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THE PATENTS ACT 1952

DECLARATION IN SUPPORT OF A CONVENTION APPLICATION FOR A PATENT

AUSTRALIA
CONVENTION
STANDARD
& PETTY PATENT
DECLARATION SFP4

In support of the Convention Application made for a patent for an invention entitled:

Title of Inv[illegible]

"PROCESS AND INSTALLATION FOR THE AUTOMATIC CONTROL OF A UTILITY VEHICLE"

Full name(s) and address(es) of Declarant(s)

I/~~We~~ Hans-Reinhard Knepper,

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Federal Republic of Germany

do solemnly and sincerely declare as follows:

Full name(s) of Applicant(s)

1. I am/~~We are~~ the applicant(~~s~~) for the patent

(or, in the case of an application by a body corporate)

1. ~~I am/We are authorised by~~

~~the applicant(s) for the patent to make this declaration on its/their behalf.~~

2. The basic application(~~s~~) as defined by Section 141 of the Act was/~~were~~ made

Basic Country(ies) in Switzerland

Priority Date(s) on 15 October 1985

Basic Applicant(s) by Hans-Reinhard Knepper

Full name(s) and address(es) of inventor(s)

3. I am/~~We are~~ the actual inventor(~~s~~) of the invention referred to in the basic application(~~s~~)

(or where a person other than the inventor is the applicant)

~~3.~~

~~of~~

~~(respectively)~~ ~~is/are the actual inventor(s) of the invention and the facts upon which the applicant(s) is/are entitled to make the application are as follows:~~

Set out how Applicant(s) derive title from actual inventor(s) e.g. The Applicant(s) is/are the assignee(s) of the invention from the inventor(s)

4. The basic application(~~s~~) referred to in paragraph 2 of this Declaration was/~~were~~ the first application(~~s~~) made in a Convention country in respect of the invention(~~s~~) the subject of the application.

Declared at Oberhausen this 29th day of May 1987

Hans-Reinhard Knepper

Signature of Declarant(s)

SFP4 To: The Commissioner of Patents 11/81

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AUTOMATIC STEERING CONTROL FOR A VEHICLE

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(56) Prior Art Documents
US 3669208
US 4573547
AU 47747/68 G05D 1/02

(57) Claim

10. A system for the automatic steering of a utility vehicle over an area of ground, comprising a sensor arrangement for receiving and outputting of signals correlated with an actual distance of the vehicle from a stationary guide structure, a unit presetting a nominal value and delivering signals which are likewise correlated with a nominal vehicle distance, with a comparator unit wherein the signals delivered from the sensor arrangement and from the presetting unit are compared and which outputs a signal corresponding to the difference to the steering and/or drive means of the vehicle, characterized in that the sensor arrangement is part of echo distance measuring means affixed to the vehicle, which means deliver a signal proportional to the nominal distance of the vehicle from the surfaces rising above the area of ground, and that the presetting unit likewise outputs a signal proportional to the distance in accordance with the desired vehicle path along the rising surfaces.

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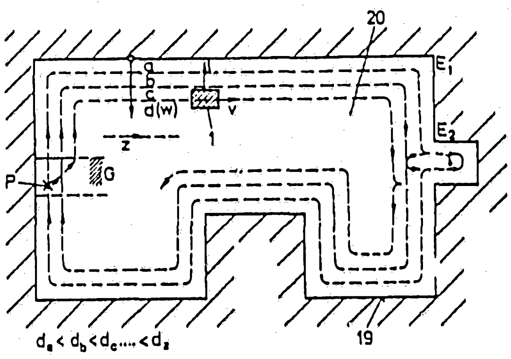
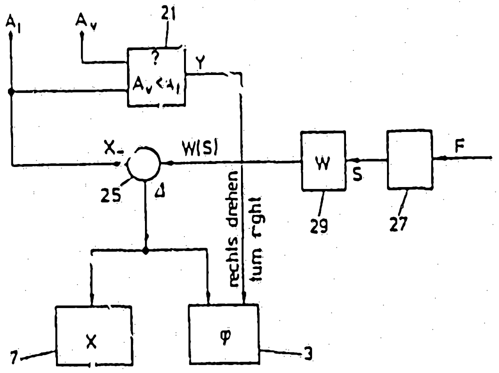
(54) Title: PROCESS AND INSTALLATION FOR THE AUTOMATIC CONTROL OF A UTILITY VEHICLE

(54) Bezeichnung: VERFAHREN UND ANORDNUNG ZUR AUTOMATISCHEN STEUERUNG EINES ARBEITSFAHRZEUGES





(57) Abstract

In order to stear automatically a vehicle on the ground (30) and to make optimum use of the ground structures, the vehicle (1) is driven at a distance in relation to the structures (19). The effective lateral distance (A_l) is compared with a drive signal ($W_{(s)}$) and the signal representing the difference is transmitted to the vehicle in order to operate the relevant drive (7) and stearing (3) components. The drive signal is modified according to predetermined criteria (29).

(57) Zusammenfassung

Um ein Fahrzeug automatisch auf einem Bodenareal (30) zu führen, dabei Strukturen im Bodenareal optimal auszunützen, wird das Fahrzeug (1) bezüglich Strukturen (19) abstandsgeregelt geführt. Der einseitige IST-Abstand (A_l) wird mit einem Führungssignal ($W_{(s)}$) verglichen und am Fahrzeug, entsprechend der Regeldifferenz, Antriebs- bzw. Lenkorganen (7, 3) als Steller gesteuert. Das Führungssignal wird nach vorgegebenen Kriterien verändert (29).

Process and Installation for the Automatic Control of a Utility Vehicle

The present invention pertains to processes for the automatic control of a utility vehicle over an area of ground, in which stationary guide structures are provided, to which the utility vehicle is effectively linked at least intermittently for guidance, and to devices for this purpose, provisions being made for at least intermittent effective linkage between the vehicle and the guide structure, and control elements being provided on the vehicle so that it can be controlled via actuation of steering and/or drive elements.

Many different methods are known in the area of the automatic control of vehicles. In this respect, reference is made to the attached list concerning the state of the art, which forms an integral part of the present document.

A consideration of the technical development in this field shows that processes or devices which make use of stationary guide structures to control the vehicle have been known for a long time. The simplest guide structures are rails: The vehicle is connected mechanically to the rails and is guided by them. It is also known from, for example, W. German Patent No. 2,445,001, W. German Patent No. 2,722,222, and W. German *Offenlegungsschrift* No. 3,134,749, that "rails" in a general sense can be provided as permanent guide structures, and the vehicle can be effectively linked to them by optical or electrical means, such as by induction, so that it can be guided by them. W. German *Offenlegungsschrift* No. 3,113,086 also describes a similar method, in which reflective surfaces are provided as stationary guide structures. The position of the vehicle at any point in time is determined opto-electronically with respect to these reflective surfaces, and the vehicle is guided by means of these reflective surfaces, serving here as guide structures, to which the vehicle is optically linked.

W. German *Offenlegungsschrift* No. 2,704,852 describes a similar method, in which electromagnetic transmitters are used as guide structures, which are linked electromagnetically to corresponding receivers provided on the vehicle, the vehicle thus being guided by these transmitters.

All these methods based on the installation of stationary guide structures suffer from one or more of the following disadvantages:

- It is extremely expensive to install a system of guide structures over an area of ground. Severe limitations are thus imposed on the flexibility with which such processes or devices can be used on unprepared ground.
- If guide structures are installed permanently at relatively great distances from each other over the area, which means that the vehicle can monitor its position in the area only at relatively long time intervals, it is necessary either to accept considerable deviations between the path desired and the path actually traveled by the vehicle during the time between the vehicle checkpoints or to provide expensive measures on the vehicle which make it possible to orient the vehicle in a relative manner between the checkpoints on the basis of the recordings made of drive and/or steering element activity on the vehicle. Such relative orientation is imprecise, however, because of the unavoidable slippage between the elements mentioned and the ground and must always be verified at the checkpoints indicated.
- If, for example, transmitters are provided as stationary guide structures, it is necessary to pay for installing these devices and for laying their electrical cables, but very careful planning is also needed to take advantage of the direct lines of sight available for sending and receiving.

In the effort to make the automatic control of the type indicated independent of the layout of the ground area and thus to avoid the problems involved in installing stationary guide structures and in making precise plans, high-speed electro-optic image-processing methods have been used, as is known from W. German Patent No. 2,364,002, for example, according to which the vehicle orients itself on the basis of an "image" of the space by comparing instantaneously recorded image information with the nominal image information stored in its memory.

It is now obvious that the concept of using stationary guide structures makes accurate vehicle guidance possible only as long as the effective link between the vehicle and the guide structure is present. The longer this link remains intact or can remain intact, the simpler will be the equipment needed on the vehicle itself to guide the vehicle with some acceptable degree of precision along the intended path during the phases in which the vehicle is no longer linked with the guide structures and thus necessarily wanders off course to some extent as a result of the slippage mentioned earlier.

