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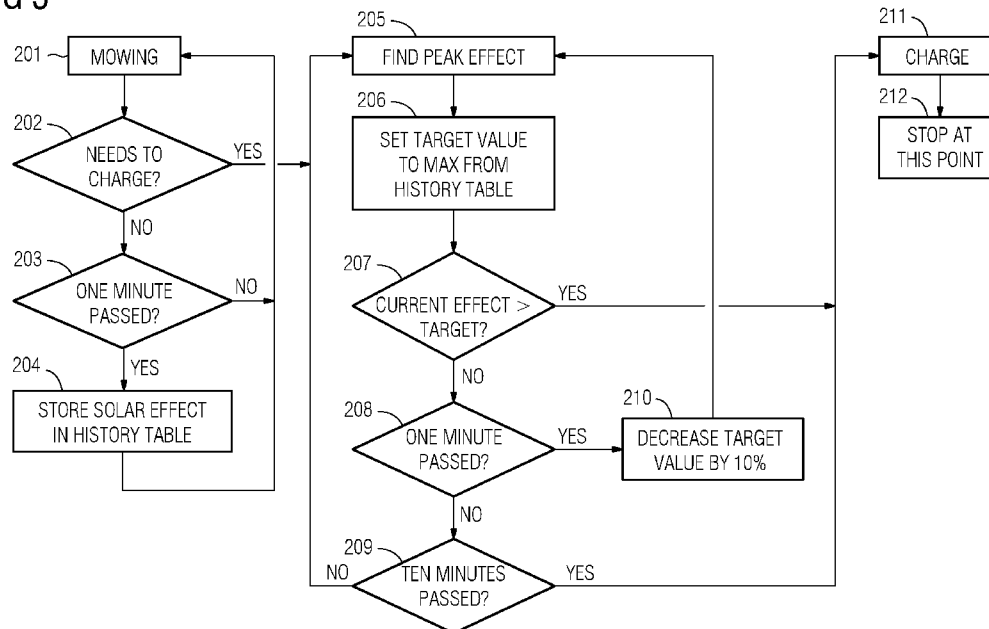
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(54) Title: METHOD AND SYSTEM FOR FINDING A CHARGING POSITION FOR A SOLAR-DRIVEN AUTONOMOUS ROBOT

FIG 3



(57) Abstract: A method for operating at least one autonomous robot (2), in particular an autonomous vegetation working robot, preferably an autonomous lawn robot, within an operating area, the robot comprising (i) an electrically driven tool, (ii) an electric motion drive for moving the robot, (iii) a photoelectric device for converting energy from illuminating light, in particular sunlight, into electric energy, and (iv) an energy storage for storing electric energy charged by the photoelectric device and for supplying the tool and the motion drive with electric energy, the method comprising the steps of a) the robot (2) working, in a working mode, within at least one working area (15) within the operating area according to a navigational routine, wherein the tool and the motion drive are both activated, b) during the working mode of the robot, monitoring the output of the photoelectric device and recording output values at successive instants of time as reference output values, c) during the working mode of the robot, monitoring the charging status of the energy storage

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and checking whether, due to a low charging status, recharging of the energy storage is required, d) if recharging is required, the robot searching for a charging position in a searching mode, e) wherein, in the searching mode, the output of the photoelectric device is monitored and f) wherein the monitored output of the photoelectric device is compared with at least one target value, which is selected or derived from the recorded reference output values, and g) wherein the charging position is reached as soon as the monitored output value of the photoelectric device is larger than or at least equal to the at least one target value.

Method and system for finding a charging position for a solar-driven autonomous robot

Field of Technology

The invention relates to a method for operating an autonomous robot, in particular
5 an autonomous vegetation working robot such as an autonomous lawn robot, and to an autonomous robot system.

Background of the Invention

10 Autonomous lawn robot systems are used for keeping a lawn permanently cut or mowed with autonomous lawn mowing robots and, in some cases, for maintaining the lawn in other ways such as mulching, scarifying, irrigating or fertilizing. Such autonomous lawn robots are autonomous (or: independent) with regard to the navigation within a specified lawn area and with regard to energy supply, so that at
15 least during a certain time period no human supervision or interaction is necessary for navigating the robot or providing the robot with energy.

For an autonomous navigation of a robot a variety of features need to be implemented to make the navigation independent of humans and yet fully reliable, including in particular sensing and using real time signals from external systems such
20 as bordering wires, guide wires, antennas or beacons or using positioning systems or mapping of the area.

For an autonomous energy or power supply the known systems mainly use electric
25 energy and rechargeable batteries as energy storage carried by the robot which supply the electric consumers in the robot, in particular the cutting or mowing tool(s), the drive system and the control unit and display with the electric energy needed.

30 In solutions using photovoltaic (or: photoelectric) cells or modules carried by the lawn robot the illuminating light, usually sunlight, is converted into electric energy,

which is fed to and stored in the rechargeable batteries. Such an autonomous lawn robot driven by solar energy (or: solar-driven robot) does not need to return to a charging station for recharging.

- 5 A solar-driven autonomous lawn robot was proposed in US 5,444,965 A and put into practice in the SolarMower sold by Husqvarna already in the 1990ties.

WO 2015/094054 A1 discloses a robotic work tool system with an autonomous solar lawn robot, wherein an obstacle map is generated to determine when an area will
10 be shadowed with regard to satellite reception and with regard to the sun. The obstacle map is a shadow map giving information on areas that are at least partially shadowed at specific times. The robotic work tool schedules its operation so that the robotic work tool is exposed to as much sunlight as possible.

- 15 EP 3 503 205 B1 discloses an automatic working system with a self-moving device, configured to move and work in a working area and comprising a photoelectric conversion unit and an energy storage unit to store the electric energy obtained from the photoelectric conversion unit, and a control module that receives positioning information and illumination intensity information at one or more locations of the
20 self-moving device in the working area, and generates an illumination map of the working area based on the received positioning information and illumination intensity information and on time.. The illumination intensity information is obtained from an illumination sensor or by estimating an output voltage of the photoelectric conversion unit. In a charging mode the self-moving device is moved, based on the
25 illumination map, to a location at which illumination intensity satisfies a preset level and that is closest to a current location and the device recharges its batteries. The illumination map may also contain attitude information of the device at the locations. The self-moving device determines, by rotating the solar panel on the device or by rotating the whole device, an optimal solar radiation angle.

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- CN 104393359 A discloses an intelligent smart home cleaning robot for automatically cleaning the floor in a room. When the light intensity value measured by a photosensitive sensor exceeds a light intensity threshold, a corresponding high intensity position of the robot is stored. The robot further determines whether the
35 battery power of the intelligent robot is lower than a power threshold, and, if yes,

moves to any of the high intensity positions and the solar battery is charged by light energy. The high intensity position coordinates of the robot may be mapped with corresponding time points and the robot may move to a high intensity position mapped by a recorded time point closest to the current time point. The robot may, 5 for recharging, also move to the position with the highest light intensity value mapped previously or, alternatively, to the nearest high intensity position. The robot may also only run during the day for instance between 8:00-17:00 and stand by during the night or a period of time without sunlight when the battery is too low, and will then automatically search for areas with light to charge when it is sunny in 10 the morning.

