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Fully automatic straddle carrier with local radio detection and laser steering

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Abstract of the disclosure

The invention relates to a fully automatic driverless straddle carrier for transporting and stacking freight containers, which is equipped with several different sensor systems for the vehicle detection and navigation, the signals of which being evaluated and monitored in an electronic sensor fusion system and the current coordinates of the location determined thereby then being transmitted to a system of electric controls for automatically steering, driving and positioning the vehicle on preset paths stored in an electronic path control, laser scanners being arranged at the vehicle for automatically guiding the vehicle over a container stack; in said straddle carrier, one of the absolute sensor systems for the vehicle detection consists of a local radio detection system (22), which is arranged on the vehicle (1) as a mobile radio base station, a plurality of radio transponders (7) being stationarily positioned in the traveling area of the working site, an automatic switching device (28) being provided for switching the steering from the automatic steering by navigation to an automatic steering by laser scanners (2, 11, 12) and vice versa, when the vehicle (1) reaches, travels over or leaves a container stack (4).

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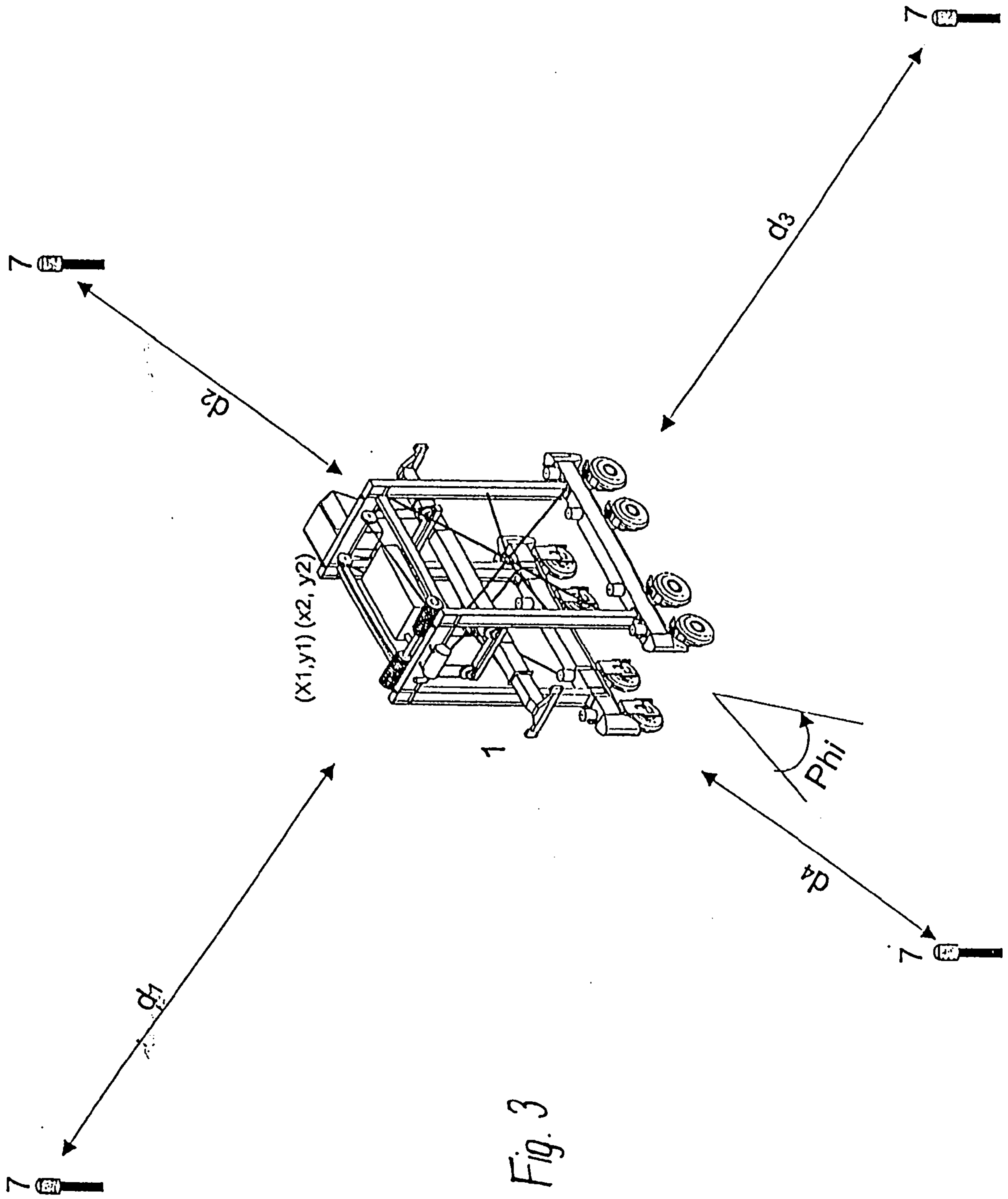

Fig. 3

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AUSTRALIA

Patents Act 1990

COMPLETE SPECIFICATION

Standard Patent

Applicant(s):

Noell Mobile Systems GmbH

Invention Title:

FULLY AUTOMATIC STRADDLE CARRIER WITH LOCAL RADIO DETECTION AND LASER STEERING

The following statement is a full description of this invention, including the best method for performing it known to me/us:

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Fully automatic straddle carrier with local radio detection and laser steering

The present invention relates to a fully automatic driverless straddle carrier for transporting and stacking freight containers according to the features of the first claim. The invention relates to straddle carriers as they are used all over the world in seaports and container terminals for transporting and stacking containers. As shown in U.S. Design Patent No. US D526,932 S, they consist of two traveling gears with wheels running to the left and to right of the container stack, and of vertical supports placed thereon forming together with the machine scaffold positioned thereon a portal. This portal travels over the containers and lifts them by means of its lifting gear or puts them down. The straddle carriers have a diesel-electric or a diesel-hydraulic drive and in most cases an electrohydraulic steering mechanism, and after presetting the deflection of the steering wheel by the driver a steering computer controls the hydraulic proportional valves which in their turn cause the deflection of the wheels by means of hydraulic cylinders. Also driverless fully automatic straddle carriers are known. They use in most cases the commonly known processes used for the navigation of all autonomous driverless industrial trucks, in particular individual systems or combinations of absolute and relative navigation sensors.