The goal of the present invention is to retain the advantages mentioned above inherent to processes and devices based on the use of stationary guide structures while eliminating their disadvantages or while making better use of such guide structures insofar as can be accomplished by maintaining the active link with the vehicle over a much longer period of time.

This goal is achieved under a first aspect of the invention in the form of a process in that the distance between the vehicle and the guide structure is under closed-loop control, whereas the nominal distance value is under open-loop control. The distance is measured from the vehicle by means of, for example, ultrasonic sensors.

The basic idea is that, if, in a closed-loop or feedback control system for controlling the distance to the guide structures, the nominal distance value can be changed in an open-loop control system, the effective link to the installed stationary guide structures can be kept intact for a much longer period of time so that the vehicle can be guided accurately on its paths across the ground area. Thus the vehicle remains linked to the guide structures insofar as its distance to these structures is controlled, even though it can be guided on completely different paths by the same guide structure through changes in the nominal distance value: Setting the distance eliminates in principle one of the degrees of freedom of vehicle movement, but the adjustment of the nominal distance value restores this degree of freedom.

Another method according to the invention for solving the problem mentioned above involves the use of the vehicle to lay a track, preferably a track on completed work. The distance of the vehicle from this track, which serves as a guide structure, is then feedback-controlled.

In a process consisting of a combination of processes according to the invention, a track, preferably a track of completed work, is laid by the vehicle, at least intermittently, and the distance of the vehicle from this track, serving as guide structure, is feedback-controlled; in addition, the distance of the vehicle from another guide structure is also feedback-controlled, at least intermittently.

Thus the distance of the vehicle from the so-called other, permanent guide structure is initially under closed-loop control until, for example, a sufficiently long track has been laid, after which this track is then used as a guide structure. So that structural contours, such as corners, can be easily followed in a distance-controlled manner, it is also proposed that the distance to the guide structures be determined in the direction of at least two fixed vehicle axes and that the distance in the one direction be used as the actual distance value for the closed-loop control, while the distance in the other direction is used as the control variable for the drive and/or steering elements on the vehicle.

If, for example, a vehicle is passing along a guide structure at a feedback-controlled distance and the guide structure has a recessed corner, this recess is registered as a sudden increase in distance in that one direction; the closed-loop control system alone is sufficient to follow this recessed corner. But if the vehicle encounters a projecting corner of the guide structure, which the vehicle follows at a controlled distance, the distance in the other direction, which suddenly decreases on approach to the projecting part of the guide structure, is registered, and this is used as the control variable or control signal for the drive or steering elements in such a way that the vehicle executes a corresponding turn, by which means the distance determination in the first direction, as an actual value determination, continues to function as input to the closed-loop control system. Thus the vehicle travels at all times under closed-loop control on one side, always keeping a guide structure, no matter what its shape, at a feedback-controlled distance.

It is also proposed that the vehicle be able to detect when it has arrived at an area over which it has already travelled. For example, this is essential when a guide structure with a closed shape is followed, as is the case, for example, with the perimeter wall around an area, so that a decision can be made as to when the nominal distance value should be changed.

For this purpose it is proposed that, from the vehicle, a path already traveled be registered by the measurement of drive and/or steering element activity, and that this information be used to establish agreement between the current position of the vehicle and a previously occupied position.

Another proposal for this purpose consists in that the detection takes the form of registering a mark at a predetermined position with respect to the vehicle.

As proposed below, the nominal distance value is then changed on the basis of the discovery that the vehicle has arrived at a part of the area over which it has already travelled.

A vehicle which now follows a closed guide structure at a controlled distance according to the invention and whose nominal distance value is changed every time it arrives at a previously travelled part of the area travels along a spiral path. It is in accordance with the second concept of the invention that the vehicle always uses the track it has just laid as a guide structure for the continuation of its travel.

When a vehicle with this type of closed-loop distance control system encounters a free-standing obstacle, which it has never before seen, additional control processes must be provided in response. However such control responses are designed, the vehicle must first recognize that the obstacle is free-standing, so that it does not simply travel around the obstacle at the prevailing nominal distance and thus possibly leave a wide, unworked strip around the obstacle. For this purpose it is proposed that a travelled vehicle path be registered and that at least part of it be stored. On the basis of these stored parts of a closed vehicle path, at least parts of a vehicle path with a modified nominal distance value to be travelled immediately thereafter are calculated and also stored. If, thereafter, the path or parts thereof actually travelled by the vehicle deviate from the precalculated and stored parts, the conclusion is drawn that a free-standing obstacle is present in the area.

An additional case to be considered is that in which narrow passages are present, by which, for example, two wider parts of the grounds are separated. To register this, it is also proposed that a travelled vehicle path be recorded, crossovers and/or overlaps be determined, and the presence of narrow passages be inferred from that information.

It is also proposed that preselected parts of the guide structures be selected as effectively controlling guide structures and/or a chronological sequence be established according to which these parts are to become effectively controlling. By means of this measure it is possible, for example, in the case of grounds with obstacles and narrow passages, to subdivide the grounds into simply structured partial regions; to have the vehicle work over one of these regions first, for example, without regard to the others; and then to have the vehicle travel to a second partial region, which is then worked over independently of all the others, etc.

Through the preselection of which parts of the guide structures are to be effectively controlling and/or through the presetting of the chronological sequence with which they are to be registered as effectively controlling, it is also easy to guide the vehicle over any predetermined path. Presetting which guide structures become effectively controlling at which times can be accomplished easily by recording, on the vehicle, the path travelled by the vehicle and by controlling, at predetermined points along this "relative" path, which is likely to be somewhat off-course, the side of the vehicle on which the guide structure which is intended to become effectively controlling appears, possibly within a distance framework or window. The path recorded by the vehicle can suffer from error without detriment, because, after the guide structure which is to become effectively controlling has been recognized, the distance between the vehicle and the guide structure is adjusted accurately regardless of the position in which the vehicle has recognized this structure.

Devices for the automatic control of the type described above are specified in Claims 12, 13, and 14; preferred embodiments are specified in Claims 15-22.

The invention is explained below by way of example on the basis of the figures:

-- Figure 1 shows a schematic diagram of the structure of a vehicle according to the invention;

-- Figure 2 shows the distance control system according to the invention for the vehicle according to Figure 1 on an area of ground;

-- Figure 3a shows a closed-loop/open-loop control system on the vehicle according to Figure 1 on the basis of a functional block diagram;

-- Figure 3b shows three different variants for detecting when a vehicle according to the invention arrives at a section already travelled;

-- Figure 4 shows an additional guidance variant of a vehicle according to the invention with, on the left, the path travelled by this vehicle;

-- Figure 5 shows the behavior of a vehicle according to the invention with path criteria for recognizing a narrow passage;

-- Figure 6 shows a section of the grounds with a free-standing obstacle to illustrate the behavior of a vehicle according to the invention for determining the characteristic features of free-standing obstacles;

-- Figure 7 is a block diagram of a closed-loop/open-loop control system for a vehicle according to the invention, making use of the criteria found for narrow passages and obstacles;

-- Figure 8a shows an area with complicated structure and a simple vehicle control system according to the invention therein;

-- Figure 8b,c shows a signal flow chart for a vehicle control system like that shown in Figure 8a; and

-- Figure 9 is a block diagram of a control system according to the invention for the vehicle with the closed-loop control unit.

In Figure 1, the principal design features of a vehicle *1* are shown in purely schematic fashion. This can be a lawn mower, a floor sweeper, a vacuum cleaner, a street sweeper, a transport vehicle, etc. It is designed mechanically to suit its intended purpose. Vehicle *1* includes, as an example, front wheels *5*, rear wheels *9*, a controllable drive *7* for the rear wheels, which can be actuated by way of control inputs E_7 for forward and backward movement, both at variable speed. Front wheels *5*, which are designed as steering wheels, as indicated by the symbol ϕ, are made to pivot around joints *11* by a steering control unit *3*. Drive *7* and steering control unit *3* with control inputs E_3 can be electric motors, for example; and steering control unit *3* can be built with linear motors, which act by way of appropriate gears on their respective wheels *5*, *9*. One or more tools *13* (shown schematically) can be provided on vehicle *1*, such as a vacuum bar, a cleaning bar, a mower, etc., with corresponding drives (not shown) of conventional type. On the vehicle, furthermore, are distance-measuring devices, such as ultrasonic sensors, i.e., a forward-looking (*V*) distance sensor 17_v and a left-looking distance sensor 17_l. With this sensor arrangement, the vehicle is set up for distance control toward the left. Outputs A_v, A_l are connected to a closed-loop control device *15* provided on the vehicle, which controls steering control unit *3* or drive *7* on the basis of the signals at outputs A_l, A_v.

Figure 2 shows an area defined by means of a boundary structure, such as walls *19*, as a permanent guide structure. A spiral path travelled by a vehicle according to Figure 1 is shown schematically proceeding from a starting point *P* in dotted line.

Figure 3a shows the layout of the closed-loop control system *15* according to Figure 1 for realization of the working path illustrated in Figure 2.

