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METHOD FOR NAVIGATION OF A ROBOT AND ROBOT FOR CARRYING OUT
THE METHOD

The present invention relates to a method for navigating a vehicle according to the preamble of claim 1 and a vehicle for carrying out the method according to the preamble of claim 12.

Navigating vehicles, including robots of all types, are widespread and are used, for example, as self-propelled mowers. It is known in the prior art to enter the limits of an area to be processed (for example, to be mowed) into the navigation system, wherein the navigation system then continuously determines its position relative to the limits, changes the course of the robot upon reaching a limit such that this robot continues moving in the area. As a result, the robot moves chaotically back and forth in the area to be processed so that the entire area is processed after a period of time.

EP 3 018 548 shows a navigating robot, which is to move within a work area, for example, to mow a lawn. The control system is first trained in a recording mode for a reference path (reference trail recording mode), in that it traverses the same and thereby generates data, called intermediate information, regarding the work area, which data are used in the work input of the robot in a navigation mode in order to facilitate precise navigation during the work. For the navigation, data from various sensors, like camera images or position signals from UWB anchors and odometry data from a towed wheel of the robot may be amalgamated, together with the intermediate information, using a mathematical algorithm known as a Kalman filter, into a "robust" estimate of the current position of the robot.

The training and the generation of the intermediate information are complex. Correspondingly, it is the object

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of the present invention to provide a navigating vehicle which precisely navigates along a predetermined path without the abovementioned intermediate information.

The problem is solved by the characterizing features of claims 1 and 12.

That is, in the state observer representing a kinematic model of the vehicle, the weighting of the data relating to the driving mode, in this case data from the distance measurement and from the odometry, is dynamically changed according to the geometry of the predetermined path, which results in an improved and thus more precise navigation, as in each case the weighting of these data is correspondingly adapted to a change in the reliability of the same, i.e., the weighting may be increased or reduced according to the reliability. By this means, a predetermined path may also be laid out more efficiently, whether this is in regard to a small overlap of adjacent tracks or an optimal course with the shortest possible length while simultaneously minimizing errors in the complete coverage of the entire area to be processed.

Further preferred embodiments have the features of the dependent claims. The invention is subsequently explained in somewhat greater detail by way of the figures.

As shown in:

Figure 1 a schematic area to be processed by a vehicle using the example of a football field to be mowed,

Figure 2 a schematic embodiment of a vehicle,

Figure 3 a flow chart for determining the navigation of the robot (has one part for localization, one part for position and direction determination, and one part for trajectory controller), and

Figure 4 a schematic known to a person skilled in the art for a controlled system with a state observer, which may be designed according to the present invention.

Figure 1 schematically shows one embodiment of the present invention by way of a vehicle designed as a robotic mower 1 for a football field 2. The robotic mower navigates along a predetermined path 3, which in the figure consists of straight horizontal sections 4 and straight vertical sections 5, which together form a checkered pattern for the observer of football field 1, as this is generally known. The robotic mower respectively turns in curves 6 in order to generate the checkered pattern in the mowed lawn. According to the invention, robotic mower 1 navigates with a deviation of, for example, ± 4.5 cm for $\pm 3 \delta$ (i.e., that for 99.7% of the values of the measurements for the deviation from the predetermined path are ± 4.5 cm). This precision allows the overlap of adjacent tracks to be correspondingly small, and thus also keeps the entire length of the predetermined path to a minimum, wherein simultaneously small islands in the form of not-mown areas may also be prevented. In addition, the checkered pattern presented to the observer is visually perfect, with the desired, straight parallel tracks due to this precision of the navigation.

Four UWB anchors 7 to 10 are provided for navigating robotic mower 1 and arranged around football field 2. A person skilled in the art may also provide a different number, e.g., two, three, or more than four UWB anchors in specific cases. A location determination by means of trilateration or multilateration is known in and of itself to the person skilled in the art, wherein it is also conceivable to provide bilateration for simple situations using distance measurements in only one plane, in that, for example, two UWB anchors are arranged at a specified distance from

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predetermined path 3, so that two locations result during the measurement, of which one may be omitted from the outset. Instead of UWB anchors, a GNSS (global navigation satellite system), for example, or another suitable system may also be used, which uses a wireless distance measurement, or has transmitters for signals for distance measurement.

Instead of football field 2, another work area may naturally be processed, like a golf course or another property, in any way (for example, mowed), wherein the radii of curvature of the predetermined path to be driven by the robotic mower may vary, and, for example, may also be indicated by the contour of the work area. The predetermined path itself is then determined by the person skilled in the art based on the characteristics of the respective property. UWB anchors are then preferably arranged, suitably distributed around or in the work area, wherein the person skilled in the art may determine the locations thereof to be suitable in specific cases.

A coordinate system 12 may be used for the location determination and navigation of robotic mower 1, wherein the x, y coordinates stand for the location of robotic mower 1 and angle Θ stands for its orientation or driving direction.

Figure 2 schematically shows one embodiment of the navigating vehicle according to the invention, designed here as a robotic mower 1, according to figure 1 in a side view. A drive wheel 15 is visible, arranged on a side on robotic mower 1, and which covers a second drive wheel 15' on the side of robotic mower 1 facing away in the figure. A towed wheel 16 is further visible, which is movable about a vertical axis so that robotic mower 1 may drive a curve in the case of correspondingly differently driven drive wheels. A vehicle preferably results, in which two wheels 15, 15' of the vehicle or robot are arranged adjacent to one another in

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the driving direction and a third wheel (16) of the robot is designed as a towed wheel.

An arrangement 18 for mowing a lawn is provided in the front on robotic mower 1, which is located here in its raised, idle position. An antenna 19 with a receiving unit 19' functions for receiving signals from UWB anchors 7 to 10 (see figure 1). It should be noted that a navigating vehicle, or a vehicle designed according to the invention, like robotic mower (1), may also have a differently designed wheel drive, for example, 4 wheels with a conventional steering by two adjacently arranged wheels, or another drive configuration, up to a track drive.

A drive unit of robotic mower 1 with a steering arrangement for driving the drive wheels, which drives drive wheels 15, 15' with an identical speed for straight line travel, and with different speed for traversing curves, is covered by housing 20 of robotic mower (1) (or omitted to relieve the figure). Sensors 21 are only symbolically indicated and continuously detect the angular position of wheels 15, 15', and thus provide odometry data regarding the driving state of robotic mower 1, said odometry data are suitably processed in a controller 22, likewise symbolically depicted, see, regarding this, the description related to figures 3 and 4. A vehicle thus preferably results, in which sensors (21) for odometry data have sensors which detect the rotation of two wheels of the robot.