The following absolute navigation systems are known:

- satellite navigation (differential GPS, DGPS)
- radar navigation (with a radar device having a rotating antenna on the roof of the vehicle and stationary passive reflectors in the surroundings)
- transponder navigation (with transponders or magnets buried in the ground).

The following relative navigation systems are known:

- inertial navigation (gyroscopes, inertial measuring units (IMU))
- dead reckoning navigation with odometry (distance measuring by rotary encoders at the wheels) and probably additional measuring of the steering angle by means of a further sensor at the steering mechanism.

For a fully automatic steering, driving and positioning, these known navigation systems must allow the detection of the vehicle position very reliably and with an accuracy of one centimeter. The navigation is therefore very complex and the requirements are only

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fulfilled by a combination of different redundant diversity, absolute and relative navigation processes.

In "Kalmar launches Autoshuttle" WorldCargo News (Jan. 31, 2008) http://www.worldcargonews.com/htm/w20080131.534586.htm, a solution for fully automatic straddle carriers has been described. The system works with transponder navigation according to the FROG technology, **F**ree **R**anging **O**n **G**rid, in which antennas or magnetic-field sensors are placed at the bottom of the vehicle, which detect transponders or magnets buried in the roadway and recalibrate the odometry in this manner.

"An Autonomous Straddle Carrier for Movement of Shipping Containers", IEEE Robotics & Automation Magazine of Sept. 2007, uses a combination of DGPS (satellite based global positioning system), rotating dwarf waves radar, inertial navigation and odometry. The detection signals of these individual navigation systems are combined in a sensor fusion system consisting of Kalman filters and evaluated in order to obtain a reliable and precise detection signal, since each individual sensor alone would be too unreliable or too inaccurate for a fully automatic driving mode.

In *DE 103 36 084 A1* a local position measuring system is described which has a base station located on a mobile object, the position of which is to be determined, a plurality of transponders being distributed around the locality.

These known processes for a fully automatic vehicle steering for straddle carriers have some disadvantages.

Solutions as that according to the FROG technology have the disadvantage that considerable time and efforts are required for the installation of the magnets in the ground. Since the FROG antennas at the bottom of the vehicle cannot be wider as the two traveling gears on each vehicle side, i.e. about 70 cm, a very high density of the transponders is required for the case that the odometry drifts off so that at least one transponder or magnet is detected on these 2 x 70 cm in order to allow a recalibration. Thus, thousands of holes must be drilled into all roadways of the terminal in order to install the magnets in the ground. Besides these substantial efforts the handling of goods is obstructed during the installation.

Solutions with a combination of DGPS with radar have the disadvantage that the mechanics of the dwarf waves navigation radar mounted on the vehicle are expensive and susceptible to faults and the required expenses in electronics in such a radar device are in economic aspects hardly justifiable.

Both solutions have the further disadvantage that the vehicles do not orient themselves at the container stack itself when traveling over a container stack but at external marks, like satellites in the case of DGPS, reflectors in the case of rotating radar, magnets in the case of FROG. By these means, the vehicle is guided along a merely theoretical path, stored in the electronic control, on which the container stack should be positioned theoretically. When the containers are in reality not exactly placed on this theoretic path, grazing, collisions, damages and thus working interruptions may occur.

It is therefore the object of the present invention to overcome the disadvantages of the known state of the art and to provide a fully automatic driverless straddle carrier with fully automatic steering, the absolute navigation sensor technology of which requires a substantially lower expense as hitherto existing solutions and which during traveling over the container stack orients itself directly at the container stack itself.

This object is attained by the characterizing features of the first claim.

Further advantageous embodiments of the invention are shown in the dependent claims.

The solution according to the invention provides an automatic driverless straddle carrier for transporting and stacking freight containers, which is equipped with several different sensor systems for the vehicle detection and navigation, the signals of which being evaluated and monitored in an electronic sensor fusion system, and the current coordinates of the location determined thereby then being transmitted to a system of electric controls for automatically steering, driving and positioning the vehicle, so that the vehicle is guided, driven and positioned on preset paths stored in an electronic path control, the laser scanner serving the purpose of automatically guiding the vehicles over container stacks.

According to the invention, one of the absolute sensor systems for the vehicle detection consists of a local radio detection system, a mobile radio base station being arranged on the vehicle and a plurality of radio transponders being stationarily positioned in the traveling area of the working site. It is advantageous to arrange the radio transponders in an elevated position on the ground. Furthermore, an automatic switching device is provided, which changes the steering from an automatic steering by navigation to an automatic steering by means of the laser scanner when the vehicle travels over or is shortly in front of a container stack.

The straddle carrier according to the invention may be provided with a navigation system, which is arranged in addition to the local radio detection and positioning system. For this purpose, a mobile DGPS-receiver for the satellite based differential global positioning system may be arranged at the straddle carrier. The straddle carrier further comprises an electronic path control. Furthermore, laser scanners, preferably at least two laser scanners, for an automatic steering are provided. The laser scanners supply raw data concerning their surroundings and transmit them to the laser control electronics. As soon as the straddle carrier is close enough to a container or a container wall, the laser control electronics supply a switching signal to the switching device for the reference value of the steering angle so that the switching device supplies a signal to the steering computer which in its turn switches over to automatic steering by laser scanner or, for the case that the straddle carrier removes from a container or a container wall, to the automatic steering by navigation and path control. The right and the left laser control electronics exchange plausibility signals for the purpose of detecting a container. Furthermore, the laser control electronics pass the reference value for the steering angle on to the switching device and from there to the steering computer. The laser control electronics also set the speed limit for the minimum evaluation, which is passed on to the traveling gear control, presetting the reference values for the rotational speed for the driving motors. Preferably, frequency converters are connected upstream of the driving motors.

