) such as the
25 Internet or a communication line such as a telephone line. Further, the program may be

a program for realizing some of the above-described functions. Alternatively, the program may be a program capable of realizing the above-described functions in combination with a program previously stored in the computer system, that is, a so-called differential file (a differential program).

5 [Industrial Applicability]

[0072]

According to the vehicle detection device, the lane control system, the vehicle detection method, and the program described above, when a vehicle traveling in a travel lane including a communication area of a corresponding roadside antenna is detected, it
 10 is possible to prevent a vehicle having an on-board unit mounted thereon located in a position other than the travel lane including the communication area from being erroneously detected by the antenna.

[Reference Signs List]

[0073]

15	101	travel lane
	102	travel lane
	103	travel lane
	104	AOA antenna
	105	roadside antenna
20	106	vehicle detection device
	107	relay device
	108	lane control device
	109	central processing device
	110	gantry
25	104A	AOA antenna element

	104B	AOA antenna element
	104C	AOA antenna element
	104D	AOA antenna element
	141	horizontal phase processing unit
5	142	vertical phase processing unit
	143A	heterodyne conversion unit
	143B	heterodyne conversion unit
	143C	heterodyne conversion unit
	143D	heterodyne conversion unit
10	144	local oscillator
	145	local oscillator
	160	association unit
	161	position calculation unit
	162	position determination unit
15	163	movement direction detection unit
	164	travel lane determination unit
	165	communication control unit
	166	storage unit
	201	vehicle
20	202	vehicle
	203	vehicle
	301	on-board unit
	302	on-board unit
	303	on-board unit

[CLAIMS]

[Claim 1]

A vehicle detection device that is provided corresponding to a target travel lane among a plurality of travel lanes, and detects a vehicle traveling in the target travel lane
5 among the plurality of travel lanes based on radio waves originating from an on-board unit mounted on a vehicle, the vehicle detection device comprising:

a position calculation unit that regards radio waves detected by a direction detection unit that detects an arrival direction of the radio waves received from the on-board unit as radio waves originating from in the target travel lane based on the
10 arrival direction of radio waves detected by the direction detection unit, and obtains an estimated originating position in the target travel lane;

a movement direction detection unit that detects a movement direction of a plurality of the estimated originating positions obtained by the position calculation unit based on the estimated originating positions; and

15 a travel lane determination unit that determines whether the vehicle originating the radio waves is a vehicle traveling in the target travel lane based on the movement direction detected by the movement direction detection unit.

[Claim 2]

20 The vehicle detection device according to claim 1,
wherein the travel lane determination unit determines that the vehicle travels in the target travel lane when the movement direction detected by the movement direction detection unit is a direction that is along a travel direction in the target travel lane.

25 [Claim 3]

The vehicle detection device according to claim 1 or 2, further comprising:

a position determination unit that is provided corresponding to any one target travel lane among the plurality of travel lanes, and determines whether the position obtained by the position calculation unit is in a determined range in the target travel lane,
5 wherein the movement direction detection unit detects a movement direction of the estimated originating position based on an estimated originating position determined to be in the determined range by the position determination unit.

[Claim 4]

10 The vehicle detection device according to any one of claims 1 to 3, further comprising:

a communication control unit that limits communication with an on-board unit mounted on a vehicle determined not to travel in the target travel lane by the travel lane determination unit.

15

[Claim 5]

The vehicle detection device according to any one of claims 1 to 4,

wherein the movement direction detection unit detects a movement direction of the estimated originating position based on at least three or more estimated originating
20 positions among the plurality of estimated originating positions obtained by the position calculation unit.

[Claim 6]

A vehicle detection device that is provided corresponding to a target travel lane
25 among a plurality of travel lanes, and detects a vehicle traveling in the target travel lane

among the plurality of travel lanes based on radio waves originating from an on-board unit mounted on a vehicle, the vehicle detection device comprising:

a position calculation unit that regards radio waves detected by a direction detection unit that detects an arrival direction of the radio waves received from the on-board unit as radio waves originating from in the target travel lane based on the arrival direction of radio waves detected by the direction detection unit, and obtains an estimated originating position in the target travel lane; and

a movement direction detection unit that detects a movement direction of a plurality of estimated originating positions obtained by the position calculation unit based on the estimated originating positions.

[Claim 7]

A lane control system comprising:

the vehicle detection device according to any one of claims 1 to 5; and

a lane control device that is communicably connected to the vehicle detection device and executes predetermined information processing based on information included in radio waves originating from the on-board unit determined to travel in the target travel lane by the travel lane determination unit.

[Claim 8]

A vehicle detection method of detecting a vehicle traveling in a target travel lane among a plurality of travel lanes based on radio waves originating from an on-board unit mounted on the vehicle, the vehicle detection method comprising:

a position calculation step of regarding radio waves received from the on-board unit as radio waves originating from in the target travel lane based on an arrival direction

of the radio waves, and obtaining an estimated originating position in the target travel lane;

a movement direction detection step of detecting a movement direction of a plurality of estimated originating positions obtained in the position calculation step based on the estimated originating positions; and

a travel lane determination step of determining whether the vehicle originating the radio waves is a vehicle traveling in the target travel lane based on the movement direction detected in the movement direction detection step.

10 [Claim 9]

A program that causes a computer operating a vehicle detection device that detects a vehicle traveling in a target travel lane among a plurality of travel lanes based on radio waves originating from an on-board unit mounted on the vehicle to function as:

a position calculation means that regards radio waves detected by a direction
15 detection unit that detects an arrival direction of the radio waves received from the on-board unit as radio waves originating from in the target travel lane based on the arrival direction of radio waves detected by the direction detection unit, and obtains an estimated originating position in the target travel lane;

a movement direction detection means that detects a movement direction of a
20 plurality of estimated originating positions obtained by the position calculation means based on the estimated originating positions; and

a travel lane determination means that determines whether the vehicle originating the radio waves is a vehicle traveling in the target travel lane based on the movement direction detected by the movement direction detection means.