Data buffers are provided in controller 22 and may store data relating to a predetermined path 3 (figure 1), among other things. Controller 22 is designed to generate drive and steering commands for the drive of wheels 15, 15', based on the data related to predetermined path 3, so that robotic mower 1 moves along predetermined (target) path 3. For this purpose, controller 22 processes the odometry data from sensors 21 and the data from UWB anchors 7 through 10 (figure

1), which enable controller 22 to determine the distance of robotic mower 1 (here the point in the center of the axle between wheels 15, 15') via a time-of-flight evaluation. In a simulation of the navigation according to the invention, which leads to the abovementioned precision with a deviation of ± 4.5 cm for $\pm 3^\circ$ from a respective point on the predetermined path, a robot was used that moved at 1.2 m/s (maximum 3 m/s), whose drive wheels 15, 15' have a diameter of 400 mm and whose towed wheel has a distance of 935 mm from the axle of drive wheels 15, 15'.

The navigating vehicle, designed here as robotic mower 1, is therefore able to continuously recognize its current position using the processing, according to the invention (see, regarding this, the description of figure 3) in controller 22 of the odometry data and the distance data to UWB anchors 7 to 10, and then to generate signals for course correction, which the steering arrangement implements in that drive wheels 15, 15' are suitably driven with different angular speeds. As a result, robotic mower 1 moves along predetermined path 3 (figure 1) with the precision possible according to the invention.

Figure 3 shows a flow chart relating to the navigation according to the invention, as this is carried out by controller 22 according to one embodiment of the invention by way of a Kalman filter. In step 30, the navigation is initialized in a known way, for example, in that a first position of robotic mower 1 is determined by UWB measurement at the start of the predetermined path (here in the lower left corner of football field 2, see figure 1), then robotic mower drives a short distance, e.g., 50 cm, and a second UWB measurement and an odometry position determination are carried out. The location and alignment of the robotic mower are then known, so that the navigation is initialized.

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In step 31, for example (and also in the abovementioned simulation), the instantaneous odometry data (e.g., the angular speed for two drive wheels 15, 15', see figure 2) is detected every 20 ms, and it is assumed, at a resulting speed threshold value of more than 0.025 m/s, that robotic mower 1 is moving. However, sensors 21 do not generate the true values for the angular position of drive wheels 15, 15', but instead a signal tainted by errors, wherein these errors may be expressed as process noise with a value Q . Q is then the variant for the respective true value forming the expected value of an angular position of wheel 15, 15'.

In step 32, the calculation of the odometric driving status is carried out, i.e., the calculation of the instantaneous speed and the instantaneous orientation of robotic mower 1 based on the odometry data, here the angular displacement of drive wheels 15, 15'. The odometric driving status may preferably be determined in shorter cycles than is the case for the UWB distance measurement. An averaging of the odometric speed and orientation are then carried out at the point in time at which the UWB measurement is available. In the abovementioned simulation, the odometry data were processed every 20 ms and a UWB distance measurement was carried out every 80 ms.

In step 33, it is checked whether current UWB measurement data are available, which is generally the case; however, may also not be the case due to interruptions in the determination of the data between a UWB anchor 7 to 10 and robotic mower 1.

If the UWB measurement data are not available, then a jump is carried out to step 34, in which the assumed real position and the orientation of robotic mower 1 are calculated based only on the odometry data. This preferably occurs through an averaging of one instantaneous odometric value u_k (weighted 0.7) with the three preceding values u_{k-1} , u_{k-2} , u_{k-3} (weighted

0.1), so that an odometric driving status is present every 20 ms.

If current UWB measurement data are available, the jump is carried out to the branch with steps 35 to 37, in which the assumed, real position is calculated with the aid of a Kalman filter by fusing the odometry data with the UWB data.

According to the simulation, a UWB distance measurement is carried out, for example, every 80 ms, preferably respectively sequentially to only one of UWB anchors 7 to 10 in a predetermined sequence. This UWB distance measurement leads to a current location of robotic mower 1 using the distance measured to the relevant UWB anchor 7 to 10. The distance measurements also vary with a dispersion with a value R around the expected value, i.e., the true distance from a point at the middle of the axle between drive wheels 15, 15' (see regarding this the description related to figure 2) and respective anchor 7 to 10, wherein the variance may be gathered from the data sheet for the UWB anchors or may be determined by the person skilled in the art through his own measurements. A value for a measurement uncertainty R , which is present during the continuous UWB distance measurements, results from the variance of the UWB distance measurements.

In step 35, controller 22 compares the instantaneous position, currently assumed for robotic mower 1, with predetermined path 3 and determines whether robotic mower 1 is located on a curve or a straight line, i.e., controller 22 detects properties of predetermined path 3 at the location, where the position of robotic mower 1 is located, as determined by the controller. According to the simulation, a curve is preferably assumed on predetermined path 3 when, at the operating speed of robotic mower 1, its vehicle turn rate threshold value of 0.25 rad/s is exceeded. The person

skilled in the art may also set the vehicle turn rate threshold value differently in a specific case.

In step 36, a dynamic adaptation is carried out of the value for measurement uncertainty R of the current UWB distance measurement and of the value for process noise Q of the current odometric driving status, according to the position determined in step 35, before the fusion of the odometry data and the UWB distance measurements is carried out in a Kalman filter (preferably an unscented (or extended) Kalman filter).

The initial position for the dynamic adaptation of these values is their base value, determined by the person skilled in the art for the specific case. In the simulation for the robotic mower according to figure 1, used for mowing a football field 2, high precision UWB anchors are provided, as they are obtainable at the time of the present application, which thus have, for example, a value for measurement uncertainty R of $3.5 \cdot 10^{-3} \text{ m}^2$ (variance of the dispersion of the measurement data from the data sheet for the UWB anchors, see above regarding step 33).

It is valid for the base value of the process noise Q of robotic mower 1 in football field 2 (figures 1 and 2), that it represents the degree of confidence in the odometric system model used, which is given, for example, by the following equations:

$$f(\dot{\theta}) = \frac{r_{Nenn}}{B} \cdot (\omega_r - \omega_l)$$

$$f(\dot{x}) = \cos(\theta) \cdot \frac{r_{Nenn}}{2} \cdot (\omega_r + \omega_l)$$

$$f(\dot{y}) = \sin(\theta) \cdot \frac{r_{Nenn}}{2} \cdot (\omega_r + \omega_l)$$

where B is the distance between drive wheels 15, 15', r_{enn} is their radius, and ω is the angular speed of wheels 15, 15'.

For alignment Θ , process noise Q represents, in the case of a robotic mower 1 according to figure 2, among others, the deviation due to the swiveling movement of the caster wheel mount (towed wheel(s)) of robotic mower 1 used here. For the position, it represents, e.g., the error due to minimal traction losses or slip of drive wheels 15, 15'.