Local radio detection systems have been disclosed in numerous documents and there is therefore no reason to describe them in detail. The use of such radio detection systems for vehicles is known, in particular, radio detection systems used for straddle carriers are known, in order to be able to track the containers during the transportation, a so-called container tracking. In the present case, this radio detection system substitutes the DGPS, which in some cases, e.g. due to obstructions in the visual contact by cranes, ships, high buildings or the like, works in an unreliable or inaccurate manner. A straddle carrier, which is also automatically steered and driven by means of such a local radio detection system, is not known.

DGPS-systems have been described in many documents and they are thus not described in detail. The data from the radio detection system and, as the case may be, the DGPS-navigation system are passed on to a sensor fusion system as actual values of the vehicle position. The sensor fusion system provides for that signals with measuring errors and unreliable signals from the different sensors are evaluated by specific software programs, e.g. Kalman filters, and the most probable measuring value for the vehicle position resulting therefrom is calculated. In a simple system for sensor fusion, the signals are only examined regarding their plausibility and the relative sensors are recalibrated with the signals of the absolute sensors. Rotational speed sensors at the wheels of the vehicle send distance measurement data to the sensor fusion, which sends current actual values to the path control.

Also the electronic path control is known from robot technology and there is no need to describe it in detail herein. The paths on which the vehicle should travel are stored therein in the form of path segments or path points. The path segments may be straight pieces, circular arcs or curves and are limited by a starting and a final point, the associated local coordinates of which are stored. The path control compares always the current position of the vehicle with its preset position on the path curve and calculates therefrom a reference value for the steering angle, which is supplied to the steering computer, and a reference value for the speed, which is supplied to the traveling gear control. The path control passes the calculated reference value for the steering angle via a switching device on to the steering computer.

The automatic steering by means of laser scanners is carried out in that at least one laser scanner measures the distance to a container wall from different angles during traveling over the container stack und passes the measured angles on to an electronic control, which calculates a reference value for the steering angle for the electronically controlled steering of the vehicle. The laser scanner may be a two-dimensional laser scanner. Furthermore it may be arranged in the front of the vehicle's traveling gear. Of course, a laser scanner may also be arranged at the rear of the vehicle's traveling gear for reversing. Furthermore, the laser scanner of the two-dimensional laser scanner may be arranged in the buffer. Commercially available robust two-dimensional laser scanners are suited as laser scanners. The laser steering is not manually switched on by the driver but by an automatic switch as soon as the laser scanners have detected a container. The detection of a container and the discrimination from another general obstacle is made in that in each case the left and the right laser scanner measure the current distance between the traveling gear of the straddle carrier and the left or the right, respectively, wall of the container. By means of the two measured values, the electronic control is able of calculating the width of the obstacle. If this corresponds to the internationally standardized container width, the vehicle may travel on over the container. If this is not the case, the vehicle will be stopped.

The switching device may be an electronic control or a software program, which is integrated in the software package of the sensor fusion. Such software programs for switching signals may be programmed in a relative simple manner, which is well known to one skilled in the art. Therefore, they are not described in detail.

In the following text, the invention is described in detail by means of an embodiment and six drawing figures. The drawings show:

Fig. 1: a straddle carrier, which is traveling over a container stack, a laser scanner being attached to the left front of the traveling gear in a manner protected by the buffer,

Fig. 2: the laser scanner of Fig. 1,

Fig. 3: the radio detection system of the straddle carrier with radio transponders,

Fig. 4: a diagrammatic representation of the software functions of the navigation and vehicle guide system for an automatic driverless straddle carrier, shown as block diagram and signal flowchart,

Fig. 5: the hardware structure of the electronic control system of the straddle carrier according to the invention with a bus topology and all bus subscribers at three CAN buses,

Fig. 6: a representation of the principles of the laser control.

Fig. 1 shows a straddle carrier 1 above a container stack 4, the laser scanner 2 being arranged at the front of the vehicle's traveling gear 3 in a buffer. The straddle carrier 1 is traveling over a container stack 4.

The laser scanner 2 is shown in Fig. 2 in detail. It represents a two-dimensional laser scanner.

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Fig. 3 shows a straddle carrier 1, on which a base radio station is arranged. Radio transponders 7 are arranged on posts in the surroundings of the transport vehicle 1, which are in communication with the base radio station by means of signals (d1, d2, d3, d4).