Output signals A_l and A_v of distance sensors *17* are sent to a comparator *21*, which determines whether the distance toward the front is smaller than the controlled distance toward the left. Signal A_l of sensor 17_l is transmitted as the controlled variable or actual value *X* to a differentiator *25*, to the second input of which is transmitted a distance command signal or nominal value signal *W*. The control difference Δ is transmitted to steering control unit *3*, or possibly to drive *7*, and controls the vehicle by way of these actuating units in such a way that the controlled variable *X* (actual value) becomes at least nearly the same as the reference input *W* (nominal value). Whereas signal A_l acts as the controlled variable or actual value in the closed-loop system, signal A_v of the forward sensor 17_v acts as the control signal of steering control unit *3* as soon as its value falls below the signal value of A_l, which is determined by unit *21*, and thus turns the vehicle toward the right, in the case of a vehicle with left-oriented control. In place of a comparison between A_v and A_l, it can be advantageous to compare the more stable value *W* with A_v. A reference input control *27* is controlled in a way to be described later by a control signal *F* and transmits various reference inputs or nominal value signals W to differentiator *25* by way of a reference input transmitter *29* to fulfill the function of control signal F. Reference input signal W is transmitted whenever the vehicle has completed a circuit according to Figure 2. There are various ways in which this can be detected, as illustrated schematically in Figure 3b.

The first possibility consists in placing a mark at the starting point P according to Figure 2, either on wall *19* or on the ground, especially for this purpose; or a landmark such as an edge of wall *19* or an edge of ground *20* is detected by means of a mark detector *33* on vehicle *1*. Each time mark *31* is detected from vehicle *1* at a predetermined position r, a reference input control signal F is generated, by which means the reference input value W at reference input transmitter *29* is changed (increased, according to Figure 2), and thus the feedback-controlled distance $a(w)$ is also increased.

A second way is to have vehicle *1* lay a track *35*, even if only to serve as a mark. This can be a track of moisture if the machine is used for wet cleaning; in the case of a lawn mower, the track can be the path just mowed. Both of these tracks are easy to detect. If the working track is difficult to detect, a track especially intended for the purpose can be laid by the vehicle, such as a moisture track, which remains in existence for only a relatively short period of time and then evaporates. A track detector *37* is provided on vehicle *1*, which detects when vehicle *1* encounters a previously laid track *35*, designated *35a*. Then a reference input change signal F is triggered, and, for example, again according to Figure 2, a larger reference input W is sent by reference input transmitter *29*.

A third variant consists in providing pickups *34*, *36* on the vehicle; these pickups record the steering deflections ϕ and forward movement x at the steering or drive elements. These are sent to a computing and memory unit *39*, preferably with a microprocessor, which uses the directional and distance data x, ϕ to determine continuously the travelled path B; this information is then stored. The path data B_m, corresponding to the monitoring of the instantaneous vehicle position, are first compared with path point B_p at the start of a circuit, so that, as soon as vehicle *1*, according to Figure 2, has completed a circuit, this is detected by the agreement between the instantaneous value B_m with the stored value B_p at the start of the same circuit. When agreement is found, reference input change signal F is again triggered.

A vehicle *1* equipped with a control system according to Figure 3a traverses a spiral path when placed on an area *20* according to Figure 2. It keeps a distance d_a, corresponding to a reference input signal W_a, between it and walls *16* during its first circuit *a*. When the path is completed and thus a reference input change signal F is triggered, the reference input W is increased, in a generalized manner to W_z, and the vehicle traverses a closed path z with the assigned distance d_z between it and walls *16*. The vehicle also follows projecting or recessed sections of wall. When it arrives at a corner E_1, comparator *21* determines that the distance from the forward sensor 17_v according to Figure 1 is smaller than that from sensor 17_1. Thus steering control unit *8* is actuated, and a right turn is executed. The distance detected by sensor 17_v increases again, and the distance detected with sensor 17_1 is again transmitted as the controlled variable or actual value. In the case of a recessed corner E_2, sensor 17_1 detects that the controlled distance d_1 assigned to it suddenly increases considerably, which leads to a corresponding control difference according to Figure 3a. To compensate for this, the vehicle makes a left turn, by means of which the distance detected by sensor 17_1 becomes smaller again and finally matches reference value W.

Instead of using structures inherent to the space as guide structures such as boundary walls, by which color contrasts, material contrasts, etc. are also understood, it is also possible to install guide structures such as sprayed tracks, which evaporate after a certain time. This can be done easily, because the nominal distance control system according to the invention provides the possibility of using such vehicle guidance structures to help control paths which are much longer that the extent of the guide structures themselves. Figure 2, for example, shows the length of a path on which the vehicle easily travels with precise control, the total length of the spirals being many times longer than the required length of the guide structure, that is, the length of the boundaries.

Figure 4 shows the control method according to the invention in which the guide structure is regulated by the vehicle itself. At the beginning, the vehicle, such as that already described, is guided by means of sensors *17* at a predetermined distance along walls *19* according to Figure 1 (this can also be done manually) so that the vehicle lays a track *41*. In contrast to track *35*, which was described in association with Figure 3, track *41* must be laid by vehicle *1* in at least a nearly continuous manner. In Figure 3 it is sufficient in itself for track *35* to be laid only in the area of the starting position corresponding to *P*, that is, in an area *G* indicated as in Figure 2 in broken line. Track *41* is preferably a track of completed work, e.g., a moisture track in the case of wet cleaning. Track sensors 43_r, 43_l are provided on the front of vehicle *1*, possibly together with distance sensor 17_v. If vehicle *1* leaves behind a track of moisture, the sensors detect moisture. The two sensors *43* detect whether a track *41* is present under the vehicle or not. Once the vehicle has completed its first circuit, however it may have been configured, it encounters track *41* which it has just laid, and it is guided, as shown, by sensors *43* alongside the previously laid track *41*. The retracing of the track in the design variant corresponds again to a distance control system based on structures of the ck *41*, but in this case there is no nominal distance distance is predetermined, preferably in such a way that one track is laid adjacent to or even overlapping with the other.

The control system described so far is suitable, without any initial enhancements, for working on areas of ground without narrow passages and/or free-standing obstacles. On the basis of Figure 5, the situation involving narrow passages is explained, and Figure 6 is used to explain the problem of free-standing obstacles. Narrow passages are understood to mean passages through which the vehicle can travel at least once back and forth with distance control on one side, but in which, as the distance to the wall on one side continues to increase, the vehicle is "trapped" in a certain part of that space, as illustrated in Figure 5. According to Figure 5, which shows a space of this type with a narrow passage *50*, the vehicle travels first along path *a*. After the reference input value *W* has been increased on the basis of signal *F* according to Figure 3, in area *P*, the vehicle travels on path *b*. Path *b* in narrow passage *50* is in this case already identical to path *a*, although it is travelled in the opposite direction. When the reference input and thus the distance increases, which results in path *c*, the vehicle will first turn toward the left, because the detected distance to the wall on the left at E_3 suddenly increases, whereupon sensor 17_v picks up the corner E_4 of the narrow passage in front of it. Vehicle *1* pivots again toward the right on the basis of the control signal from unit *21* according to Figure 3a, as if at a corner, such as at *K*, and follows, as indicated at c_1, walls *19* of the left partial area *20a* at a controlled distance. This area on the left is worked on until the center is reached. The right partial area *20b* to the right of narrow passage *50* is not worked on. To solve this problem in the way described below, it is necessary for the vehicle to recognize such narrow passages as such, from which conclusions can be drawn with respect to the control algorithm, that is, the transmission of the reference distance inputs.

To solve this narrow passage problem, it is assumed that whenever a circuit such as b crosses itself twice, in areas M_1 and M_2, a narrow passage must exist between them, because a crossover can originate only from the overlap of controlled distances from two opposite wall areas. Thus path intersections, possibly with overlapping areas as the limit case, are detected as the criterion for "narrow passages", and corresponding interventions can be made in the reference input control system *27*, *29* according to Figure 3a. The position and number of such intersections make it possible to identify the structure of the space and thus to control the reference inputs accordingly.

Figure 6 shows the relationships in the presence of a free-standing obstacle *51*. A free-standing obstacle is, according to definition, an obstacle which is positioned on the grounds *20* with respect to a guide structure, e.g., a boundary wall *19*, at such a distance that vehicle *1* can travel at least once without impediment between wall *19* and obstacle *51*. After successive increases in control distance d, vehicle *1* will at some point encounter the obstacle, such as on path f, and, as in the case of a corner K in Figures 2 and 5, will travel around the obstacle at the adjusted control distance d_f. There thus remains an unworked, possibly wide strip around obstacle *51*. Here, too, there is a simple criterion for finding "obstacles". A free-standing obstacle is present whenever path f of vehicle *1* just travelled deviates from the previously travelled path e, under consideration of the newly transmitted reference input W_f and thus the distance differential $d_f - d_e$.

Because intersections occur on the paths when a narrow passage is present but not, as can be seen from Figure 6, when free-standing obstacles are present, and, vice versa, because deviations occur from the path calculated from the previously travelled path and the newly adjusted distance when a free-standing obstacle is present, but not when a narrow passage is present, except when the vehicle can no longer travel through the narrow passage, criteria are available for switching to the proper algorithm for the reference input and for programming a control computer in such a way that the vehicle reacts correctly to obstacles and to narrow passages. This is readily possible for the specialist well versed in this field on the basis of the information presented here.