The base value for process noise Q results preferably from practical tests, which the person skilled in the art may carry out in the specific case. For example, an unrealistically small value (e.g., $10^{-15} \text{ rad}^2/\text{s}^2$) is selected for the alignment in the specific case, while the course of the main diagonal of the covariance matrix (from the measurement data with the deviations) is recorded and evaluated during a test operation of the vehicle or robotic mower 1, which is the minimal value that this achieves. A logical value may be set somewhat higher in the specific case by the person skilled in the art, e.g., 1.1 times the measured minimum value. Furthermore, the minimization of the RMS value of the innovation sequence (system prediction minus measurement) may be targeted for a specific time, or in an operating mode (straight movement, curved movement, and different speeds), in case precise measurements are possible. These methods for practical tests for determining the base value of a process noise are basically known to the person skilled in the art. The speed may be analogously approached in addition to the alignment. The person skilled in the art may thus determine the base value for process noise Q in the specific case.

The dynamic adaptation is now carried out according to the invention in that the base values for measurement uncertainty R and process noise Q are not maintained over the entire

length of the predetermined path, but instead are retained or changed at the current location on predetermined path 3 according to properties present there. A property is preferably given regarding whether the predetermined path is formed as straight or curved at the current location.

Correspondingly, either the value for measurement uncertainty R is set higher, for example, on a straight section 4, 5 of predetermined path 3 (see figure 1), for example, 1.1 times higher as mentioned above, i.e. to $3.55 \cdot 10^{-3} \text{ m}^2$. This means that, for the fusion of the odometry data with the UWB distance measurement data, which takes place in subsequent step 37, the trust in the UWB measurement data is reduced and thus its weighting in the fusion is reduced: a higher value for measurement uncertainty R means the adoption of a larger variance of the data from the UWB distance measurement, thus a larger than average expected deviation from the real measurement data (the expected value).

Alternatively, the value for process noise Q may also be reduced (for example, likewise by 10%) for straight sections 4, 5 in specific cases: then a smaller variance and thus a smaller average error is assumed in the odometry data, and thus a smaller average error in the speed and alignment of robotic mower 1 calculated from the odometry data. It is likewise possible to also change both values Q and R - but always so that the odometry data from a straight section 4, 5 are weighted higher during the fusion in the result. The person skilled in the art may easily determine in the specific case the size of the change of the values for process noise P and measurement uncertainty R , for example, in steps of 10% changes in connection with corresponding tests.

The result is that, in the case of a location with the property of a straight section (4, 5) or the property of an

increased skid resistance of the ground, the value for the variable of measurement uncertainty R is increased with respect to the predetermined value and/or the value for the variable of process noise Q is reduced with respect to the predetermined value.

Furthermore, a vehicle 1 results, in which preferably the controller is further designed, in the case of a location on a straight section 5, to increase the value for the variable of measurement uncertainty R with respect to the predetermined base value and/or the value for the variable of process noise Q is reduced with respect to the predetermined base value.

Conversely, in a curve 6 of predetermined path 3 (figure 1), the value for process noise Q is increased, so that a larger average error is assumed and thus the weighting of the odometry data is reduced during the fusion. Alternatively, the value for measurement uncertainty R may be reduced in turn, or both values Q and R may be changed; however always such that, as a result, the UWB distance measurement data in a curve 6 are weighted higher during the fusion.

This results in that, for a location with the property of a curved section 6, and/or the property of a reduced skid resistance of the ground, the value for the variable of measurement uncertainty R is reduced with respect to the predetermined value, and/or the value for the variable of process noise Q is increased with respect to the predetermined value.

The controller is further preferably designed, for a location on a curved section 6, to reduce the value for the variable of measurement uncertainty R with respect to the predetermined base value and/or to increase the value for the variable of process noise Q with respect to the predetermined base value.

In step 37, after the dynamic adaptation of the values for measurement uncertainty R and process noise Q , a fusion of the odometry data and the UWB distance measurement data is generated by an unscented Kalman filter. As mentioned at the outset, the algorithm of the Kalman filter is known in and of itself, likewise the unscented Kalman filter, preferred in the case of non-linear functions (for example, the function of the alignment $f(\Theta)$). This algorithm functions here, based on a previous location from different measurements, to determine the current location starting from this, to determine the current location more precisely by fusing the measured values, as is possible based on the individual (and independent) measurements. In addition, this fusion may then also be carried out by the Kalman filter when all variables (i.e., the previous location and the measured values obtained from the measurements) are present as statistical variables with an expected value and an associated (statistical) variance. The result is then a current location with an expected value and a variance, which is smaller than that of the individual measured values. It should be noted at this point, that an extended Kalman filter may also be used, for example, instead of an unscented Kalman filter.

This fusion thus results here in an assumed location and an assumed alignment of robotic mower 1 with a lower variance than is the case for measurement uncertainty R and process noise Q . The average error in the location and the alignment assumed due to the fusion is smaller than it would be without the fusion of the values obtained by the odometry or the UWB distance measurement. Based on the dynamic adaptation according to the invention, the result of the fusion is improved for the purpose of navigating the vehicle to be moved.

In step 38, the course correction is calculated by the trajectory controller, based on the more precise position calculated in step 37 according to the invention, which is based on the dynamic adaptation of the values in step 36, so that robotic mower 1 remains on predetermined path 3. The trajectory controller consists of two components, a controller for the alignment (steering) of the vehicle and a controller for the vehicle speed. The trajectory, i.e., predetermined path 3, consists of various points P , which contain information about the target values for the alignment, the position of the robotic mower, its speed, and in the case of a robotic mower, a vehicle mode, like activated mowing, etc.

The controller for the alignment of the vehicle is preferably designed as follows:

1. Search for trajectory point P_k with the smallest distance from the instantaneous position of robotic mower 1 determined in step 37 (or also in step 34).
2. Calculate the Cross Track Error, i.e., the distance of the instantaneous position of robotic mower 1 to point P_k .
- 3 Calculate the deviation of the instantaneous alignment of the vehicle to the target alignment (this is stored in the trajectory).
4. Calculate the change of the target alignment around the next point on the trajectory (i.e., the alignment in the next point P_{k+1} minus P_k).
6. Calculate the threshold value for θ .

Trajectory controllers of this type are basically known to the person skilled in the art: the person skilled in the art

may provide a suitable trajectory controller in the specific case.

The control variable for the vehicle rotational speed is limited in rotational acceleration and limited in (rotational) stutter, and is converted into a rotational speed difference of the two drive wheels. This is forwarded to the controller for the engine rotational speed.

In step 39, controller 22 decides whether the end of predetermined path 3 is reached or not. If no, then the cycle is executed again by a reset back to step 31; if no, then the navigation is terminated.

The dynamic adaptation of the values for process noise Q and measurement uncertainty R according to the invention allows, as mentioned, a more precise navigation than is the case for statistical values, i.e., in the case of a conventionally applied Kalman filter. According to the findings of the applicant, an increased slip of drive wheels 15, 15' when traveling the curves is taken into consideration artificially, yet anticipatively, by the dynamic adaptation, so that the navigation turns out to be more precise as a result. Another aspect of the dynamic adaptation is that, during the course correction, the trajectory, i.e., predetermined path 3, is less intersected, and the number of intersections may be reduced by around 50% according to the abovementioned simulation. Less severe corrections lead to a more precise navigation with a more elongated real path of the vehicle according to the invention, which also effects the optics of an area to be processed.