General Disclosure of the Invention

An underlying problem (or: object) of the invention is to propose a new method for 15 operating at least one autonomous robot and a corresponding new autonomous robot system, both in particular for working on (or: treating) vegetation, in particular lawns, wherein the autonomous robot uses, at least partially, electric energy converted from surrounding illuminating radiation, in particular sunlight. In particular the robot should be able to find a spot for recharging within the operating area in a 20 way that is easy to implement.

A solution of this problem according to the invention is proposed by embodiments according to the invention.

25 In the embodiment according to independent claim 1 a method is suggested for operating at least one autonomous robot, in particular an autonomous vegetation working robot, preferably an autonomous lawn robot, within an operating area. The robot typically comprises (i) at least one electrically driven tool, (ii) at least one electric motion drive for moving the robot, (iii) a photoelectric device (or: photovol- 30 taic unit) for converting energy from illuminating light, in particular sunlight, into electric energy, and (iv) an energy storage, in particular one or several rechargeable batteries or other energy storage devices, for storing electric energy (or: electric charge) charged or supplied by the photoelectric device and for supplying the

tool and the motion drive with electric energy. The photoelectric device may comprise one or more photoelectric cells or modules and preferably also electronic devices such as converters and energy management devices.

- 5 In a working mode (or: during normal working operation) the robot works within at least one working area, which corresponds to or is part of the operating area, according to or following a navigational routine (or: navigational pattern or algorithm). In the working mode typically both the tool and the motion drive are activated (or: switched on), and the robot uses electric energy supplied by the photoelectric device and often also energy supplied by the energy storage.
- 10

Now, according to embodiments of the invention, the output of the photoelectric device is monitored and reference output values at successive instants of time are recorded, in particular detected and stored in a storage, during the working mode

15 of the robot.

In addition, during the working mode of the robot, the charging status of the energy storage is monitored as well and it is checked whether, due to a low charging status, recharging of the energy storage is required. If recharging is required, the

20 robot searches for a charging position in a searching mode. If not, the robot will typically continue with its working mode.

In the searching mode the output of the photoelectric device is again monitored and the monitored output of the photoelectric device is compared with at least one

25 target value. The target value is selected from or derived from the recorded reference output values. The charging position is reached as soon as (or: when) the output of the photoelectric device is larger than or at least equal to the at least one target value.

30 In particular, if, as a result of that comparison, the determined stored energy or the directly associated electric quantity of the energy storage is found to be below a minimum operating threshold, the robot moves or is moved to find a charging position with sufficiently high illumination intensity for recharging the energy storage using the photoelectric device.

In the prior art mentioned above it is known that robots may look for sunny spots with high sunlight intensity while operating during the day to improve energy efficiency and recharging. The known systems mentioned above use solar maps or illumination maps where such sunny spots or positions with high illumination intensity are marked as position coordinates within the map and are used when navigating according to this navigational map. Although these known methods are technically flexible and advantageous, they require to first establish a navigational map of each working area including illumination data and also need proper positional data communication during operation.

According to embodiments of the invention, neither a navigational map nor any positional data are necessary, although not strictly excluded.

By the term "vegetation" any configuration or arrangement or cover of plants that grow, mainly in the spring and summer season, when sufficient sunlight and water is present, is comprised, including, without loss of generality, lawns, gardens, park areas, golf courses, woods, copses, groves, agricultural fields, vineyards, green houses or modern city buildings with integrated horizontal and vertical agriculture etc. The vegetation may in particular, without loss of generality, be decorative or ornamental or be used as a ground surface or as a fence or be used for gaining food or medicine or building or industrial materials or fabrics. The plants, therefore, include all kind of cultivars or agricultural or horticultural plants or crop and also wild plants or species or varieties, in particular, without loss of generality, grass or weed or bushes or trees or agricultural plants, in grown or mature form or as seedlings etc. By a "lawn" any surface is meant with grass or weed or other plants that grow, mainly in the spring and summer season, when sufficient sunlight and water is present, and can be cut regularly, including sowed lawns as well as wild grown meadows or grassland and anything in between. The robot working on the vegetation (in the working mode) includes, without loss of generality, working activities to influence vegetation, its healthy growth, shape and constitution, including gardening or agricultural activities like cutting, mulching, scarifying, collecting items such as leaves, cut off grass or even golf balls, trimming, irrigating, fertilizing, sowing or harvesting, pesticide or herbicide spraying or video monitoring.

What partial spectra (wavelengths, frequencies) of the illuminating light, in particular sunlight, will be converted by the photovoltaic unit and to what extent (conversion rate), depends on the material and type of the photovoltaic device chosen. The term "light" includes electromagnetic radiation in the visible spectrum, typically
5 from about 400 nm to about 800 nm wavelength, and in the infrared (IR) spectrum, preferably in the near infrared spectrum from about 800 nm to about 1200 nm wavelength.

Regarding the *modus operandi* during the working mode, the robot may, in most of
10 the embodiments or applications, be moving on the ground by means of ground moving units such as wheels or rolls or legs or crawlers and corresponding driving and steering devices or units, usually electric motors with transmission units such as gears. However, in some embodiments, it is also possible that the robot may be flying or moving through the air during the operation, alternatively or in addition to
15 a ground movement, and may then be equipped with flying drives like e.g. drones, including for example propellers and electric drive motors.

Usually, the robot further comprises at least one control device for controlling the tool and the motion drive and, in particular in a centralized system, for navigating
20 the robot within the operating area and/or preferably for energy management of the electric energy stored in the energy storage and the electric energy supplied to the tool and the motion drive. The robot may (further or alternatively) comprise, in particular in a distributed system, a remote communication device for communicating with external control devices and/or signal or information sources for navigation
25 tion or optionally for energy management.

In an embodiment monitoring the charging status may be accomplished for instance by determining (or: monitoring) an electric energy stored in the energy storage, in particular rechargeable battery or batteries, of the robot or a directly associated
30 electric quantity such as electric capacity or electric charge of the energy storage. Preferably, monitoring the charging status may include measuring, detecting or evaluating an electric output voltage, output current or output power of the energy storage.

A low charging status is usually understood that the remaining charge or energy or associated quantity is still enough to reach the charging position, in particular assuming an energy consumption when all electric consumers including the tool and the motion drive of the robot being activated as is the case when the robot is working and preferably adapted to the working conditions, for instance more slopes or higher grass etc. that may increase the average power consumption.

Advantageous embodiments and improvements according to the invention are disclosed in particular in the dependent claims.

In a preferred embodiment a sequence, in particular a list or table, of reference output values is recorded (or detected and stored) at respective instants of time.

The number of the respective instants of time or reference output values in the sequence is preferably a predetermined number, in particular a number between 5 and 50, preferably between 8 and 12 such as 10.

Alternatively or in addition, a or the sequence of reference output values may be recorded within a rolling recording time window, in particular between 1 to 120 minutes, preferably between 5 and 15 minutes. Preferably, when a new reference output value is recorded, the previously first recorded or oldest recorded reference output value in the sequence is discarded or deleted from storage, so that a rolling sequence with the same number of reference output values or the rolling time window is implemented.