Fig. 4 shows in the form of a block diagram and signal flowchart a general plan of the software function of the navigation and vehicle guide system for a fully automatic driverless straddle carrier. The base station of the local radio detection system 22 of the vehicle and the receiver for the satellite based global positioning system 21 are arranged on the straddle carrier. The receivers 21, 22 receive the signals of the DGPS and the LPR (local radio detection system) and pass the actual value of the vehicle position 101, 102 from the radio detection system and the DGPS on to a sensor fusion 23. Rotary encoders 18, 19 arranged at the left and at the right vehicle wheel, respectively, send a signal for distance measuring 103, 104 of the rotary encoder in question (odometry signal) to the sensor fusion 23, from which an evaluated current actual value 105 for the vehicle position is passed on to the path control 25. On the right side and on the left side of the vehicle there are arranged laser scanners 11, 12, which send in each case raw data 110, 111 of the measured surroundings to the right and to the left of the straddle carrier to the laser control electronics 13, 14 and exchange plausibility signals 112, 113 for the container detection. The laser control electronics 14 on one side, in the present case on the right side, evaluate the reference value 107 for the steering angle of the laser control and pass the switching signal 108, as the case may be, on to the switching device 28 for the reference value of the steering angle of the laser control when the vehicle is close enough to a container stack. Furthermore, the laser control may supply a signal for the speed limit 114. A signal for the speed limit 115 may also be supplied by the path control 25. The traveling gear control 27 sends reference values for the rotational speed 118 to the driving motors 16 of the wheels. The switching device 28 for the reference value of the steering angle is controlled on the basis of the switching signal 108 and the reference values for the steering angle 106, 107, the switching device 28 sending a resulting reference value 109 for the steering angle to the steering computer 26, which is in communication with an electrical proportional valve 17 for the hydraulic steering. By means of this navigation and vehicle guide system it is possible to steer and drive a straddle carrier automatically and to switch over to the automatic steering by means of the laser scanners 11, 12 when approaching a container stack.

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The steering computer 26 for the vehicle is controlled by the reference value for the steering angle 106 of the path control 25 and the reference value for the steering angle 107 of the laser control 13, 14 via the switching device 28 for the reference value for the steering angle 109, the steering computer 26 acting on the electrical proportional valve 17 for the hydraulic steering.

Fig. 5 shows in a principle representation the hardware structure of the electronic control system of the straddle carrier with a possible bus topology. The straddle carrier 1 comprises receiver 21 for the signals of a satellite based global positioning system and receivers 22 for a local radio detection system. On the right and left side, laser scanners 11, 12 are arranged, which detect the surroundings and send their signals to the left and the right laser scanner electronics 13, 14 and check themselves against one another. The arrangement of the three following CAN buses is shown in the figure:

The central CAN bus 30 of the vehicle,
the CAN bus 31 of the vehicle drives and
the CAN bus 32 of the automatization and navigation.

Fig. 6 shows containers 4 arranged one behind the other, between which lanes are arranged in which the straddle carrier travels by means of its traveling gear 3, it being required to observe a distance A relative to the container wall 5. The laser scanners 11, 12 of the right and left vehicle sides measure by means of laser beams 6 the distance A between the traveling gear 3 and the container and pass the signal of their measurements on to the laser control electronics 13, 14, which is diagrammatically shown in Figs. 4 and 5.

The fully automatic straddle carrier with local radio detection and laser steering comprises the following advantages:

- As compared with the known solutions with transponders /magnets buried into the ground, there is less technical effort, since the radio transponders may be mounted overground, e.g. at lamp poles and also the number of required transponders is substantially lower.
- The operational obstructions on the terminal, which occur during the installation of transponders/magnets buried into the ground due to drilling works, are omitted during the installation of radio transponders at lamp poles.

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- As compared with the other known solution with a mobile navigation radar, with a mechanically rotating antenna and passive overground reflectors, the technical expense is likewise diminished, since the mechanics, which wear out and are susceptible to faults as well as the control and evaluation electronics for the rotating antenna are omitted.
- During traveling over the container stack, the vehicle is guided precisely along the real container stack even if the containers are somewhat offset or inclined and does not travel only on a virtual electronically stored path as in the hitherto known solutions.
- Due to that, less precise and thus less expensive navigation systems may be used, since steering by means of the navigation system is only carried out outside of the container stacks where a precise steering is not required.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

A reference herein to a prior art document is not an admission that the document forms part of the common general knowledge in the art in Australia.

List of used reference numbers

1	Straddle carrier
2	Laser scanner
3	traveling gear with wheels
4	Container
5	Container wall
6	Laser beams
7	Radio transponder
8	
9	
10	
11	Laser scanner on the left side of the vehicle
12	Laser scanner on the right side of the vehicle
13	Left laser control electronics
14	Right laser control electronics
15	Frequency converter for the driving motors
16	Driving motors at the wheels
17	Electrical proportional valve for the hydraulic steering
18	Rotary encoder at a vehicle wheel on the left (odometry)
19	Rotary encoder at a vehicle wheel on the right (odometry)
20	
21	Receiver for DGPS
22	Local radio detection system (base station on the vehicle)
23	Sensor fusion
24	
25	Path control
26	Steering computer
27	Control of traveling gear
28	Switching device for the setting value of the steering angle
29	Evaluation of minimum
30	Central CAN bus of the vehicle
31	CAN bus of the drives of the vehicle
32	CAN bus of the automatization and navigation

Signals:

101	Position of vehicle (actual value) of the DGPS
102	Position of vehicle (actual value) of the radio detection system
103	Measured distance value of the left rotary encoder of the wheel (odometry signal)
104	Measured distance value of the right rotary encoder of the wheel (odometry signal)
105	Current actual value of the vehicle position measured by sensor fusion
106	Setting value of the steering angle of the path control
107	Setting value of the steering angle of the laser steering
108	Switching signal for the setting value from the laser steering
109	Setting value of the steering angle for the steering computer
110	Raw data of the laser scanner of the measured surroundings on the left side
111	Raw data of the laser scanner of the measured surroundings on the right side
112	Plausibility signal for the container detection
113	Plausibility signal for the container detection
114	Speed limit from the laser steering
115	Speed limit from the path control
116	Speed limit from the control for the traveling gear
117	
118	Setting values for the rotational speed for the driving motors

Abbreviations:

DGPS:	**D**ifferential **G**lobal **P**ositioning **S**ystem (satellite based global positioning system with differential error compensation of the mobile DGPS-receivers by a stationary base station
LPR:	**L**ocal **P**ositioning **R**adar (local radio detection system)
SF:	**S**ensor **f**usion
VGC:	**V**ehicle **G**uide **C**ontroller (electronic path control, vehicle guide system)
SC:	**S**teering **C**omputer (steering computer of the electro hydraulic control of the traveling gear)
GDC:	**G**antry **D**rive **C**ontroller (electronic control of the traveling gear)
LCS_L:	**L**aser **C**ontrol **S**ystem **L**eft (electronic laser control on the left side)
LCS_R:	**L**aser **C**ontrol **S**ystem **R**ight (electronic laser control on the right side)