According to the nature of the matter, the precision of the navigation also depends on the speed of the vehicle, as more measurements, and thus also more corrections, may be carried out by the trajectory controller at lower speeds in one segment of the predetermined path (the obverse at higher

speeds). In addition to the stated problem, the speed of a navigating robot may be increased with the aid of the dynamic adaptation of the values for process noise Q and measurement uncertainty R according to the present invention, without reducing its precision, in contrast to conventional navigation without dynamic adaptation.

The dynamic adaptation may preferably be carried out, not only with respect to the presence of a straight section or a curve, but also depending on the radius of curvature of a curve, for example, in such a way that the adaptation turns out more strongly as the radius of curvature becomes smaller, i.e., the corresponding values for process noise Q and measurement uncertainty R are more strongly changed. Likewise, the properties of the predetermined path may be related, not only to its geometry, but also to other properties, like the ground itself, so that, for example, in the case of an increasingly slippery or less skid resistant ground, the dynamic adaptation may be carried analogously to a curve, and in the case of an increasingly skid resistant ground, the dynamic adaptation may be carried out analogously to a straight segment. The person skilled in the art may then correspondingly design controller 22. It thus preferably results that a high traction leads to a higher trust in the odometry (smaller value for the process noise) and, conversely, a reduced traction leads to a higher trust in the distance measurement (smaller value for measurement uncertainty R).

In summary, the process noise Q and measurement uncertainty R are processing values for processing odometry data and the data from the distance measurement in the Kalman filter according to the invention. A predetermined base value is assigned to these processing values: in relation to the determination of the base value for process noise Q , see above, the description regarding step 33 (for example, tests). In relation to the determination of the base value

for measurement uncertainty R , see above, the description regarding step 33 (data sheet or measurements).

Due to the dynamic adaptation according to step 36, at least one of the process values (process noise Q or measurement uncertainty R) is then changed with respect to its predetermined base value, wherein the change is carried out according to the properties of the predetermined path at the current, specific location.

A method thus results according to the invention, in which state observer Z preferably has a Kalman filter or state observer Z is a Kalman filter. The process values are thereby preferably predetermined base values for the variables for a process noise Q of the odometry data and a measurement uncertainty R of the data from the distance measurement, wherein at least one of the values for the variables for process noise Q and measurement uncertainty R is changed with respect to the predetermined base value depending on the properties of the predetermined path at the current, specific location.

Furthermore, a vehicle 1 results with a controller 22, which preferably comprises a state observer which has a Kalman filter or is a Kalman filter. The predetermined base values for processing the odometry data and the data from the distance measurement are thereby more preferably variables for process noise Q and measurement uncertainty R of the Kalman filter.

In another embodiment of the present invention, a Luenberger observer, known to the person skilled in the art, is used instead of a Kalman filter. A Luenberger observer represents, like the Kalman filter, a state observer (which is often designated simply as the observer). The Luenberger observer and the Kalman filter have the same mathematical structure,

except that the value of the feedback matrix is calculated differently.

If a Luenberger observer is used, process values with a respectively predetermined base value A, B are likewise used according to the invention for processing the odometry data and the data from the distance measurement. These base values A, B then function for filtering the odometry data or the distance measurement data in the Luenberger observer.

Analogous to step 36, a dynamic adaptation of the process variables, i.e., of predetermined variables A, B is then carried out, such that these are changed, with respect to the predetermined base values, depending on the properties of the predetermined path at the current, specific location.

Analogous to step 37, a state observer, which has a Luenberger observer, is provided instead of the Kalman filter in one embodiment of the method according to the invention. Further preferred in the Luenberger observer, the processing values are then predetermined variables A, B for the respective filtering of the data from the odometry and the data from the distance measurement, wherein at least one of the values for variables A, B is changed with respect to the predetermined base values depending on properties of the predetermined path at the current, specific location.

A vehicle 1 correspondingly results, in which the state observer has a Luenberger observer. The predetermined base values are then further preferably variables for the respective filtering of data A from the odometry and data B from the distance measurement.

Figure 4 shows a schematic, known as such to the person skilled in the art, of a controlled system x with a state observer Z, wherein controlled system x corresponds here to a vehicle 1 (figure 2) and state observer Z corresponds to

a part of controller 22 of the vehicle (figure 2). The command u (e.g., control signals from controller 22 for the drive motors of wheels 15, 15' of vehicle 1) is executed in control path x (vehicle 1 drives along predetermined path 3, figure 1), which leads to result y (the position of vehicle 1). State observer Z contains a mathematical model $\hat{x}$ of vehicle 1, which receives the same command u as control path x , so that the result $\hat{y}$ (the position of vehicle 1) may be mathematically estimated. Difference Δ , from which a feedback matrix I is generated for model $\hat{x}$, correspondingly lies between the true position, measured here by sensors of the odometry and by, for example, the UWB anchors, so that the model may better estimate result y (position of vehicle 1). By this means, model $\hat{x}$ is able to generate a feedback matrix $-K$ for command u , i.e., to suitably modify the control signals in this case for motors 15, 15' for a more precise course on predetermined path 3 (figure 1).

As mentioned above, the state observer may be designed as a Kalman filter or also as a Luenberger observer, or have one of the same. A Kalman filter has the advantage that it takes the noises of the sensors into account and may cope well with short interruptions of sensor data using estimated values. However, the comparatively slower corrections are disadvantageous in a Kalman filter: in comparison to other algorithms, the dynamics are quite low. In contrast, the Luenberger observer allows for high dynamics, which may be selected using the so-called pole placement, which is advantageous in the case of a complicated, predetermined path 3 and greater speeds of vehicle 1. However, the Luenberger observer is disadvantageous in that the sensor noise is not smoothed and interruptions of the sensor values cause problems. The person skilled in the art may correspondingly provide a Kalman filter or a Luenberger observer for the specific case for fusing odometry data and data related to the vehicle location; it is also conceivable, to alternatively provide a state observer with a Kalman

filter or with a Luenberger observer, depending on a route segment or segment of predetermined path 3.

This therefore results in a method, in which, at a location with the property of a straight segment 4 or the property of an increased skid resistance of the ground, the value processing value for the data of the distance measurement, in particular the value for the variable of measurement uncertainty R , or variable B for filtering the data from the distance measurement, is increased with respect to the predetermined value, and/or the value for the variable of process noise Q or variable A for filtering the data from the odometry is reduced with respect to the predetermined value. Correspondingly, the controller is preferably designed for a vehicle 1, to increase the value processing value for the data of the distance measurement, in particular the value for the variable of measurement uncertainty R , or variable B for filtering the data from the distance measurement with respect to the predetermined value and/or to reduce the value for the variable of process noise Q or variable A for filtering the data from the odometry with respect to the predetermined value, at a location with the property of a straight 5 segment.