The successive instants of time preferably follow each other after a recording time interval (or recording time increment), which is chosen in particular between 10 s and 360 s, preferably between 30 s and 90 s. In other words, a new reference output value is recorded each time the recording time interval or span has lapsed. The recording time interval is preferably constant but can also be varied according to a predetermined function or rule.

In a preferred embodiment not only one target value is used, but a sequence of target values is selected or derived from the recorded reference output values,

wherein in the sequence each subsequent target value is smaller than the predecessor target value, or, in other words, the target values are in descending order. The monitored output value of the photoelectric device is compared with successive target values in the sequence until, at least after a respective monitoring time period, the monitored output value of the photoelectric device is larger than or at least equal to one of the target values in the sequence, in which case the charging position is reached.

Also the sequence of target values may comprise a predetermined number, in particular a number between 5 and 20, preferably between 8 and 12, of target values.

Preferably, the largest reference output value in the sequence of reference output values is chosen as the target value or as the first target value in the sequence of target values.

For deriving target value(s) from the reference output values, in one embodiment at least one of or each of the target values in the sequence of target values is computed from the largest reference output value by applying a pre-determined reduction algorithm or reduction function, in particular by multiplying the the largest reference output value with a reduction factor smaller than 1, especially between 0.8 and 0.95, or by subtracting a certain amount or percentage, especially 5 % to 20 %, from the the largest reference output value-

In another advantageous embodiment, for deriving target value(s) from the reference output values, at least one or each new target value in the sequence of target values is computed from the previous or predecessor target value by applying a pre-determined reduction algorithm or reduction function, in particular by multiplying the previous target value with a reduction factor smaller than 1, especially between 0.8 and 0.95, or by subtracting a certain amount or percentage, especially 5 % to 20 %, from the previous target value.

In yet another embodiment at least two or each of the target values in the sequence of target values may also be selected or chosen from the sequence of reference output values.

In a preferred embodiment, in the searching mode, the monitored output of the photoelectric device is preferably compared with the current target value for a searching time interval, which is in particular chosen from 10 s to 180 s, for example 60 s, and/or which is preferably equal to the recording time interval and/or which is preferably constant. After lapse or expiry of the searching time interval without the monitored output value of the photoelectric device having become larger than or at least equal to the current target value, the next target value is derived or chosen and the monitored output of the photoelectric device is now compared with this next target value. In other words, a new target value may be derived or selected each time the searching time interval or span has lapsed.

Preferably the robot stops at or close to the current position, if the last searching time interval for the last or smallest target value has expired without the monitored output value at least having reached this last or smallest target value.

In a further embodiment, an adjustment or alignment procedure may be provided, wherein the orientation of the robot and its photoelectric device at the charging position is adjusted towards the source of the illuminating light, in particular the sun, in order to increase or optimize the intensity area density of the incident illuminating light on the surface of the photoelectric device, in particular by rotating movement of the robot and/or by tilting and/or rotating movement of the photoelectric device relative to a robot body or chassis

Normally, during the working mode the tool and the motion drive are both activated. During the searching movement, the tool and motion drive of the robot preferably both stay activated to use also the searching movement for working activity. Alternatively, when the robot moves or is moved to the charging position, the tool of the robot may be deactivated and the motion drive activated. Typically the robot stays at the charging position in the charging mode, until the photovoltaic device has recharged the energy storage sufficiently, in particular so that the stored energy or the directly associated electric quantity of the energy storage is above a minimum operating threshold by a sufficient margin, and then resumes operating in the working mode. When the robot is at the charging position or in the charging mode, the tool and the motion drive of the robot are usually both deactivated.

An autonomous robot system according to embodiments of the invention comprises at least one autonomous robot, in particular an autonomous vegetation working robot, preferably an autonomous lawn robot, within an operating area, the robot comprising a1) at least one electric tool, a2) at least one electric motion drive for moving the robot, a3) at least one photoelectric device for converting energy from illuminating light, in particular sunlight, into electric energy and a4) at least one energy storage for storing electric energy charged by the photoelectric device and for supplying the tool and the motion drive with electric energy. The system with the robot is configured to carry out or execute a method according to any embodiment of the invention.

Many searching routines are suitable and can be implemented for searching the charging position and be integrated into or just keep following the normal navigational routines and movement patterns or paths applied during normal working operation of the robot, including random navigational routines such as turning at a bordering cable or wire or other bordering element such as e.g. a wall or fence at a randomly picked change of direction or angle, or following certain navigational patterns such as parallel lines in a meandered fashion or spirals or zick-zack movements etc.

It is understood that, as is usual in autonomous systems, any of the conditions and steps taken on the fulfillment or non-fulfillment of a condition according to the invention may be of lower priority than higher priority conditions such as for instance failure or hazard detection. The method according to the invention is however carried out in the absence of such higher priority conditions.

The embodiments disclosed herein are only examples, and the scope of this disclosure is not limited to them. Particular embodiments may include all, some, or none of the components, elements, features, functions, operations, or steps of the embodiments disclosed herein. Embodiments according to the invention are in particular disclosed in the attached claims directed to a method and a system, wherein any feature mentioned in one claim category, e.g. method or system, can be claimed in another claim category as well. The dependencies or references back in the attached claims are chosen for formal reasons only. However any subject matter re-

sulting from a deliberate reference back to any previous claims (in particular multiple dependencies) can be claimed as well, so that any combination of claims and the features thereof are disclosed and can be claimed regardless of the dependencies chosen in the attached claims. The subject-matter which can be claimed comprises not only the combinations of features as set out in the attached claims but also any other combination of features in the claims, wherein each feature mentioned in the claims can be combined with any other feature or combination of other features in the claims. Furthermore, any of the embodiments and features described or depicted herein can be claimed in a separate claim and/or in any combination with any embodiment or feature described or depicted herein or with any of the features of the attached claims.

Exemplary Embodiments

The invention will, in the following, be described further with reference to exemplary embodiments, also referring to the schematic drawings.

FIG 1 depicts a vegetation working robot with a photovoltaic device,
FIG 2 shows the vegetation working robot of FIG 1 within a vegetation working
area and
FIG 3 illustrates a find a charging position routine for a vegetation working robot
in a flow diagram.

Corresponding entities, parts and quantities are designated by the same reference signs in the figures if not indicated otherwise.

In FIG 1 and 2 an autonomous vegetation working robot, in particular lawn robot 2, is shown with ground wheels 21 driven by an electric motion drive 20 comprising at least one electric drive motor for moving the robot 2 on and over a surface of a lawn 10 within a pre-determined operating area, either comprising or being a working area 15, and according to autonomous navigation algorithms or routines or patterns provided by a navigational system. Also an operating area for the robot with several working areas may be provided (not shown). The ground wheels 21 of the robot 2 stand on a surface of the working area 15, here the lawn 10, and define a driving plane 22 or a chassis plane of the robot chassis.