The basic structure of a control system designed for such cases is shown in Figure 7. On vehicle *1*, forward movements x and steering deflections ϕ are registered by means of appropriate detectors *53*. These values are sent to a computing unit *55*. Computer *55* calculates from these data the instantaneous position $P(t)$ of vehicle *1* with respect to a stationary system of coordinates. The corresponding data $P(t)_{\#}$ are sent to a path memory unit *57*, where the travelled path is stored with the totality Σ of the data on the individual positions. From the totality of these position data $\Sigma P(t)_{\#}$ and the instantaneous position data $P(t)_{\#}$, computer *55* determines the intersections P_k if the path just travelled and positions P_G, at which a travelled path becomes closed, as indicated schematically by block *59*. A reference input control system *61* operates according to certain rules in correspondence with the position of the intersections or closure points which have been found.

When a closed path has been completed, furthermore, the new reference value signal W to become active is sent to computer *55* as the input variable. From the path $\Sigma P(t)_{\#}$ previously travelled and stored in memory *57*, and in the knowledge of the new reference input value W, the computer calculates path $\Sigma P(t + T)_{\#}$ to be followed immediately thereafter and loads its data into a reference path memory *63*. While the vehicle now travels along the new path, computer *55* compares continuously the instantaneous path positions $P(t)_{\#}$ expressed by x and ϕ with the reference path data $P(t + T)_{\#}$ stored in reference path memory *63*. If the two sets of data differ from each other, it is concluded that an obstacle such as that indicated by block *65* is present, and the reference input control system *61* is adjusted according to the predetermined rules.

Instead of recognizing narrow passages and obstacles, as described above, and solving control algorithms developed for such cases, the procedure describ below is based on dividing complicated spaces into simple partial spaces and on moving the vehicle from one space to another as it finishes its work in the former. This can be realized by temporarily disconnecting the control system and moving the vehicle in the simplest way possible with however much error along an approximate path from the one partial area to the other. This procedure also makes it possible to steer the vehicle on any desired predetermined path on a space of ground from one point to another automatically; the vehicle will be operating predominantly in a distance-controlled manner, but it can be told when it is to use which guide structures appearing in its field of vision as effectively controlling structures.

Figure 8a shows an area *70* with a relatively complicated structure. This area *70* can be divided, for example, into regions *A* and *B*. These partial regions *A* and *B* are connected by a narrow passage *C*. As can be seen from Figure 8a, the vehicle is to be started at *P*, work over partial region *A* first, as if the other regions did not exist, as shown in broken line, and then, as shown in dotted line, perform its work in region *B*, as if regions *A* and *C* did not exist.

Figure 8b shows a signal flow diagram, which helps explain how the vehicle is controlled so that it does not enter narrow passage *C*, that is, so that it first completes its work in region *A*. For this purpose, Z-coordinates Z_1 and Z_2 corresponding to the position of narrow passage *C* are compared with instantaneous values Z_m recorded on the vehicle. The latter are, as has already been described, determined by evaluation of the length and directional pickup signals (x, ϕ) at the drive and steering elements, respectively, of the vehicle. In the region between the two preset values Z_1 and Z_2, the feedback control system is disconnected, and the vehicle receives the simple instruction to go straight. As soon as a value lower than the limit value Z_2 is reached, the vehicle is switched back to closed-loop operation, so that it can do its work in partial region *A* without being guided into narrow passage *C*.

Figure 8c shows a signal flow diagram for moving the vehicle through passage *C* and into partial region *B* after it has completed its work in partial region *A*. For this purpose, a maximum distance reference input value or nominal distance value W_{max} corresponding to region *A* is compared with the instantaneously on-line distance reference value W_m. If agreement is found, the feedback-control system is turned off, and the vehicle is controlled according to predetermined forward and steering movements $x(t)$ and $\phi(t)$. Then the maximum forward movement x_{max} thus travelled is compared with the instantaneous forward movement x_m detected at the vehicle drive and, if agreement is found, the vehicle is again switched over to its closed-loop operating mode: it starts work again in partial region *B* under full feedback control.

Figure 9 shows a block diagram of a control system for executing operations such as those explained on the basis of Figure 8a. Sets of data which specify selected positions $P_{FZ\#}$ on the area are stored in a memory unit *72*. In a comparator *74*, these position values are compared with instantaneous position values P_{FZm}, which are recorded on the vehicle by means of a detector *76*, which can encompass the drive element and steering element pickups for x and ϕ described previously. Depending on which preset position values $P_{FZ\#}$ the instantaneous position values P_{FZm} agree with, the closed-loop controller is turned on or off by way of a selector unit *78*, and a path *1* is steered without feedback by the length and steering deflection control of x and ϕ, or a path *2* is taken; or, for example, a guide structure, which is now on the left of the vehicle, is detected in an effectively controlling manner. If several structures are on the left of the vehicle, the ones which are closer than 5 m, for example, are detected as the effectively controlling ones, etc. In this way it is possible with little effort to guide the vehicle in any way desired over a piece of ground, making use again and again of the distance control process according to the invention for selected guide structures.

In all cases, the present invention thus is based on the principle of guiding the vehicle at a controlled distance from structures in accordance with predefined rules. It thus becomes possible to make optimum use of the information inherent in the area in question. After all, such structures define the piece of ground. In this way it is made possible, even when areas with complicated structures are to be traversed without error, to proceed from a simple basic concept and thus to solve special cases such as negotiating narrow passages and travelling around obstacles by means of relative orientation. It is obvious, of course, that a man of the art will think of many possible rules for solving the special cases mentioned.

The claims defining the invention are as follows:

1. A process for the automatic steering of a utility vehicle over a piece of ground, with utilization of a stationary guide structure, wherein an actual value depending upon the vehicle's distance from the guide structure is determined on the vehicle, then compared with a value nominal value associated with a nominal distance of the vehicle form the guide structure, steering the vehicle by the result of the comparison, at least on partial path sections, in a regulating fashion so that the vehicle follows the guide structure while maintaining the nominal distance, characterized in that the actual value is determined, as a quantity proportional to the distance, by echo distance measurements from the vehicle with reference to surfaces rising over the piece of ground and delimiting the same, that a quantity proportional to the nominal distance is inserted as the nominal quantity identifying the nominal distance, and that the steering is effected by presetting the nominal quantity according to the desired vehicle track.

2. The process according to claim 1, characterized in that the distance is determined in the direction of at least two axes fixed with respect to the vehicle and that the distance in the one direction is used as the nominal quantity and the distance in the other direction is used as an additional steering quantity for the vehicle.

3. The process according to any one of Claims 1 or 2, characterized in that detection is effected on the vehicle when the vehicle travels once more over a previously passed area.

4. The process according to Claim 3, characterized in that a previously traveled track is determined by recording drive member (x) movements and steering member (φ) movements and that therefrom coincidence of an instantaneous position (B_m) of the vehicle with an earlier assumed position (B_p) is determined.

5. The process according to Claim 3, characterized in that detection is effected by registering a mark at a predetermined position (r) of the vehicle.

6. The process according to any one of Claims 3 through 5, characterized in that during, or after, detection of a previously worked area, the nominal distance is modified.

7. The process according to any one of Claims 1 through 6, characterized in that a travelled vehicle path is registered and at least parts thereof are stored, and that from the stored parts of a vehicle path loop, a vehicle track to be travelled immediately thereafter with a modified nominal distance is calculated and stored, and that, when the path subsequently travelled by the vehicle deviates from the calculated path, a conclusion concerning the presence of a freely rising obstacle on the area of ground is drawn.

8. The process according to any one of Claims 1 through 7, characterized in that a travelled vehicle path is registered, and that intersections (P_K) and/ or overlaps are determined, and that the presence of narrow passages on the area of ground is inferred therefrom.

9. The process according to any one of Claims 1 through 8, characterized in that parts of the surfaces are selected as effectively regulating guide structures and/or that the time sequence in which parts of the surfaces are to become effective for regulation is defined.

10. A system for the automatic steering of a utility vehicle over an area of ground, comprising a sensor arrangement for receiving and outputting of signals correlated with an actual distance of the vehicle from a stationary guide structure, a unit presetting a nominal value and delivering signals which are likewise correlated with a nominal vehicle distance, with a comparator unit wherein the signals delivered from the sensor arrangement and from the presetting unit are compared and which outputs a signal corresponding to the difference to the steering and/or drive means of the vehicle, characterized in that the sensor arrangement is part of echo distance measuring means affixed to the vehicle, which means deliver a signal proportional to the nominal distance of the vehicle from the surfaces rising above the area of ground, and that the presetting unit likewise outputs a signal proportional to the distance in accordance with the desired vehicle path along the rising surfaces.

11. The system according to Claim 10, characterized in that on the vehicle there are provided at least two distance measuring devices (17_1, 17_v) which are effective in two directions affixed to the vehicle, wherein one of the devices represents the echo distance measuring means and the other device as an additional control signal transmitter, is interactingly connected with a steering and/or drive means of the vehicle.