Conversely, a method results in which, at a location with the property of a curved segment 6 and/or the property of a reduced skid resistance of the ground, the processing value for the data of the distance measurement, in particular the value for the variable of measurement uncertainty R , or variable B for filtering the data from the distance measurement, is reduced with respect to the predetermined value, and/or the value for the variable of process noise Q or variable A for filtering the data from the odometry is increased with respect to the predetermined value. In a vehicle 1, a controller is then preferably designed to increase the processing value for the data of the distance measurement, in particular the value for the variable of

measurement uncertainty R , or variable B for filtering the data from the distance measurement with respect to the predetermined value and/or to reduce the value for the variable of process noise Q or variable A for filtering the data from the odometry with respect to the predetermined value at a location with the property of a straight 5 segment.

Predetermined path 3 (figure 1) may have many other properties, in addition to the curvature or skid resistance, which may be classified by the person skilled in the art as relevant for precise navigation in the specific case. A threshold for relevance may result; however, the processing variables may also be changed as a function (proportional, non-proportional, gradually) of the respective property. A method thus preferably results, wherein at least one of the processing variables (Kalman filter or Luenberger observer, see the description below), in particular for the variables for process noise Q and measurement uncertainty R or variables A , B for the respective filtering of the data from the odometry and the data from the distance measurement is changed with respect to the predetermined base values depending on the intensity of the properties.

In addition, as mentioned above, the person skilled in the art may also naturally provide a state observer with another suitable algorithm, which fuses the odometry data and the data related to the vehicle location, thereby changing, dynamically adapting according to the invention, at least one of the processing variables for processing the odometry data or the data for the distance measurement, depending on the property of the predetermined path at the current, specific location.

In summary, a method results for moving a vehicle (1) along a predetermined path (3), wherein a current location on predetermined path (3) and a driving direction (θ) of vehicle

(1) at this location is cyclically determined by a state observer Z through the fusion of odometry data from robot (1) and data regarding the vehicle location from a wireless distance measurement, and afterwards, a course correction for vehicle (1) is determined in a trajectory controller from the obtained location with the obtained driving direction, characterized in that the process values are respectively provided with a predetermined base value for processing the odometry data on the one hand and the data from the distance measurement on the other hand in state observer Z, and at least one of the process values is changed with respect to its predetermined base value, depending on the properties of the predetermined path at the current, specific location, so that a precise navigation is achieved.

In one preferred embodiment, a method results for moving a vehicle 1 along a predetermined path 3, wherein a current location on predetermined path (3) and a driving direction (Θ) of vehicle (1) present at this location is cyclically determined by a Kalman filter through the fusion of odometry data of robot (1) and data regarding the robot location from a wireless distance measurement, and afterwards, a course correction for vehicle (1) is determined in a trajectory controller from the obtained location with the obtained driving direction, and wherein predetermined base values are used in the Kalman filter for the variables for a process noise Q of the odometry data and a measurement uncertainty R for the data from the distance measurement, characterized in that at least one of the values for the variables for process noise Q and measurement uncertainty R is changed with respect to its predetermined base value, depending on the properties of the predetermined path at the current, specific location, so that a precise navigation is achieved.

Furthermore, a vehicle (1) results with a drive configuration for locomotion on the ground, sensors (21) for odometry data from the movement of wheels (15, 15'), a steering arrangement

for changing the locomotion direction of the robot, a controller (22) for the steering arrangement, and a receiving unit (19') for the data from transmitters for a wireless distance measurement, wherein controller (22) is designed to cyclically determine a distance of vehicle (1) to a distance measurement point from the data of the distance measurement, and to fuse it with the odometry data using a state observer Z , and to thus determine a current location and a driving direction (Θ) of vehicle (1), characterized in that controller (22) is further designed to change predetermined base values for processing the odometry data and the data for the distance measurement of the state observer Z , depending on the properties of the predetermined path at the current, specific location, so that a precise navigation is achieved.

A property is preferably thereby provided, by whether the predetermined path is formed as straight or curved at the current location.

A vehicle 1 preferably results with a drive configuration for locomotion on the ground, sensors (21) for odometry data from the movement of wheels (15, 15'), a steering arrangement for changing the locomotion direction of the robot, a controller (22) for the steering arrangement, and a receiving unit (19') for the data from transmitters for a wireless distance measurement, characterized in that controller (22) is designed to cyclically determine a distance of robot (1) to a distance measurement point from the data of the distance measurement, and to fuse it with the odometry data using a Kalman filter, and to thus determine a current location and a driving direction (Θ) of robot (1), characterized in that controller (22) is further designed to change predetermined base values for the variables for the process noise Q and measurement uncertainty R of the Kalman filter, depending on the properties of the predetermined path at the current, specific location, so that a precise navigation is achieved.

P A T E N T K R A V

1. Fremgangsmåde til at bevæge af et køretøj (1) langs en forudbestemt sti (3), hvor en aktuel position på den forudbestemte sti (3) og en på denne position eksisterende kørselsretning (θ) af køretøjet (1) bestemmes cyklisk ved hjælp af en tilstandsobservatør (Z) ved fusionen af odometridata af køretøjet (1) og data for køretøjspositionen fra en trådløs afstandsmåling og derefter bestemmes en kursjustering for køretøjet (1) fra den eksisterende position med den eksisterende kørselsretning i en baneregulator, **k e n d e - t e g n e t v e d , a t** der tilvejebringes bearbejdningsværdier som hver især har én forudbestemt grundværdi for bearbejdningen af odometridataene på den ene side og, på den anden side, for bearbejdningen af dataene fra afstandsmålingen i tilstandsobservatøren (Z), og mindst én af bearbejdningsværdierne ændres i forhold til sin forudbestemte grundværdi, alt efter egenskaber af den forudbestemte sti ved den bestemte, aktuelle position, således at en præcis navigation opnås.

2. Fremgangsmåde ifølge krav 1, hvor tilstandsobservatør (Z) omfatter et Kalmanfilter eller er et Kalmanfilter.

3. Fremgangsmåde ifølge krav 2, hvor bearbejdningsværdierne er forudbestemte grundværdier for variableerne for en processtøj Q af odometridataene og en måleusikkerhed R af dataene fra afstandsmålingen, hvor mindst én af værdierne for variableerne for processtøjen Q og måleusikkerheden R ændres i forhold til den forudbestemte grundværdi, alt efter egenskaber af den forudbestemte sti ved den bestemte, aktuelle position.

4. Fremgangsmåde ifølge krav 1, hvor tilstandsobservatøren omfatter en Luenberger-observatør.

5. Fremgangsmåde ifølge krav 4, hvor i Luenberger-observatøren er bearbejdningsværdierne de forudbestemte variabler A , B for henholdsvis filtreringen af dataene fra odometrien og dataene fra afstandsmålingen, hvor mindst én af værdierne for variableerne A , B ændres i forhold til den forudbestemte grundværdi, alt efter egenskaber af den forudbestemte sti ved den bestemte, aktuelle position.