The working area 15 is confined by a border 16 which may be defined by a bordering wire or border cable 56 or beacons or mapping or obstacles such as walls or hedges or other known systems. Besides the lawn 10 the working area 15 comprises
5 other vegetation such as for example trees or bushes or hedges. Examples of a tree 12, a hedge 13 and a bush 14 are depicted in FIG 2. During sunlight, each of the higher or taller parts of vegetation cast shadows (or: shades), e.g. the tree 12 the shadow 12A, the hedge 13 the shadow 13A and the bush 14 the shadow 14A.

10 The robot 2 has at least one electrically driven working tool 8 for working on the lawn 10 including an electric tool drive comprising at least one electric tool drive motor. The tool 8 comprises in particular a cutting tool or blade(s), in particular rotating and/or pivoting blades or cutting tool, for mowing or cutting the lawn 10 and possibly, in addition or alternatively, a mulching tool and/or scarifying tool.

15 The navigational system for the robot 2 typically comprises navigational software, implemented in a control device 7 of the robot 2 alone or, in a distributed system, in control hardware in the robot 2 and external hardware, the control device or hardware typically comprising at least one digital processor and digital storage for
20 digital data processing.

The robot 2 further comprises at least one sensor system 25 and/or communication equipment for sensing and/or transmitting and receiving signals used for navigation. The signals used for navigation may, without loss of generality, be signals
25 from bordering wires, in particular the border cable 56, or beacons sensed by the sensor system 25 or sensor signals indicating obstacles or bordering elements such as walls or fences for instance.

Although also positioning signals from known positioning systems and basically any
30 of the navigational systems known *per se* from the state of the art may be used for guiding and navigating the robot 2 within its working area, the method and system according to the invention is especially advantageous and suitable for autonomus robots without positioning systems or knowledge of the actual position.

The robot 2 comprises one or several rechargeable batteries as energy storage 4 for storing electric energy and at least one photoelectric device (or: photovoltaic device or module) 3, usually comprising several photoelectric or photovoltaic cells for converting light energy, in particular sunlight L of the sun 6, into electric energy by means of the photoelectric effect and for supplying the electric energy directly to the electric consumers in the robot 2 and/or to the batteries for recharging.

A great variety of photoelectric devices or cells are suitable and can be used for the robot 2 together with suitable electronic converters or power controllers. The photoelectric device 3 or its cells are preferably based on p-n-junctions or diodes of semiconductor materials such as, mostly monocrystalline or polycrystalline Silicon (Si) or, esp. in thin film technology, GaAs, ZnSe or CdS, which generate an output photoelectric voltage and change their electric impedance depending on the intensity of the incident light. The photoelectric device 3 may, topologically, be composed of a contiguous illumination area (or: surface) or several disjunct or disjoint illumination areas (or: surfaces) and each area may be composed of one or more parts or cells. The photoelectric device 3 may be made rigid or of rigid cells and mounted onto the robot 2. Also photoelectric material flexible in shape may be used for the photoelectric device 3 such as photoelectric foils or solar membranes or photoelectric coatings or thin-film photovoltaics applied onto the housing of the robot 2.

The rechargeable batteries of the energy storage 4 of the robot 2 are preferably Lithium-ion (Li-ion) batteries, in particular because of their high energy-to-weight ratio, low memory effect and slow self-discharge, although other materials for the batteries are also possible. Typically battery packs of several (Li-ion) battery cells grouped and switched together to achieve the desired total battery voltage and in order to achieve the desired electric capacity or electric discharge current. The geometric configuration of the battery pack can be adapted to the shape and space within the robot 2. The electric power is approximately the product of the battery discharge voltage and the discharge current at the various instants of time. The capacity of the battery determines the overall electric energy, i.e. the time integral over the electric power, the robot 2 may consume during one working cycle until recharging is needed. A higher electric capacity of the batteries is typically needed for covering a larger working area.

The robot 2 further comprises a battery monitoring system which monitors the remaining capacity or charge of the batteries or the state of charge (SOC) or charging state of the energy storage 4. There are several methods known *per se* for determining or estimating the actual remaining capacity or charge and thus the remaining electric energy of a battery by the battery management system. The remaining charge or capacity (measured in Ah or C) and is a direct measure for the remaining electric energy (measured in J or Wh) that can be supplied by the battery; at constant output voltage U the remaining electric energy E is $E = C U$. The State of Charge (SOC) is the ratio of the remaining charge or capacity and the maximum or rated charge or capacity of a battery. In order to determine the remaining charge or capacity or the SOC known battery or energy management systems may use various SOC estimation methods for instance using current integration (Coulomb counting) or Kalman filters or Neural Networks or impedance measurement or output voltage measurement (terminal voltage) or combinations thereof, in particular using the converters or electronics of the energy management system. For evaluating the SOC or the remaining electric energy electric parameters like the voltage, current, capacity, impedance, charging/discharging rate may be used and the temperature and chemical type of the battery be taken into account as well. Also State of Health (SOH) calculations or estimations may be considered-

The robot 2 also comprises a photoelectric monitoring system which monitors the photoelectric output, in particular the output power P_{out} , of the photoelectric device 3 over time t and determines corresponding output values at various instances of time. The output power P_{out} corresponds to the product of output voltage and output current. Also another physical quantity can be detected as output values of the photoelectric device 3, e.g. the output current.

According to embodiments of the invention, special routines for operating and re-charging the robot 2 are provided. Exemplary embodiments are described in the following referring also to the flow diagram of FIG 3.

The robot 2 is operated in normal working mode with the working tool(s) and the drive(s) and the navigation and control systems being powered with electric energy

and working, as long as there is enough charge or energy stored in the energy storage 3. In the exemplary embodiment of FIG 3 this operation is depicted as STEP 201 labelled with "MOWING".

5 The battery monitoring or management system permanently checks the charging status of the batteries or energy storage 3 of the robot 2 (in FIG 3 STEP 202 labelled "NEEDS TO CHARGE"). If the battery charging status is ok and the battery is not low, i.e. in particular not below a minimum working capacity or charge C_{min} , (in FIG 3 STEP 202 NO), the robot 2 continues to operate in the working mode for a
10 certain recording time interval Δt_A , preferably chosen from 10 s to 180 s, for example one minute (60 s), and then records, i.e. detects and stores, the output value P_{out} of the photoelectric device 3 at the corresponding instant of time t_i with i being a natural number ($i = 1, 2, 3, \dots$) in a storage, e.g. in form of a list or (history) table (in FIG 3 STEP 203 labelled "ONE MINUTE PASSED?" and STEP 204 labelled
15 "STORE SOLAR EFFECT IN HISTORY TABLE)). Thereby, a sequence, in particular a list or table, of recorded reference output values value $P_{out}(t_i)$ of the photoelectric device 3 at various subsequent instants of time (or: measuring points in time) t_i for different successive natural numbers i is obtained. Preferably, the recording time interval Δt_A is chosen to be constant so that $t_{i+1} = t_i + \Delta t_A$.