12. The system according to any one of Claims 10 or 11, characterized in that on the vehicle there is provided a detector unit for a preset mark in a predetermined position of the vehicle, the detector unit outputting a signal (F) when the mark is detected.

13. The system according to Claim 12, characterized in that the mark is mark provided outside the vehicle on the area of ground and that the detector unit has a detector window and outputs the signal (F) when the mark appears in the window.

14. The system according to Claim 13, characterized in that there are provided transducers of the lengths of vehicle movement and of the directions of vehicle movement for storing transducer output signals as marks.

15. The system according to any one of Claims 12 through 14, characterized in that the detector unit acts on the side of the output (F) on a control input of the presetting unit.

16. The system according to any one of Claims 10 through 15, characterized in that there are provided transducers of the lengths of vehicle movement and of the directions of vehicle movement (f) and a computer unit with which the outputs of the transducers are connected and which calculates the instantaneous positions of the vehicle from the transducer signals; that there is provided a memory unit for the positions, this unit being interfaced with the computer; and that there is provided a comparator unit for comparing the instantaneous vehicle path positions with position values stored in the memory unit to determine the coincidence of instantaneous vehicle positions with previous vehicle positions.

17. The system according to Claim 16, characterized in that there is provided a reference path memory interfaced with the computer unit, wherein the computer unit, on the basis of position data in the memory unit and a nominal distance value to be switched on in the future, calculates a future position sequence of the vehicle and stores the same in the reference path memory, and that there is provided a comparator unit comparing instantaneous positions of the vehicle with positions stored in the reference path memory to determine vehicle path deviations which were not previously calculated and were therefore unexpected.

18. The system according to any one of Claims 10 through 17, characterized in that there is provided a detector unit for detecting signals at predeterminable vehicle positions, and that the output of the detector unit is connected with a control input which controls the operating mode of the automatic steering.