6. Fremgangsmåde ifølge krav 1, hvor en egenskab er givet ved om den forudbestemte sti ved den aktuelle position er lige eller krum.

7. Fremgangsmåde ifølge krav 2, hvor et Unscented eller et udvidet (ENG: Extended) Kalmanfilter anvendes som Kalmanfilter.

8. Fremgangsmåde ifølge krav 1, hvor ved en position med egenskaben af et lige afsnit (4,5) eller med egenskaben af et øget vejgreb af underlaget forstørres bearbejdningsværdien for dataene af afstandsmålingen, især værdien for variabelen af måleusikkerheden R , eller variabelen B for filtreringen af dataene fra afstandsmålingen i forhold til den forudbestemte grundværdi og/eller formindskes værdien for variabelen af processtøjen Q , eller variabelen A for filtreringen af dataene fra odometrien i forhold til den forudbestemte værdi.

9. Fremgangsmåde ifølge krav 1, hvor ved en position med egenskaben af et krumt afsnit (6) og/eller med egenskaben af et reduceret vejgreb af underlaget formindskes bearbejdningsværdien for dataene af afstandsmålingen, især værdien for variabelen af måle-

usikkerheden R , eller variabelen B for filtreringen af dataene fra afstandsmålingen i forhold til den forudbestemte grundværdi og/eller forstørres værdien for variabelen af processtøjen Q , eller variabelen A for filtreringen af dataene fra odometrien i forhold til den forudbestemte værdi.

5 **10.** Fremgangsmåde ifølge krav 1, hvor mindst én af bearbejdningens værdier, især for variablene for processtøjen Q og måleusikkerheden R , eller variablene A, B for henholdsvis filtreringen af dataene fra odometrien og dataene fra afstandsmålingen ændres i forhold til den forudbestemte grundværdi afhængig af intensiteten af egenskaberne.

11. Fremgangsmåde ifølge krav 1, hvor køretøjet er en robot.

10 **12.** Køretøj (1) med en drivkonfiguration til fremdrift på et underlag, sensorer (21) til odometridata fra bevægelse af hjulene (15, 15'), en styreanordning til ændringen af fremdriftsretningen af køretøjet, en styreindretning (22) for styreanordningen og en modtageenhed (19') til dataene fra sendere for en trådløs afstandsmåling, **kendetegnet ved, at** styreindretningen (22) er udformet til cyklisk at bestemme en afstand af
15 køretøjet (1) til et afstandsmålepunkt fra dataene af afstandsmålingen og til at fusionere denne med odometridataene ved hjælp af en tilstandsobservatør (Z) og derved at bestemme en aktuel position og en kørselsretning (θ) af køretøjet (1), **kendetegnet ved, at** styringsindretningen (22) yderligere er udformet til at ændre forudbestemte grundværdier for bearbejdningen af odometridataene og dataene for afstandsmålingen af
20 tilstandsobservatøren (Z), alt efter egenskaberne af den forudbestemte sti ved den bestemte, aktuelle position, således at en præcis navigation opnås.

13. Køretøj (1) ifølge krav 12, hvor tilstandsobservatøren (Z) omfatter et Kalmanfilter eller er et Kalmanfilter.

14. Køretøj (1) ifølge krav 13, hvor de forudbestemte grundværdier for bearbejdningen af odometridataene og dataene fra afstandsmålingen er variable for processtøjen Q og måleusikkerheden R af kalmanfilteret.

15. Køretøj (1) ifølge krav 12, hvor tilstandsobservatøren (Z) omfatter en Luenberger-observatør.

30 **16.** Køretøj (1) ifølge krav 15, hvor de forudbestemte variable er variable for henholdsvis filtreringen af dataene A fra odometrien og dataene B fra afstandsmålingen.

17. Køretøj (1) ifølge krav 12, hvor en egenskab er givet ved om den forudbestemte sti ved den aktuelle position er lige eller krum.

18. Køretøj (1) ifølge krav 12, hvor styringsindretningen yderligere er udformet til ved en position på et lige afsnit (5) at forøge bearbejdningens værdien for dataene af afstandsmålingen, især værdien for variabelen af måleusikkerheden R , eller variabelen B for filtreringen af dataene fra afstandsmålingen i forhold til den forudbestemte grundværdi og/eller at formindske værdien for variabelen af processtøjen Q , eller variabelen A for filtreringen af dataene fra odometrien i forhold til den forudbestemte værdi.

40 **19.** Køretøj ifølge krav 12, hvor styringsindretningen yderligere er udformet til ved en position på et krumt afsnit (6) at formindske bearbejdningens værdien for dataene af af-

standsmålingen, især værdien for variabelen af måleusikkerheden R , eller variabelen B for filtreringen af dataene fra afstandsmålingen i forhold til den forudbestemte grundværdi og/eller at forstørre værdien for variabelen af processtøjen Q , eller variabelen A for filtreringen af dataene fra odometrien i forhold til den forudbestemte værdi.

- 5 **20.** Køretøj ifølge krav 12, hvor to hjul (15,15') af køretøjet er arrangeret ved siden af hinanden i kørselsretningen og et tredje hjul (16) af robotten er udformet som slæbehjul.

21. Køretøj ifølge krav 12, hvor sensorerne (21) for odometridataene omfatter sensorer som registrerer drejningen af de to hjul af robotten.