Claims

1. A fully automatic driverless straddle carrier for transporting and stacking freight containers, which is equipped with several different sensor systems for vehicle detection and navigation, the signals of which being evaluated and monitored in an electronic sensor fusion system and the current coordinates of the location determined thereby then being transmitted to a system of electronic controls for automatically steering, driving and positioning the vehicle on preset paths stored in an electronic path control, laser scanners being arranged at the vehicle for automatically guiding the vehicle over a container stack,

   characterized in that
   one of the absolute sensor systems for the vehicle detection consists of a local radio detection system (22), which is arranged on the vehicle (1) as a mobile radio base station, a plurality of radio transponders (7) being stationarily positioned in the traveling area of the working site,

   an automatic switching device (28) being provided for switching the steering from the automatic steering by navigation to an automatic steering by laser scanners (2, 11, 12) and vice versa, when the vehicle (1) reaches, travels over or leaves a container stack (4).

2. A straddle carrier as claimed in claim 1, characterized in that the local radio detection system (22) as a base station of the straddle carrier (1) and the receiver (21) of the navigation system send actual values for the vehicle position (101, 102) to the sensor fusion (23), and that rotary encoders (18, 19) are arranged at the vehicle wheels, from which measured distance values (103, 104) are sent to the sensor fusion (23), by which the current actual value (105) for the vehicle position is passed on to the path control (25).

3. A straddle carrier as claimed in claims 1 and 2, characterized in that the switching device (28) for the reference value for the steering angle (109) receives a reference value for the steering angle (106, 107) from the path control (28) and the laser control electronics (13, 14) and passes the reference value for the steering angle (109) on to a steering computer (26) und the electrical proportional valve (17) for the hydraulic steering.

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4. A straddle carrier as claimed in claims 1 to 3, characterized in that the switching device (28) receives from the laser control electronics (13, 14) a switching signal (108) for the reference value for the steering angle (109).

5. A straddle carrier as claimed in claims 1 to 4, characterized in that frequency converters (15) arranged at the driving motors (16) for the wheels receive a reference value for the rotational speed (118) from the control of the traveling gear (27) on the basis of a minimum evaluation (29), into which the speed limits (114, 115) of the path control (25) and the laser control (13, 14) are integrated.

6. A straddle carrier as claimed in claims 1 to 5, characterized in that the radio transponders (7) are arranged in an elevated position over the ground.

7. A straddle carrier as claimed in claims 1 to 6, characterized in that the automatic switch device (28) for the steering is in the form of an electronic switch or a software program for an electronic control.

8. A straddle carrier as claimed in claims 1 to 7, characterized in that at least two laser scanners (2, 11, 12) are arranged at the straddle carrier (1).

9. A straddle carrier as claimed in claim 8, characterized in that the laser scanner (2, 11, 12) is a two-dimensional laser scanner.

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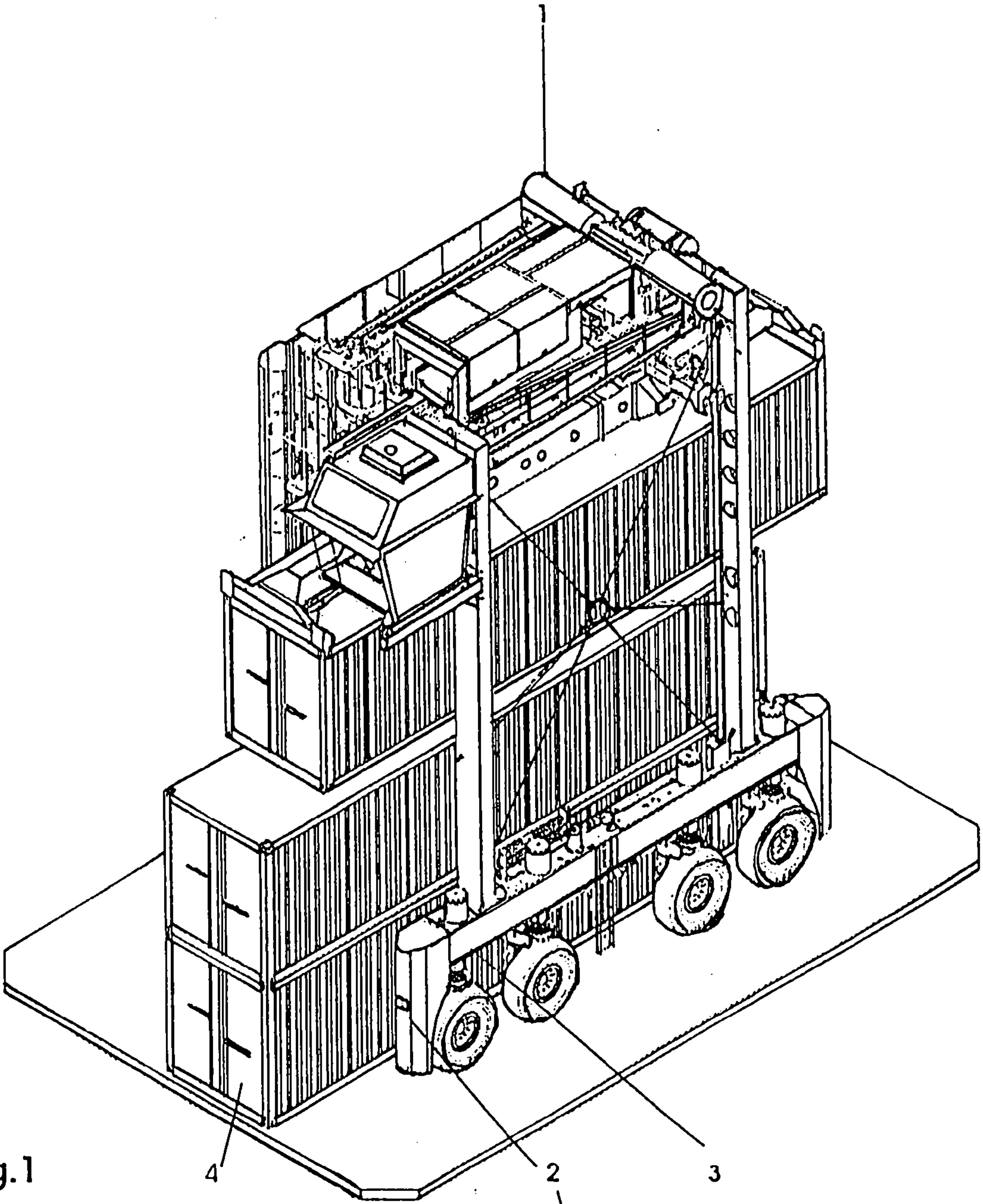