DATED this SEVENTEENTH day of APRIL 1990
Hans-Reinhard Knepper

Patent Attorneys for the Applicant
SPRUSON & FERGUSON

rhk/0101E

Translation of Figures

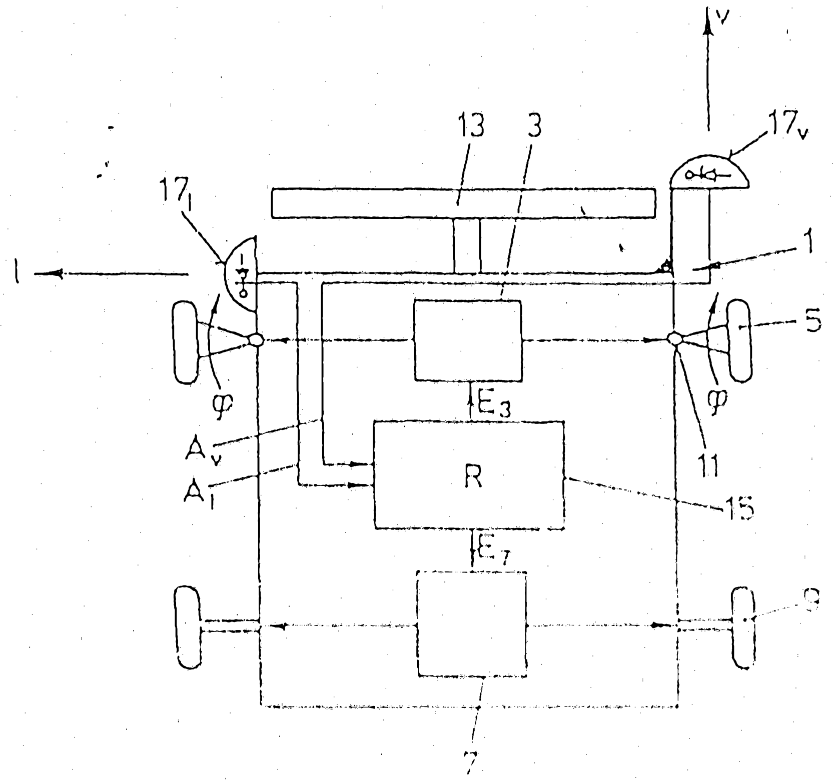


FIG.1

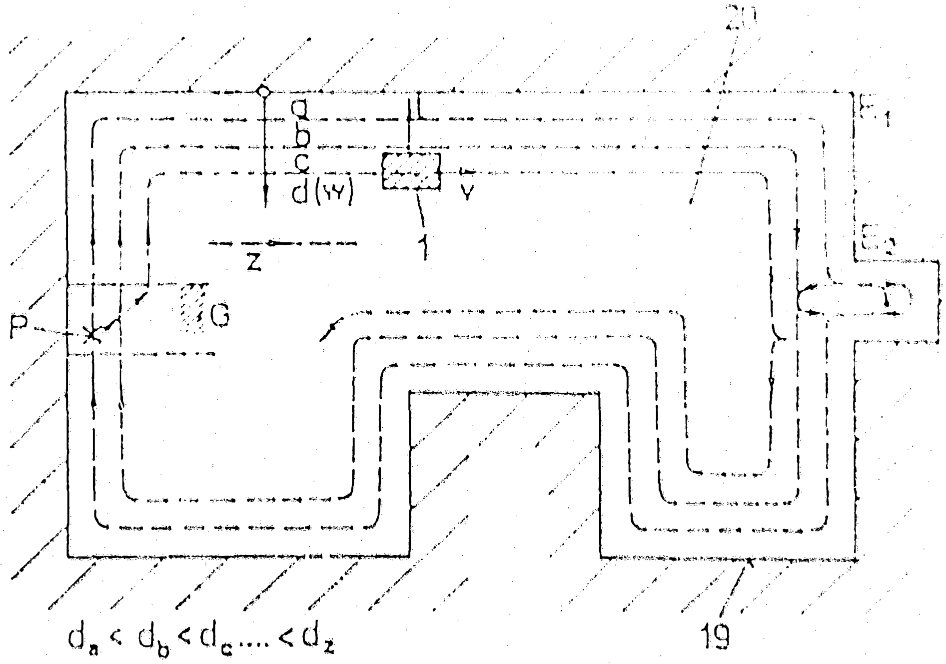


FIG. 2

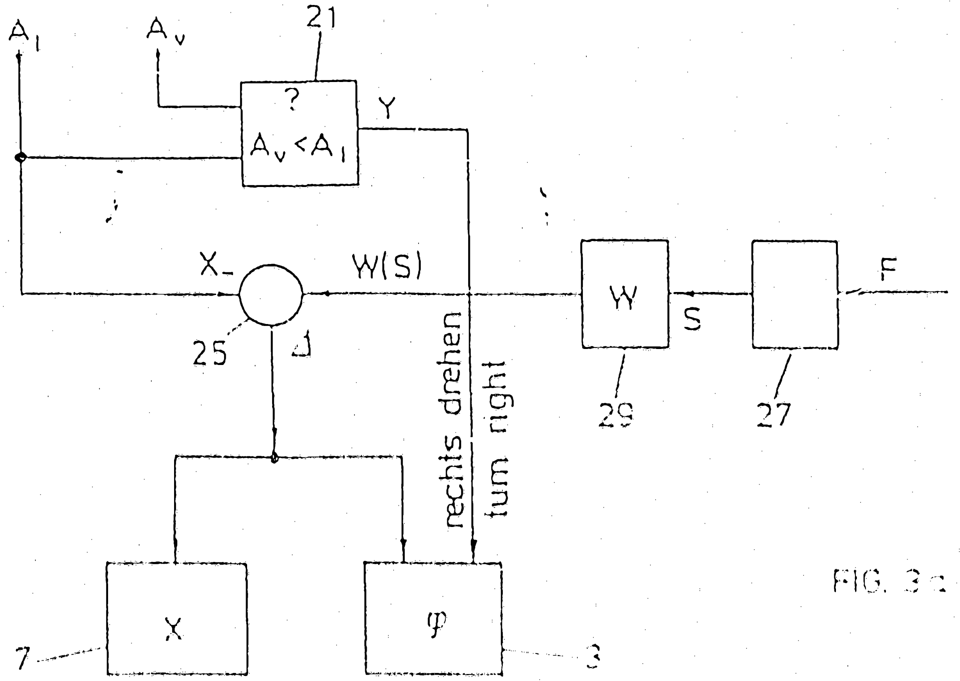

A_l
A_v
21
?
A_v<A_l
Y
X_
W(S)
25
Δ
rechts drehen
turn right
W
S
F
29
27
X
φ
7
3

FIG. 3a

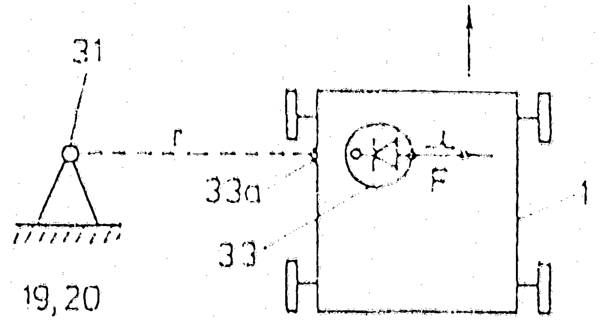
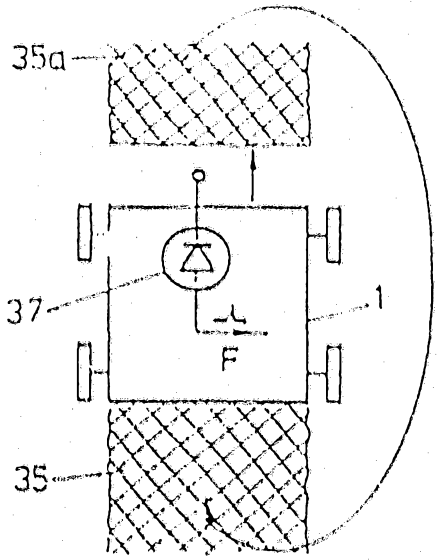
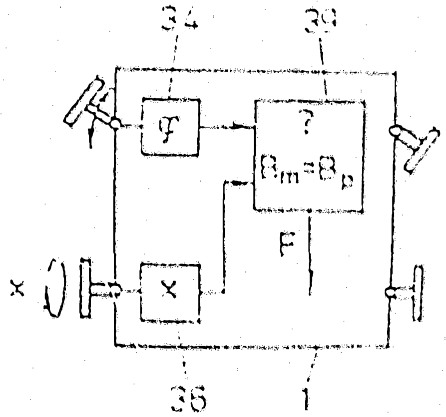

31
r
33a
33
F
1
19,20

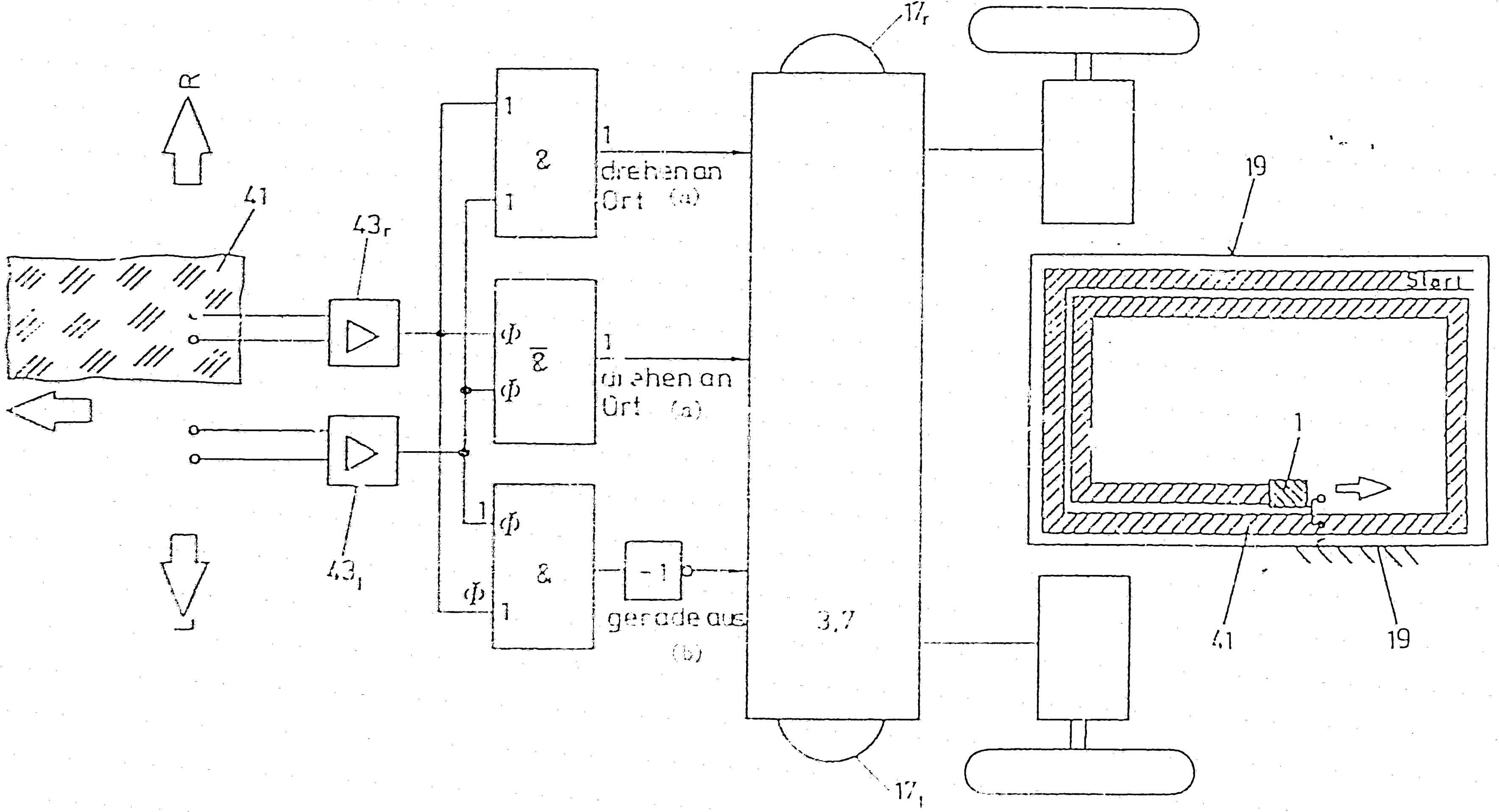
FIG. 3b


35a
37
F
1
35


34
39
φ
?
B_m=B_p
F
x
X
36
1

19 10 89   64088

Figure 4. KEY: (a) turn in place; and (b) go straight.