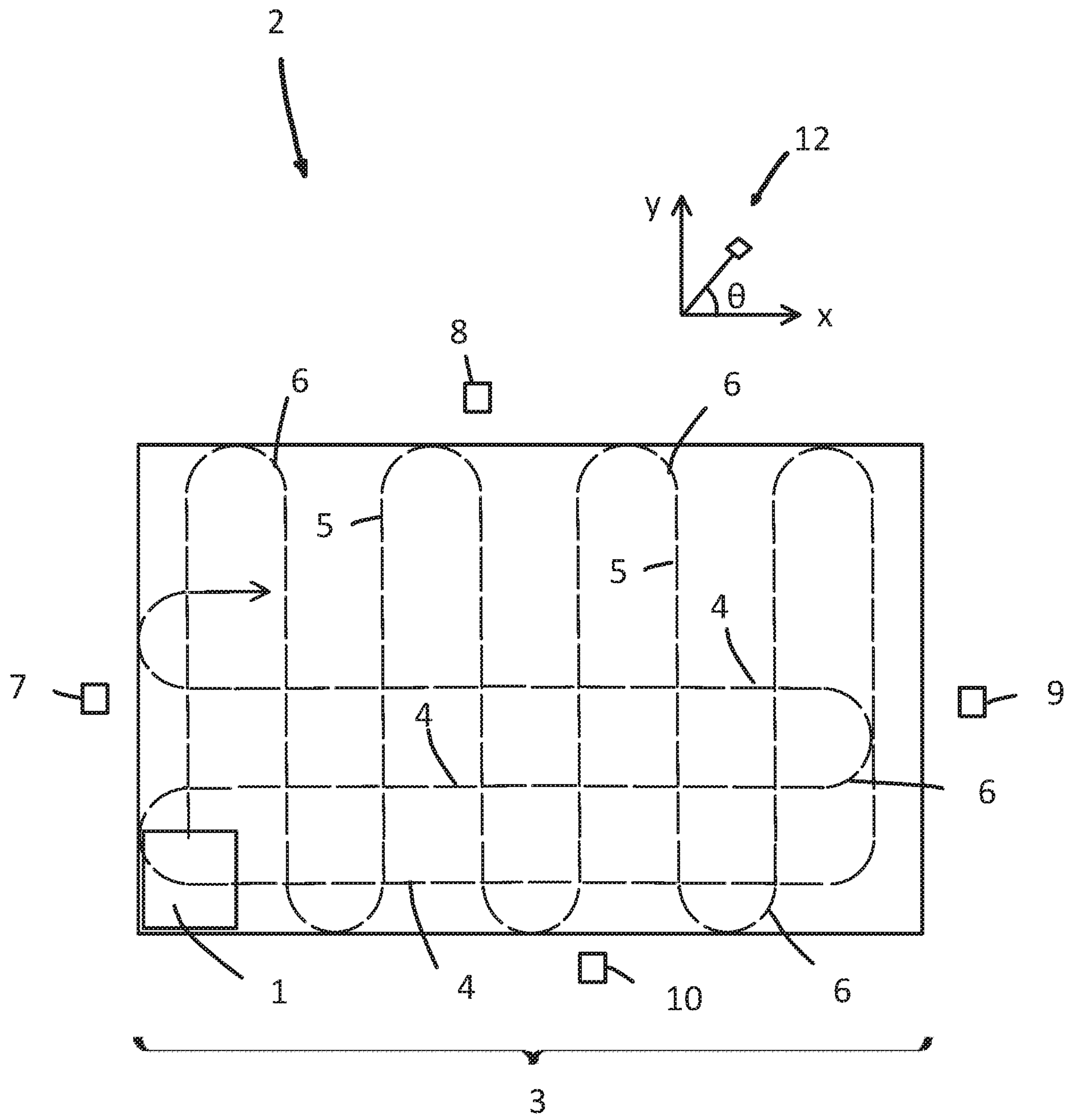


Fig 1

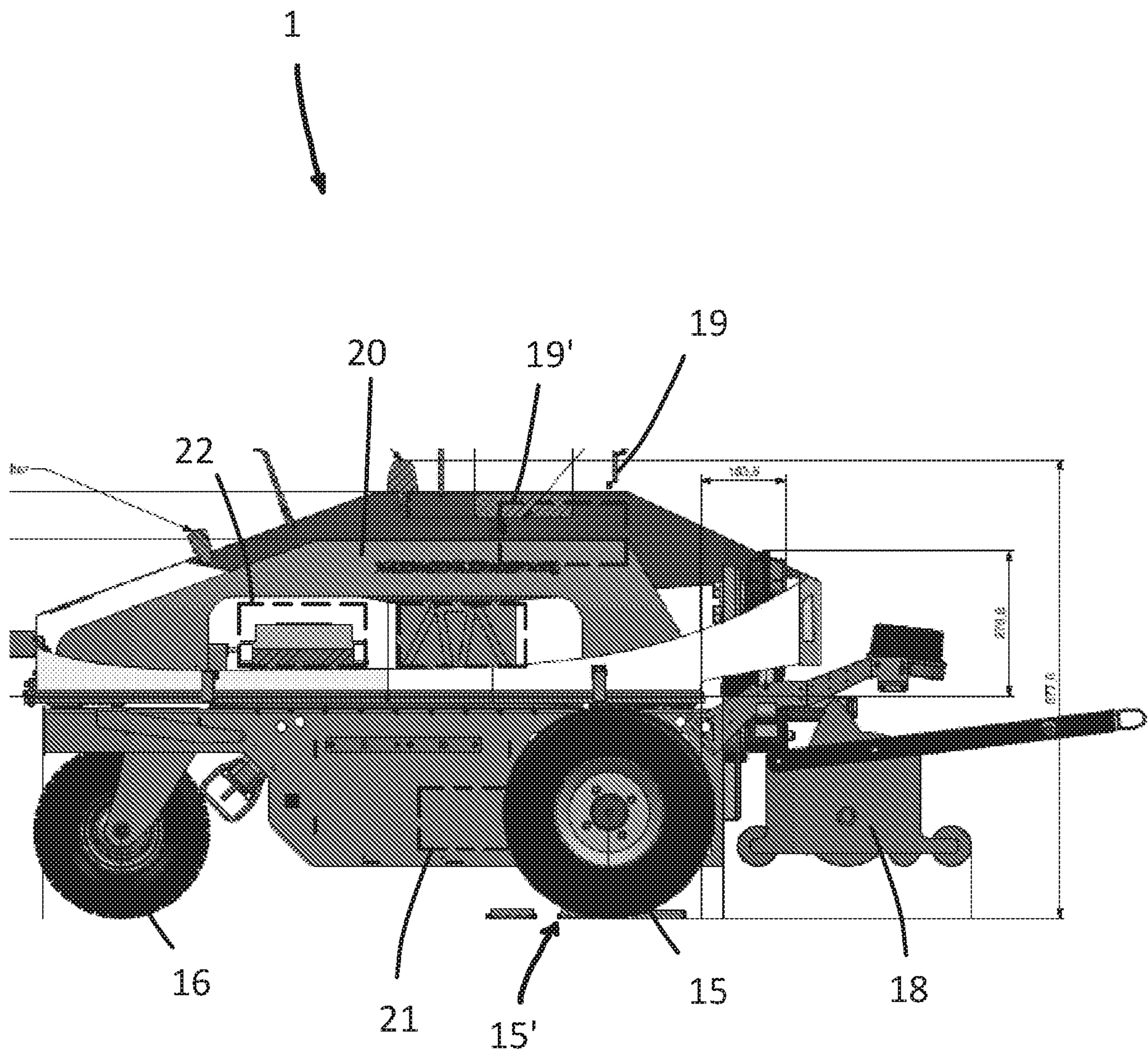


Fig 2