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The number of reference output values $P_{out}(t_i)$ in the sequence, in particular list or table, is usually kept below a maximum number, for instance between 5 to 50 depending on the recording time interval Δt_A , to keep the reference values within a certain (historical) period during the day or illumination period right before the actual time and to have realistic values indicating the or being correlated to the
25 actual illumination situation. Therefore, in a preferred embodiment, a rolling time interval or a rolling sequence of a predetermined number of output values is provided, so that as soon as a new reference output value, e.g. $P_{out}(t_{11})$, is recorded the oldest reference output value, e.g. $P_{out}(t_1)$, in the sequence is discarded or deleted.
30 The number of stored output values corresponds in particular to a time length of the table, which is in particular the number of recorded reference output values multiplied by the recording time interval Δt_A . In a preferred embodiment the number of recorded reference output values is 10 and/or the length of the table or rolling time interval is 10 minutes.

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If, however, the battery charge is low, i.e. below a minimum working capacity or charge $C_{\min}$, (in FIG 3 STEP 202 YES) and thus the batteries cannot provide enough electric energy required for working properly in the working mode for much longer, a searching routine is started for searching a charging position with high or peak
5 light intensity (in FIG 3 STEP 205 labelled "FIND PEAK EFFECT").

For this purpose, the maximum reference output value $P_{\max}$ in the stored sequence, in particular list or (history) table, of stored reference output values value $P_{\text{out}}(t_i)$ of the photoelectric device 3 is determined and chosen or set as a (starting or first)
10 target value P_T (in FIG 3 STEP 206 labelled "SET TARGET VALUE TO MAX FROM HISTORY TABLE"). The target peak effect to look for is, therefore and in particular, the maximum peak detected a certain time back while mowing.

The actual or current output value $P_{\text{out}}(t)$ of the photoelectric device 3 is then
15 measured or determined and compared to the target value P_T (in FIG 3 STEP 207 labelled "CURRENT EFFECT > TARGET?").

If the current output value $P_{\text{out}}(t)$ of the photoelectric device 3 is larger than (or at least equal to) the target value P_T (in FIG 3 STEP 207 YES) then the robot 2 is al-
20 ready at a position with the highest or a high illumination intensity, at least relatively highest or high illumination intensity during the period considered for the sequence of reference output values that period or time of the day, and may therefore enter a charging mode (in FIG 3 STEP 211 labelled "CHARGE") and stop at this point as the charging position (CP in FIG 2) for recharging (in FIG 3 STEP 212 la-
25 belled "STOP AT THIS POINT").

If, however, the current output value $P_{\text{out}}(t)$ of the photoelectric device 3 is and remains smaller than (or at least not larger than) the target value P_T (in FIG 3 STEP 207 NO) for a certain searching time interval Δt_B (in FIG 3 STEP 208 labelled "ONE
30 MINUTE PASSED" YES), then the robot 2 has not found a charging position at the maximum recorded reference output value $P_{\max}$.

In this situation, after a searching time interval Δt_B has passed unsuccessfully, the target value P_T is decreased by a certain amount or percentage (in FIG 3 STEP 210
35 labelled "DECREASE TARGET VALUE BY 10 %") and the searching routine (in FIG 3

STEP 205 labelled "FIND PEAK EFFECT") is continued or repeated or resumed with this reduced or decreased new target value P_T .

5 The searching time interval Δt_B is in particular chosen from 10 s to 180 s, for example one minute (60 s) and preferably equal to the recording time interval Δt_A and/or preferably constant.

10 The new target value P_T , is, in one embodiment, reduced or decreased with respect or compared to the previous target value P_T target value P_T i.e. the new target value P_T new = reduction factor $\times P_T$ old, for instance by a factor between 0,7 and 0,95, in particular 0,9, or by a percentage (decrease percentage) between 5 % and 30 %, in particular 10 %, each time the searching time interval Δt_B has passed.

15 In another embodiment the target value P_T is reduced or decreased with respect or compared to the maximum output value $P_{\max}$ in the stored sequence, for instance by subtracting a percentage (decrease percentage) of the maximum output value $P_{\max}$ from the previous target value P_T to arrive at the new target value P_T , each time the searching time interval Δt_B has passed.

20 Also another reduction function can be used to decrease the target value, using variable factors or a function with decreasing values.

25 In yet another embodiment, not shown in FIG 3, instead of decreasing the target value by a certain percentage or factor as shown in STEP 210, also the next smaller reference output value in the sequence, in particular list or table, of recorded reference output values can be selected. Thereby, successively decreasing reference output values are picked or selected from the sequence of reference output values previously recorded in the recording time interval or rolling time window as target value(s), until, hopefully, the current output value is larger than the target value (STEP 207).

35 This routine with the steps of reducing or decreasing the target value P_T is repeated until a maximum searching time period (or: time to look for peak effect) has been reached or has expired, which is typically smaller than or at most equal to the time at which the final decreased target value P_T is too low or cannot be reduced any

more (in FIG 3 STEP 209 labelled "TEN MINUTES PASSED?"). Such a maximum searching time period is for instance chosen to be the searching time interval Δt_B divided by the decrease percentage, so for instance for decrease percentage = 10 % it is $10 \times \Delta t_B$ and for $\Delta t_B = 1$ minute it is 10 minutes. But the maximum searching time period can be chosen smaller or differently too and can, like the searching time interval Δt_B , depend on the time of the day also or other factors.

As long as the maximum searching time period has not passed (in FIG 3 STEP 209 labelled "TEN MINUTES PASSED?" NO) the searching routine continues (in FIG 3 STEP 205 labelled "FIND PEAK EFFECT").

If, however, the maximum searching time period has passed (in FIG 3 STEP 209 labelled "TEN MINUTES PASSED?" YES) and the current output value $P_{out}(t)$ of the photoelectric device 3 is still not larger than (or at least equal to) the repeatedly decreased target value P_T the searching routine is stopped and the robot 2 stays at the current position for recharging (in FIG 3 STEP 211 and STEP 212). This might happen in a situation when the illumination decreased rapidly for instance due to darkening by sun set or heavy clouds.

In an embodiment, while moving and looking for the peak effect, it is not certain that the target peak is found. Therefore, the target peak is lowered as time passes. If the target peak is never detected within a certain time, the robot stops anyway. This can happen at sunset or if it is cloudy.

By these measures, described above, no positioning is needed to stop at a sunny or well illuminated spot. The charging position CP in FIG 2, due to the method or system chosen according to the invention, is likely outside of any of these shadows 12A, 13A and 14A of tree 12, hedge 13 or bush 14 (or any other obstacles that cast shadows). Also the function is independent of time of day, day of year, country, gardens (working areas) and obstacles.

In an advantageous embodiment, after stopping at the charging position (CP in FIG 2, STEP 212 in FIG 3), adjustment measures are provided so that the illumination surface(s) of the photoelectric device 3 are directed or oriented towards the sun at the time of recharging at the respective charging position CP. This means that an

optimal angle of incidence, preferably around or at least close to 90° , of the light L of the sun on the surface of the photoelectric device 3 should be achieved. Therefore, an orthogonal axis of the surface of the photoelectric device 3 is oriented as close as possible, preferably parallel to the position of the inclined axis of the sun, i.e. in the best case oriented at the same elevation angle and the same azimuth angle as the sun at that instant of time.