Fig.1

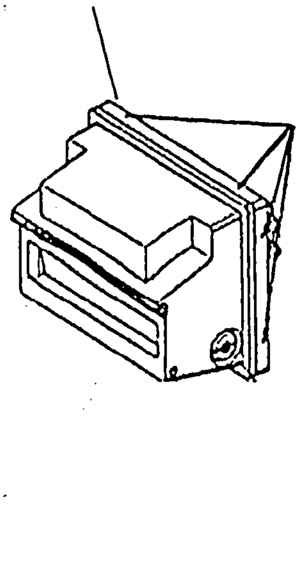


Fig. 2

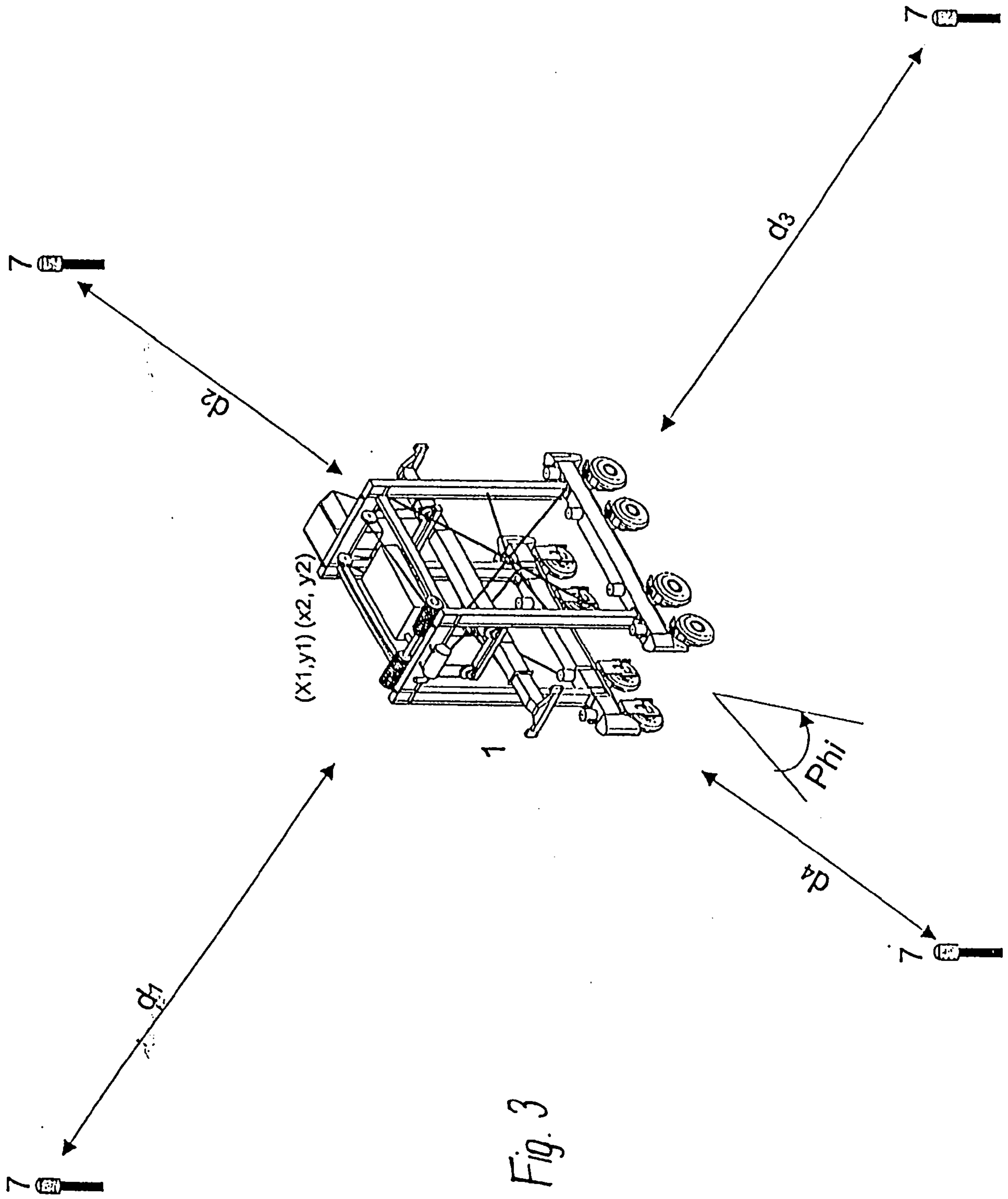
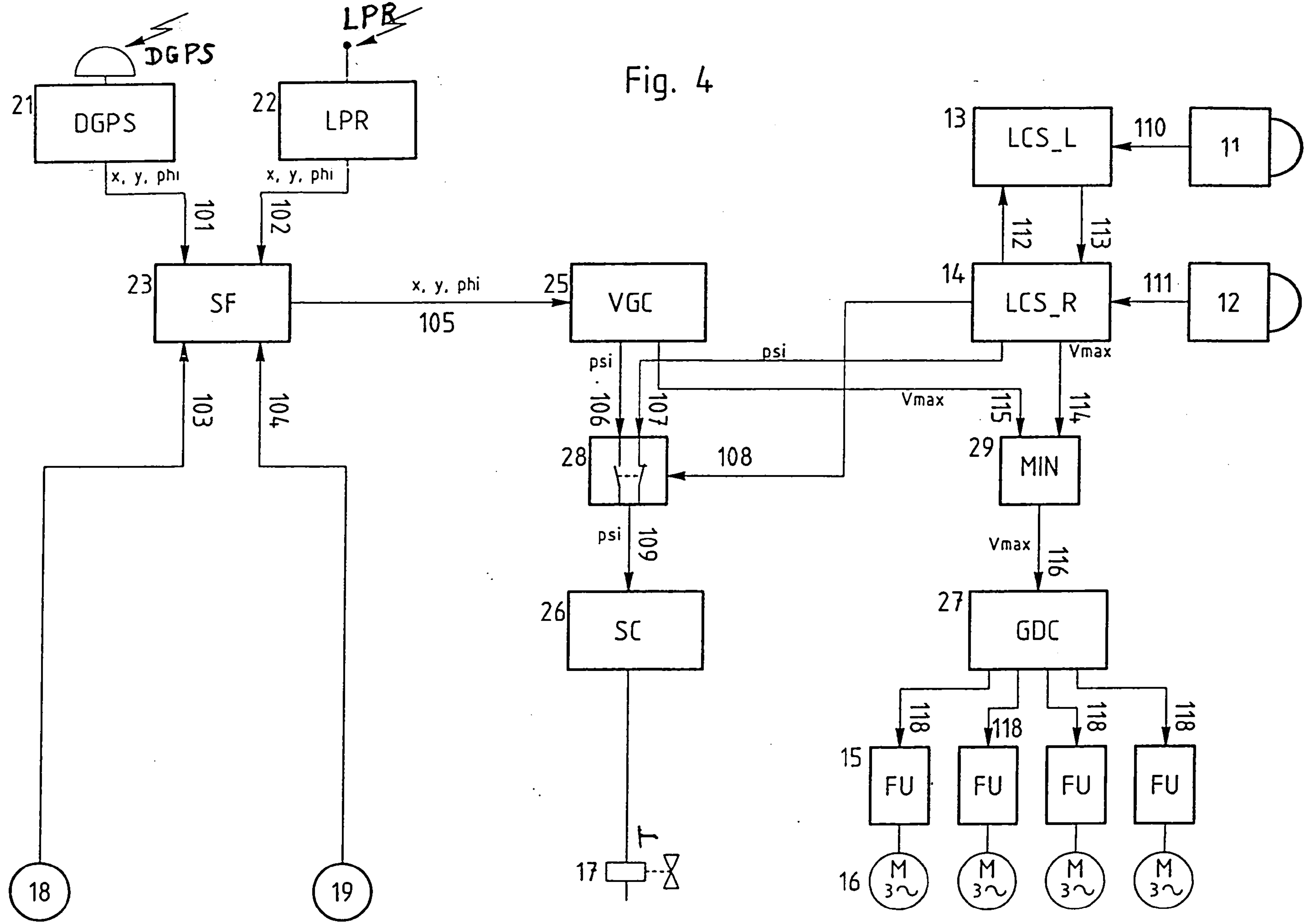