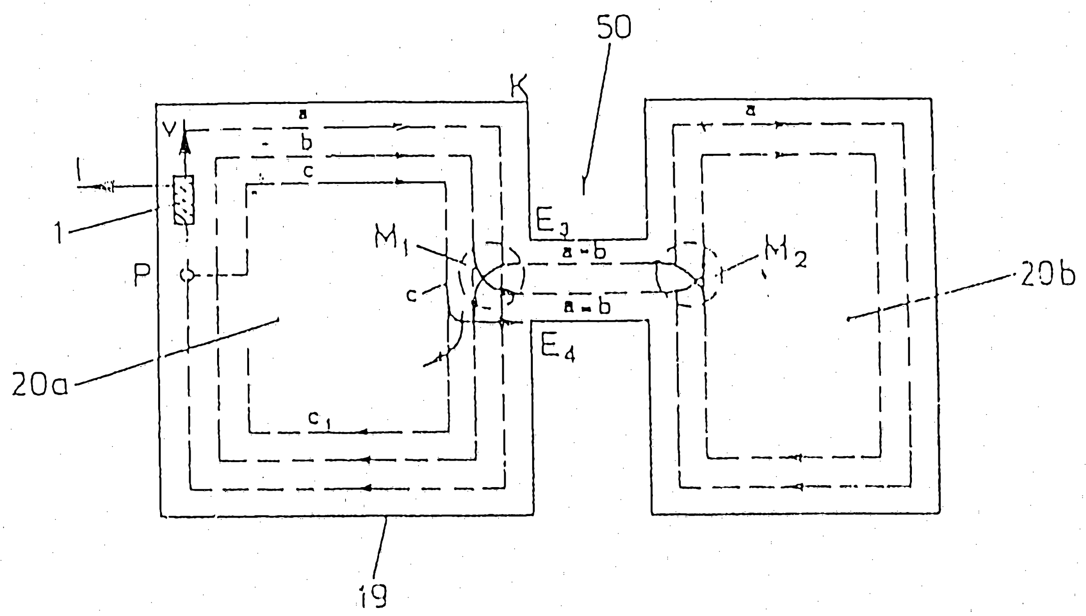


FIG.5

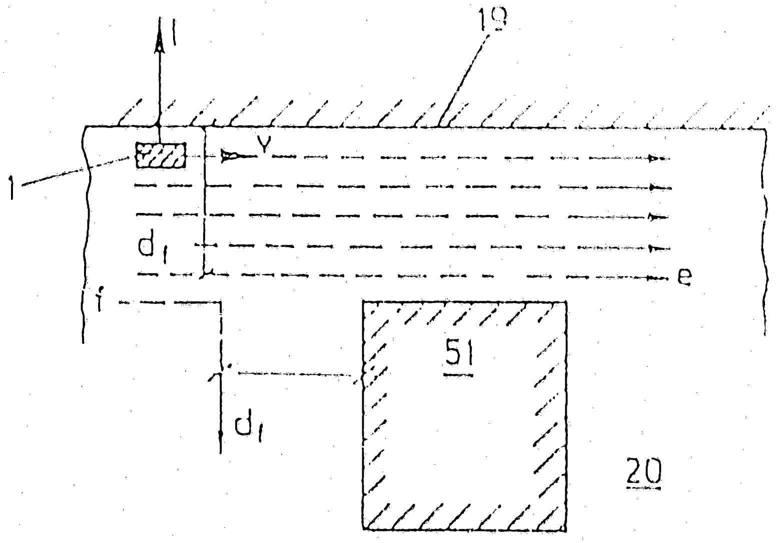
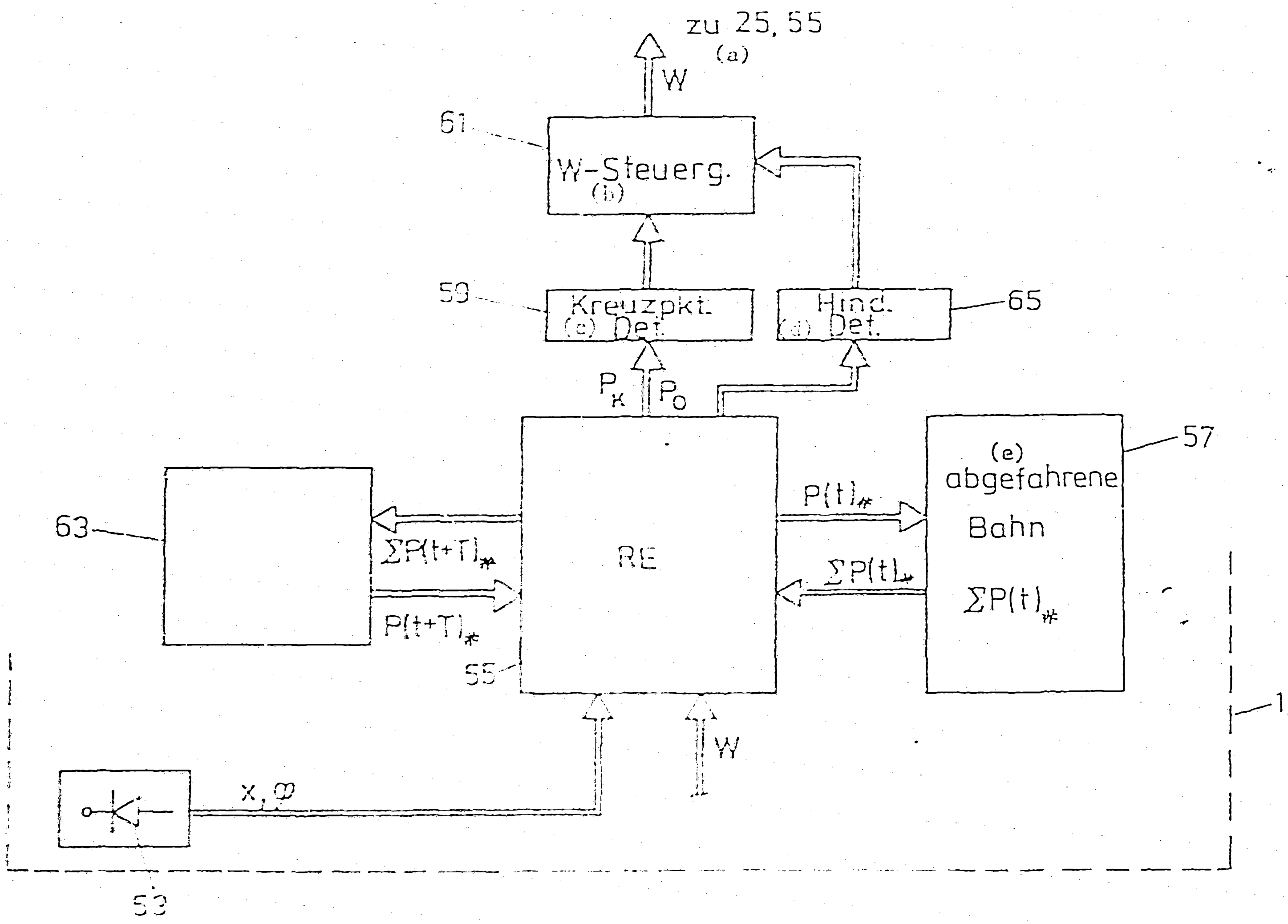


FIG.6

Figure 7. KEY: (a) to 25, 55; (b) reference input control system; (c) determination of intersections; (d) determination of obstacles; and (e) travelled path.