As can be seen best in FIG 1, the illumination surface of the photoelectric device 3 is, in the exemplary embodiment shown, inclined under an inclination angle α with respect to the driving plane 22 or the robot chassis, thereby increasing or optimizing the output of the photoelectric device.

An azimuthal adjustment of its photoelectric device by rotating (or: turning or circling) the photoelectric device or the whole robot with the photoelectric device about a vertical axis by an (azimuth) angle of 360° , i.e. at least one full turn or revolution. During this full turn or revolution the effect or output of the photoelectric device 3 is monitored and a maximum output (or: highest output) during the rotation or turn and the corresponding rotational position or azimuth angle are identified. The robot or the photoelectric device is then rotated to the rotational position or azimuth angle, where the maximum output of the photoelectric device was observed or detected. The robot may in the azimuthal adjustment procedure also be rotated at an azimuth angle which is a bit, e.g. between 1 % to 5 %, further towards the West than the detected azimuth angle in order to optimize the light intensity density over the charging time interval without having to move the robot again during recharging.

In an embodiment, an elevation adjustment is performed, in addition or without the azimuthal adjustment. During the elevation adjustment the inclination of the surface of the photoelectric device 3 towards the sun is optimized or at least improved, preferably so that the normal or orthogonal axis of the surface of the photoelectric device 3 (normal incidence) is inclined at the elevation angle of the sun or at least as close as possible to it with respect to the horizontal plane-

The adjustment routine for the azimuth angle and the inclination or elevation angle, whether performed by moving the whole robot 2 or by moving just the photoelectric

device 3, can be repeated once or more to follow or adjust to the course of the sun during a recharging procedure at the charging position

Many navigational routines are suitable and can be implemented for the working mode and also for searching the charging position. Preferably, when searching the charging position the robot 2 stays in the working mode and keeps following the normal navigational routines and movement patterns or paths applied during normal working operation of the robot. Examples for such navigational routines are random routines, where the robot 2, when encountering a border element such as the border cable 56, turns back into the working area at a randomly picked direction or angle or pattern in parallel lines in a meandered fashion or spirals or zick-zack movements or other forms. But, alternatively, the robot may also follow specific search patterns in the searching mode, which are optimised for efficient searching for and finding of a charging position.

It is understood that, as is usual in autonomous systems, any of the conditions and steps taken on the fulfillment or non-fulfillment of a condition according to the invention may be of lower priority than higher priority conditions such as for instance failure or hazard detection, critical charge conditions, or severe weather conditions or a time schedule defining non-working periods. The method according to the invention is however carried out in particular in the absence of such higher priority conditions, which usually rarely occur.

The invention is by no means delimited by or to the exemplary embodiments. Various other embodiments are also possible and fall within the scope of the invention.

For instance, although the exemplary embodiments describe an autonomous vegetation working robot, in particular lawn robot 2, the invention can be applied also to other types of autonomous robots operating in an operating area, e.g. cleaning robots, service robots, surveillance or guarding robots, or any robots as described in the prior art mentioned in the beginning. Furthermore, other locomotion or propelling drive systems can be provided as well for moving the robot on ground as a ground robot, for instance rolls or balls or legs or chain drives instead or in addition to wheels, or air propelling drives, in the air, as a flying robot like a drone or as a carrier drone for flying the ground robot from one place to the other (not shown).

Instead of the sun 6 also artificial light sources may be used, for instance lights or lamps or floodlights, e.g. in an application for final cutting of lawn in sports like football, tennis or golf.

- 5 The robot could also, instead of or in addition to rechargeable batteries, include power to fuel or power to hydrogen technology converting the electric energy to fuel such as methanol or methane or hydrogen for storage in form of chemical energy and using a fuel cell for converting the energy in the fuel or hydrogen back into electric energy esp. once such systems become small and light and efficient
- 10 enough for such an autonomous robot. If the photoelectric or solar recharging may not be sufficient, a hybrid solution with external recharging in a charging station, in particular equipped with stationary solar cells itself, is also possible, and/or a plug in cable or manual recharging in case of emergency.

Designating numerals

	2	robot
	3	photoelectric device
5	4	energy storage
	7	control device
	8	tool
	10	lawn
	11	slope
10	12	tree
	12A	shade
	13	hedge
	13A	shade
	14	bush
15	14A	shade
	15	working area
	16	border
	20	motion drive
	21	wheels
20	22	driving plane
	25	sensor system
	56	border cable
	60	control station
	200 to 212	STEP
25	CP	charging position
	L	light
	α	tilting angle

Claims

1. A method for operating at least one autonomous robot (2), in particular an autonomous vegetation working robot, preferably an autonomous lawn robot, within an operating area,
- 5 the robot comprising (i) an electrically driven tool, (ii) an electric motion drive for moving the robot, (iii) a photoelectric device for converting energy from illuminating light, in particular sunlight, into electric energy, and (iv) an energy storage for storing electric energy charged by the photoelectric device and for supplying the tool and the motion drive with electric energy,
- 10 the method comprising the steps of
- a) the robot (2) working, in a working mode, within at least one working area (15) within the operating area according to a navigational routine, wherein the tool and the motion drive are both activated,
 - b) during the working mode of the robot, monitoring the output of the photoelectric device and recording output values at successive instants of time as reference output values,
 - 15 c) during the working mode of the robot, monitoring the charging status of the energy storage and checking whether, due to a low charging status, recharging of the energy storage is required,
 - 20 d) if recharging is required, the robot searching for a charging position in a searching mode,
 - e) wherein, in the searching mode, the output of the photoelectric device is monitored and
 - f) wherein the monitored output of the photoelectric device is compared with at least one target value, which is selected or derived from the recorded reference output values, and
 - 25 g) wherein the charging position is reached as soon as the monitored output value of the photoelectric device is larger than or at least equal to the at least one target value.

2. Method according to claim 1,
wherein a sequence, in particular list or table, of reference output values is recorded at respective instants of time, wherein the successive instants of time preferably follow each other after a, preferably constant, recording time interval, which is chosen in particular between 10 s and 360 s, preferably between 30 s and 90 s.
3. Method according to claim 2,
wherein the recorded sequence comprises a predetermined number, in particular a number between 5 and 50, preferably between 8 and 12, of reference output values at respective instants of time and/or wherein the sequence of reference output values is recorded within a rolling recording time window, in particular in a time between 1 to 120 minutes, preferably between 5 and 15 minutes, and/or wherein, when a new reference output value is recorded, the previously first recorded or oldest reference output value in the sequence is discarded.
4. Method according to any of the preceding claims,
 - a) wherein a sequence of target values is selected or derived from the recorded output values, wherein in the sequence each subsequent target value is smaller than the predecessor target value,
 - b) wherein the monitored output of the photoelectric device is compared with successive target values in the sequence until, at least after a respective searching time interval, the monitored output of the photoelectric device is larger than or at least equal to one of the target values in the sequence, in which case the charging position is reached.
5. Method of claim 4,
wherein the sequence of target values comprises a predetermined number, in particular a number between 5 and 20, preferably between 8 and 12, of target values .
6. Method according to any of the preceding claims, wherein the largest reference output value in the sequence of reference output values is chosen as the target value or as the first target value in the sequence of target values,