Fig. 3

Fig. 4



DGPS
LPR
21
DGPS
22
LPR
x, y, phi
x, y, phi
101
102
23
SF
x, y, phi
105
25
VGC
103
104
18
19
psi
106
107
psi
28
108
psi
109
26
SC
17
13
LCS_L
110
11
112
113
14
LCS_R
111
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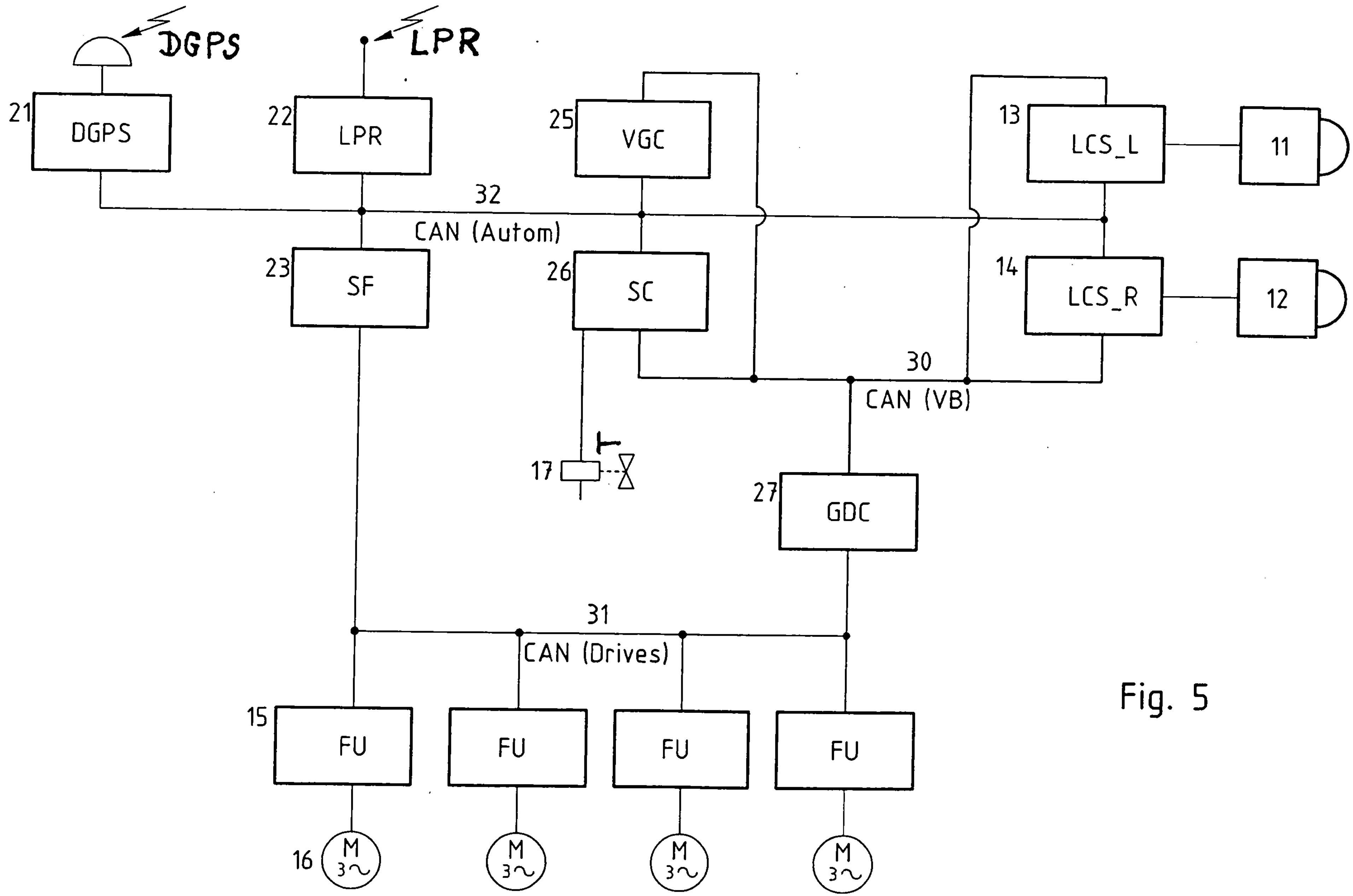
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11
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SF
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SC
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LCS_R
12
30
CAN (VB)
17
27
GDC
31
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Fig. 5

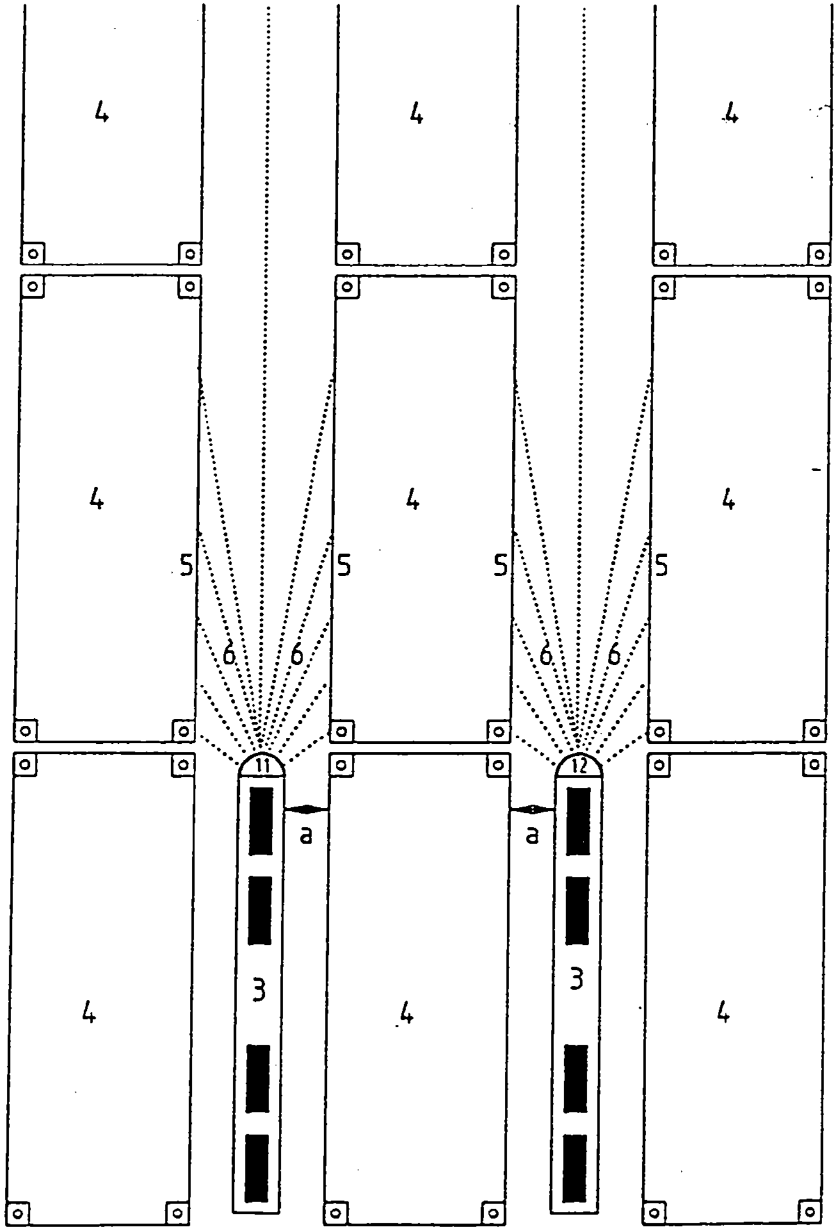

Fig. 6

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