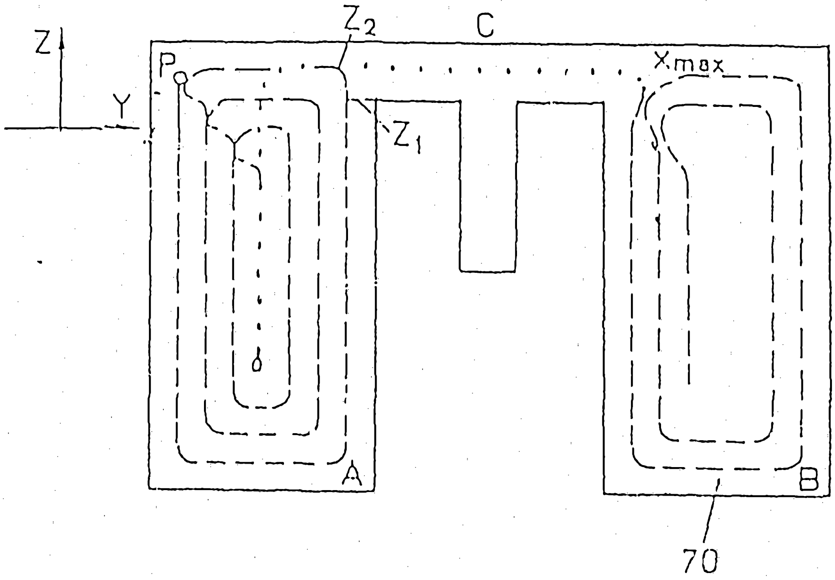

Z
Y
P
Z2
C
Xmax
Z1
A
B
70

FIG. 8a

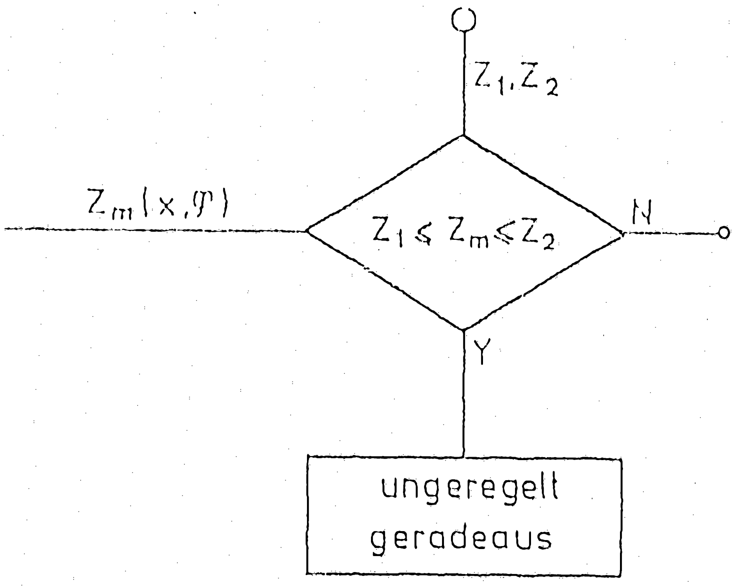

Z1, Z2
Zm(x, φ)
Z1 ≤ Zm ≤ Z2
N
Y
ungeregelt geradeaus

FIG. 8b

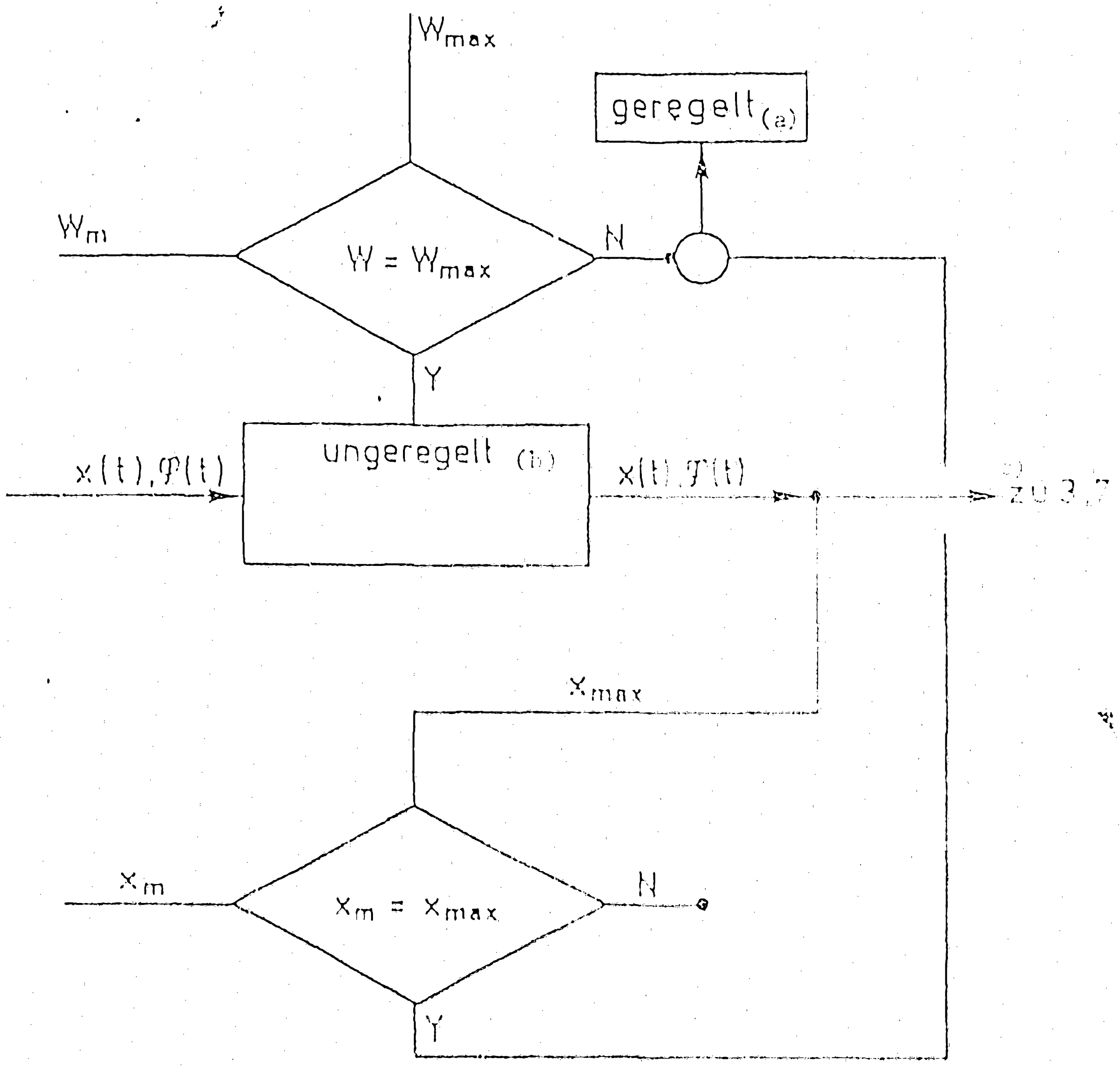


Figure 8c. KEY: (a) with feedback; (b) without feedback; and (c) to 3, 7.

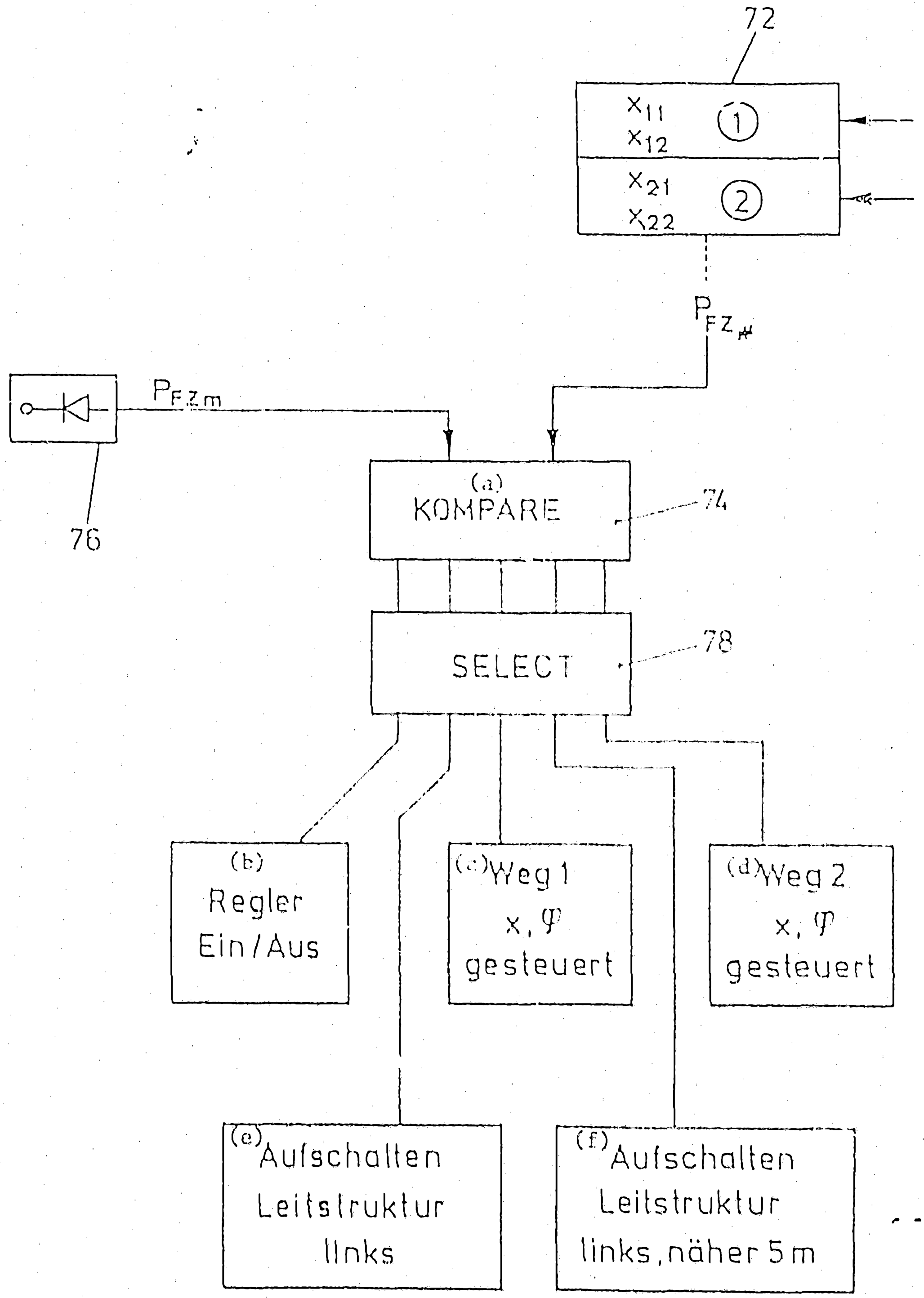


Figure 9. KEY: (a) compare; (b) closed-loop controller, on/off; (c) path 1, x, ϕ, open-loop control; (d) path 2, x, ϕ, open-loop control; (e) switch to guide structure on the left; and (f) switch to guide structure on the left closer than 5 m.

INTERNATIONAL SEARCH REPORT

International Application No PCT/CH 86/00143

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl.^{4} G 05 D 1/02

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
Int.Cl.^{4}	G 05 D

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	FR, A, 2020864 (INT.HARVESTER) 17 July 1970, see page 1,lines 6-21;page 17,lines 1-25	1-3,12
Y		4,9,11

Y	FR, A, 2255651 (KREMNITZ) 18 July 1975,see page 8,line 15 - page 13,line 21;figures 1, 6	4,9,11
A	(cited in the application)	8,20-22

A	FR, A, 2526181 (TRAITEMENT DE L'INFORMATION TECHNIQUES NOUVELLES) 11 April 1983,see page 7,line 3 - page 10,line 28;page 12, lines 13-22;figures 1-4 (cited in the application)	6,7,10 15-20

X	FR, A, 2548401 (KUBOTA) 4 January 1985,see abstract;figure 1	13
	----	./.

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 14 January 1987 (14.01.87)	Date of Mailing of this International Search Report 13 February 1987 (13.02.87)
International Searching Authority European Patent Office	Signature of Authorized Officer

International Application No. PCT/CH 86/00143

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	EP, A, 0142594 (AUTOMAX) 29 May 1985,see abstract;page 5,line 11 - page 6,line 30: page 10,line 21 - page 14,line 14;figures 1,5 (cited in the application)	20,21
A	FR, A, 2554612 (O.N.E.R.A.) 19 May 1985, see abstract;figures 8,9 (cited in the application)	1
A	DE, A, 3107674 (D.HIRT) 16 September 1982, see abstract (cited in the application)	1

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/CH 86/00143 (SA 14820)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 02/02/87

The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR-A- 2020864	17/07/70	US-A- 3669208	13/06/72
		GB-A- 1289474	20/09/72
FR-A- 2255651	18/07/75	NL-A- 7416427	24/06/75
		DE-A,C 2364002	03/07/75
		GB-A- 1487360	28/09/77
		US-A- 4119900	10/10/78
		JP-A- 50095684	30/07/75
		CH-A- 619799	15/10/80
FR-A- 2526181	04/11/83	None	
FR-A- 2548401	04/01/85	JP-A- 60009404	18/01/85
		US-A- 4573547	04/03/86
		JP-A- 60009405	18/01/85
		AU-A- 2232283	24/01/85
		JP-A- 60024109	06/02/85
		GB-A- 2143654	13/02/85
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		JP-A- 60093524	25/05/85
FR-A- 2554612	10/05/85	EP-A- 0146428	26/06/85
DE-A- 3107674	16/09/82	None	

For more details about this annex :
see Official Journal of the European Patent Office, No. 12/82