7. Method according to any of claims 4 to 6,
wherein at least one of or each of the target values in the sequence of target
values is computed from the largest reference output value by applying a pre-
determined reduction algorithm or reduction function, in particular by multiply-
5 ing the the largest reference output value with a reduction factor smaller than
1, especially between 0.8 and 0.95 or by subtracting a certain amount or per-
centage, especially 5 % to 20 %, from the the largest reference output value.
- 10 8. Method according to any of claims 4 to 7,
wherein at least one or each new target value in the sequence of target values
is computed from the previous target value by applying a pre-determined re-
duction algorithm or reduction function, in particular by multiplying the previ-
ous target value with a reduction factor smaller than 1, especially between 0.8
15 and 0.95, or by subtracting a certain amount or percentage, especially 5 % to
20 %, from the previous target value.
9. Method according to any of claims 4 to 8,
wherein at least two or each of the target values in the sequence of target
20 values are selected from the sequence of reference output values.
10. Method according to any of the preceding claims,
wherein, in the searching mode, the monitored output of the photoelectric de-
vice is compared with the current target value for the searching time interval
25 (Δt_B), which is in particular chosen from 10 s to 180 s, for example 60 s,
and/or which is preferably equal to the recording time interval and/or which is
preferably constant, and after expiry of the searching time interval without the
monitored output value of the photoelectric device having become larger than
or at least equal to the current target value, the next target value is derived
30 or chosen and the monitored output of the photoelectric device is now com-
pared with this next target value,
wherein preferably the robot stops at or close to the current position, if the
last searching time interval for the last or smallest target value has expired
without the monitored output value at least having reached this last or small-
35 est target value.

11. Method according to any of the preceding claims,
wherein the orientation of the robot and its photoelectric device at the charging position is adjusted towards the source of the illuminating light, in particular the sun, in order to increase or optimize the intensity area density of the incident illuminating light on the surface of the photoelectric device, in particular by rotating movement of the robot and/or by tilting and/or rotating movement of the photoelectric device relative to a robot body or chassis.

12. Method according to any of the preceding claims,
wherein the robot stays at the charging position until the photovoltaic device has recharged the energy storage sufficiently, in particular so that the stored energy or the directly associated electric quantity of the energy storage is above a minimum operating threshold by a sufficient margin, and then resumes operating in the working mode.

13. An autonomous robot system comprising

a) at least one autonomous robot (2), in particular an autonomous vegetation working robot, preferably an autonomous lawn robot, within an operating area (15),

the robot comprising

a1) at least one electric tool,

a2) at least one electric motion drive for moving the robot,

a3) at least one photoelectric device for converting energy from illuminating light, in particular sunlight, into electric energy and

a4) at least one energy storage for storing electric energy charged by the photoelectric device and for supplying the tool and the motion drive with electric energy;

b) the system with the robot being configured to carry out a method according to any of the claims 1 to 12.