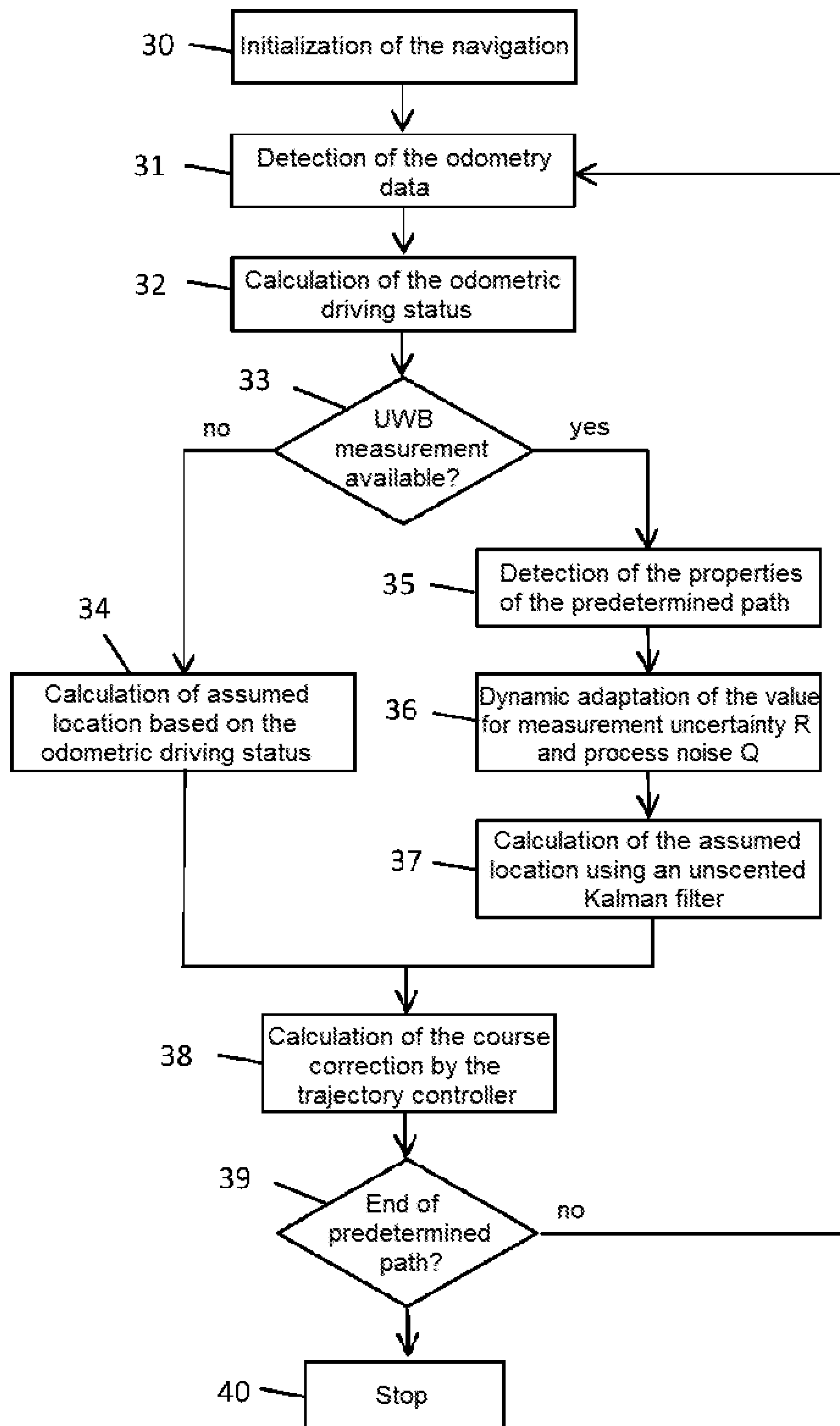
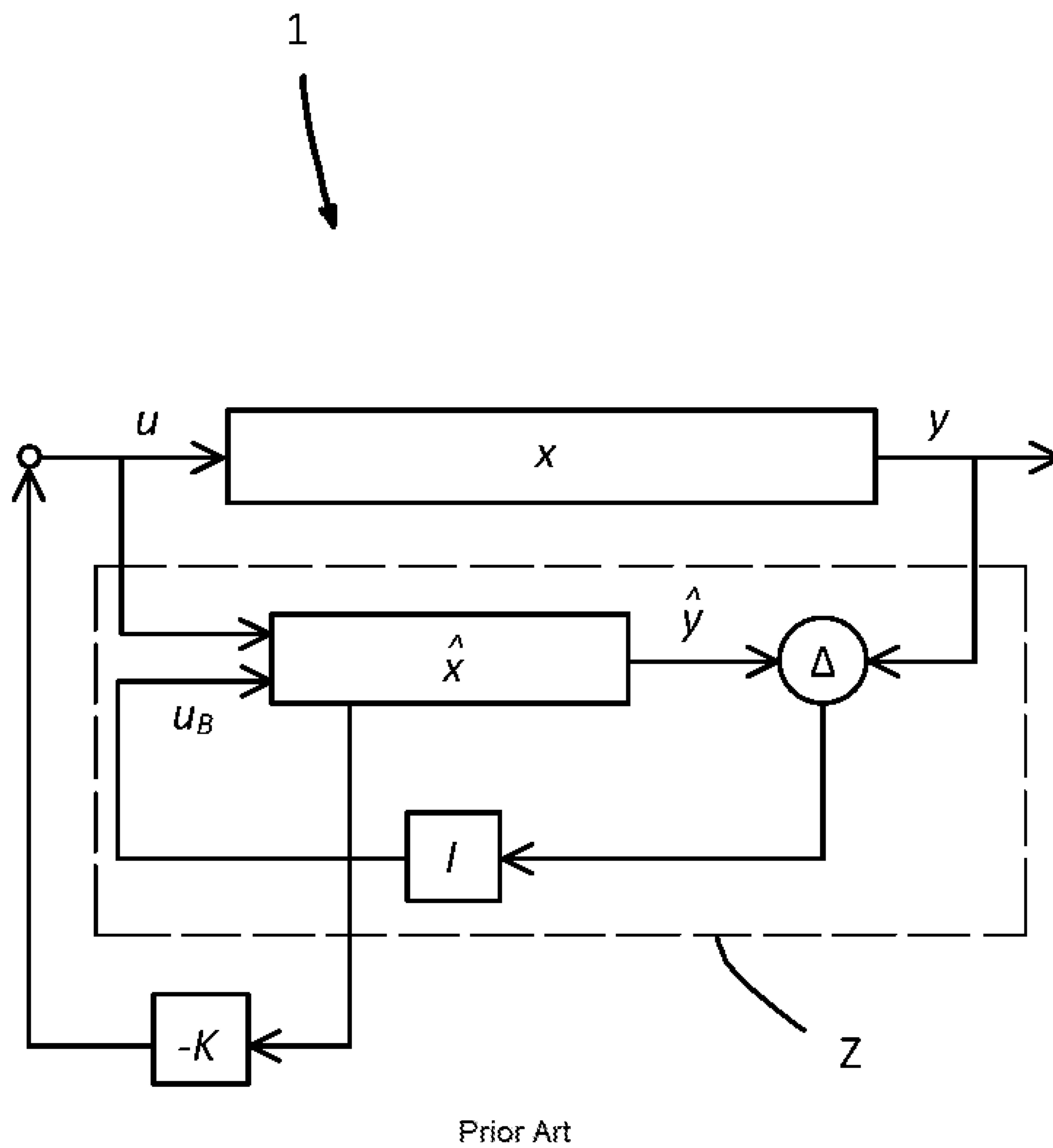


Fig 3



Prior Art

Fig 4