FIG 1

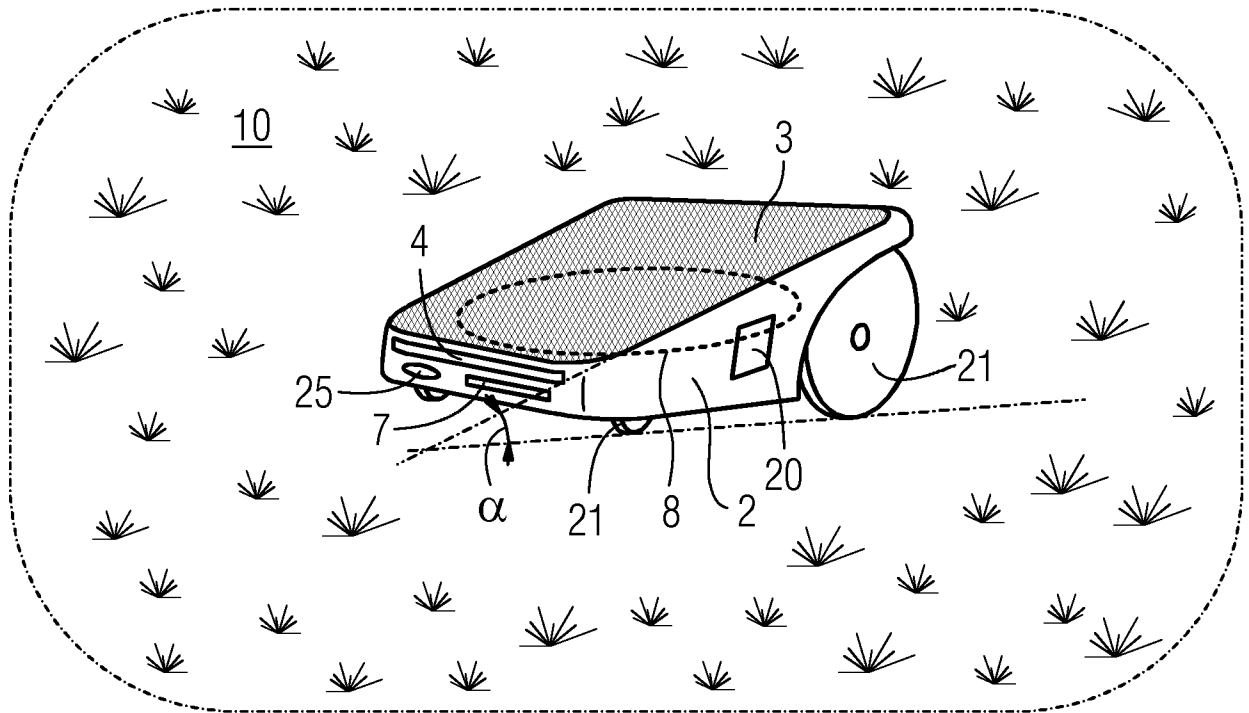


FIG 2

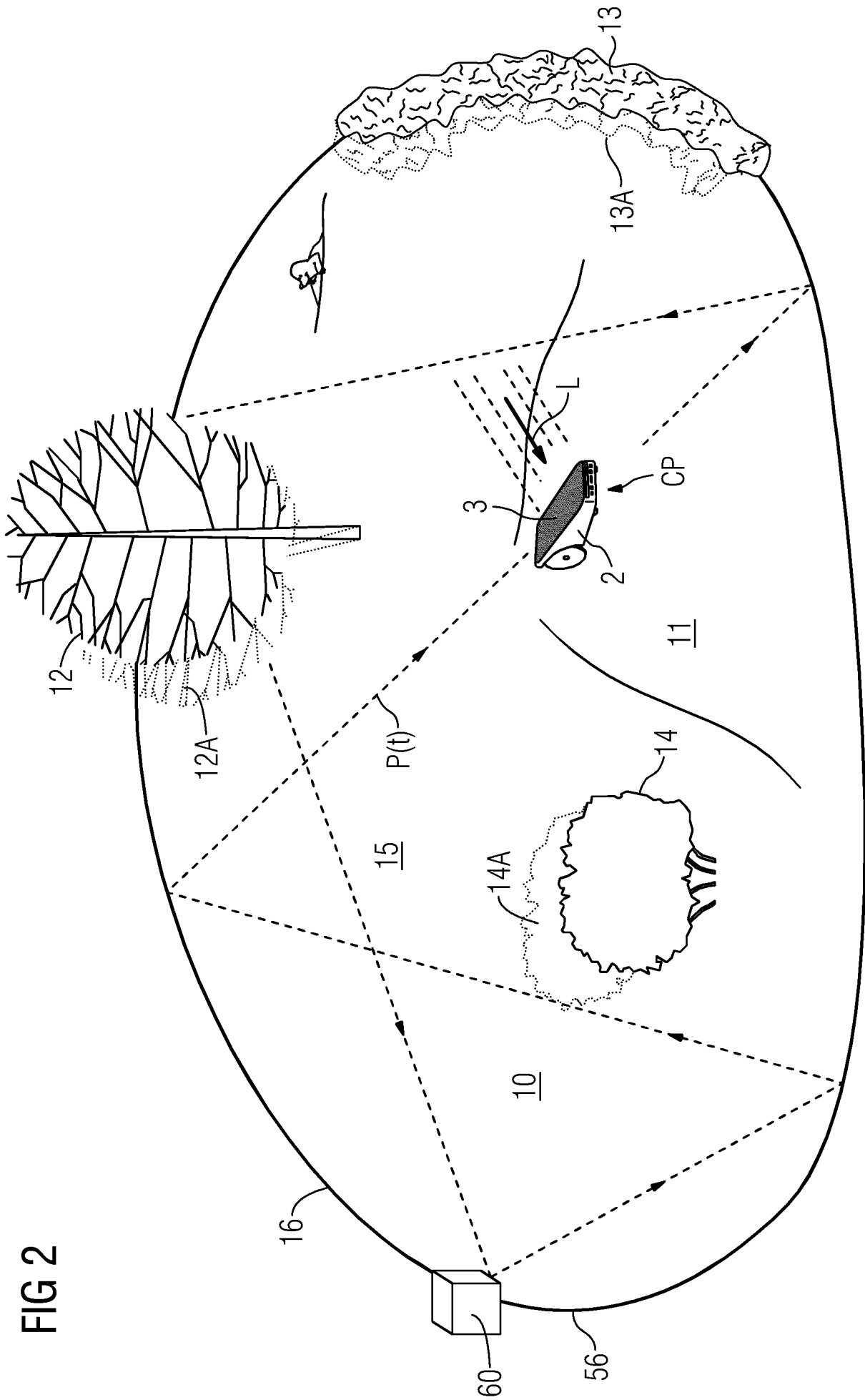
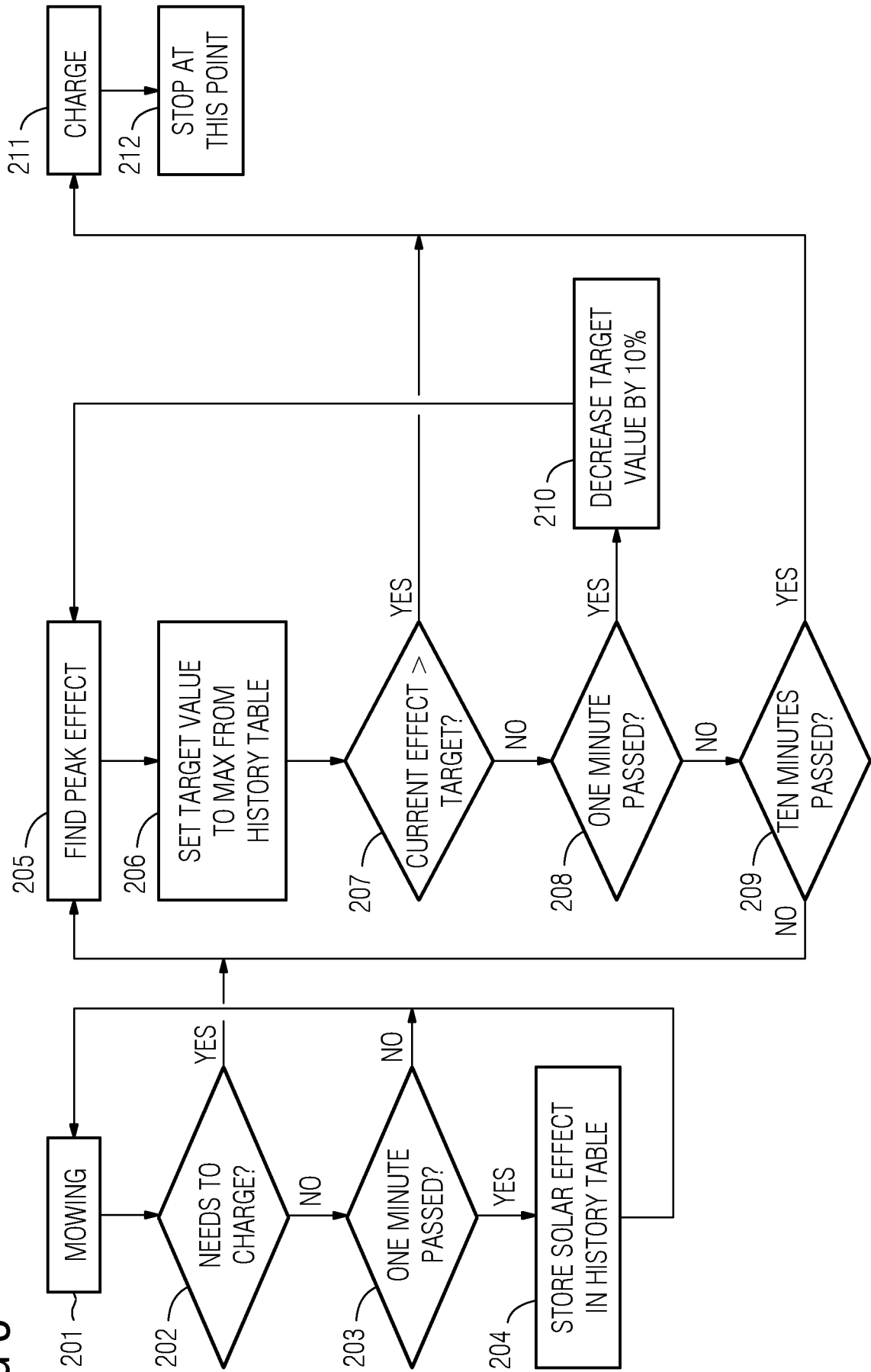


FIG 3



INTERNATIONAL SEARCH REPORT

International application No

PCT/SE2023/050054

A. CLASSIFICATION OF SUBJECT MATTER**INV. A01D34/00****ADD.**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 3 503 205 B1 (POSITEC POWER TOOLS SUZHOU CO LTD [CN]) 12 May 2021 (2021-05-12) cited in the application	1, 13
A	abstract; figures paragraph [0088] - paragraph [0168] -----	2-12



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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 when the document is taken alone

"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

Date of the actual completion of the international search

17 March 2023

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/SE2023/050054

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
EP 3503205	B1	12-05-2021	EP 3503205 A1	26-06-2019
			EP 3872867 A1	01-09-2021
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