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(54) **Title:** SYSTEM AND METHOD FOR EXECUTION OF AN AUTONOMOUS AIRBORNE SCANNING-MISSION

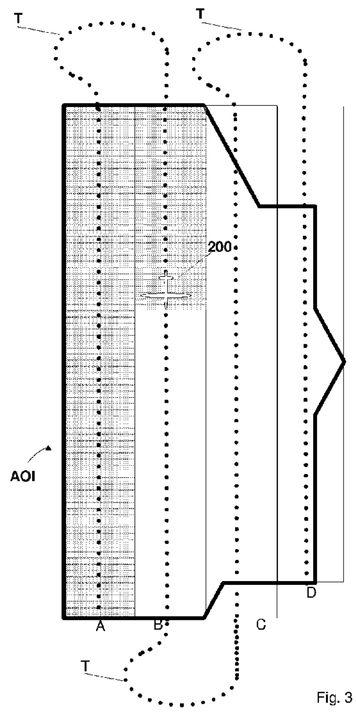

Fig. 3

(57) Abstract: The presently disclosed subject matter includes a method and system for autonomously maneuvering an aircraft over an area of interest during a scanning- mission, where the scanning-mission includes flying over the area of interest along a flight path that comprises multiple legs, wherein all legs traverse the area of interest in substantially the same direction (or azimuth) and each two consecutive legs are connected by a turn. The method and system allow generation of flight instructions dedicated for controlling the UAV during a scanning-mission for the purpose of improving the efficiency and autonomous operation of the scanning-mission execution.

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SYSTEM AND METHOD FOR EXECUTION OF AN AUTONOMOUS AIRBORNE SCANNING-MISSION

FIELD OF THE PRESENTLY DISCLOSED SUBJECT MATTER

The presently disclosed subject matter relates to the field of aerial missions executed by an aircraft.

BACKGROUND

Various types of aerial missions involve operating a payload mounted onboard an aircraft (e.g. unmanned aerial vehicle (UAV) aka unmanned aerial system or drone). For example, an imaging system mounted on a UAV can be used for the purpose of imagery collection and analysis in terrain dominance related applications such as reconnaissance, cartography, land use, environmental conditions studies and more. Other examples of missions include aerial application (crop dusting), fire extinguishing, irrigation, etc.

GENERAL DESCRIPTION

Some aerial missions, such as those related to terrain dominance mentioned above, involve flying over a certain area of interest (AOI) on the ground with the intent of systematically scanning\covering the entire area. For example, in some aerial photography missions a camera system mounted onboard an aircraft is used for systematically scanning an AOI in order to collect imaging data of the entire area.

According to an aspect of the presently disclosed subject matter there is provided a method of autonomously maneuvering an aircraft over an area of interest during a scanning-mission, where the scanning-mission includes flying over the area of interest along a flight path that comprises multiple legs, wherein all legs traverse the area of interest in substantially the same direction (or azimuth) and each two consecutive legs are connected by a turn, the method comprising:

operating at least one processing circuitry for:

obtaining mapping data indicative of boundaries of the area of interest to be scanned by the aircraft;

processing the mapping data to select a selected cross-section of the area of interest from a plurality of cross-sections, each cross-section from among the plurality of cross-sections is characterized by a different angle relative to a certain frame of reference (e.g. global coordinate system) and comprises a respective section confined by two projection points, each of the two projection points are a projection of a respective extreme vertex of a polygon representing the area of interest;

wherein the selected cross-section is characterized by the shortest respective section;

determining a selected flight direction to be substantially perpendicular to the selected cross-section;

generating the flight path comprising a plurality of legs, where all legs are aligned with the selected flight direction, thereby reducing the number of turns during the scanning-mission relative to other possible flight directions ; and

generating instructions dedicated for controlling the aircraft to fly along the flight path.

In addition to the above features, the method according to this aspect of the presently disclosed subject matter can optionally comprise one or more of features (i) to (xii) below, in any desired combination or permutation:

(i). The method further comprising operating the payload while proceeding along the flight path.

(ii). wherein the polygon representing the AOI is the area of interest.

(iii). wherein the polygon representing the AOI is a polygon tangential to the AOI.

(iv). The method further comprising:

for each cross-section of the plurality of cross-sections, calculating the length of the respective section, comprising:

projecting a plurality of vertices of the polygon on the cross-section; and determining the greatest distance between two points projected on the cross-section.

(v). The method further comprising:

obtaining information indicative of a range of angles limiting the allowed flying direction; and

selecting the selected cross-section from a plurality of cross-sections characterized by an angle substantially perpendicular to an angle that resides within the range of angles.

(vi). wherein the scanning-mission includes operating a hyperspectral imaging system over the AOI, and wherein the range of angles is determined according to the position of the sun relative to the AOI.

(vii). The method further comprising: operating the at least one processing circuitry for selecting a turning maneuver during transition from a first leg to a second leg, wherein flying direction along the first leg is substantially parallel and at an opposite direction to flying direction along the second leg, the method comprising:

determining a minimal effective turning diameter of the aircraft;

in case the minimal effective turning diameter is greater than a distance crossing between the first leg and the second leg, preforming a first turning maneuver that includes:

a first turn exiting the current leg in a first direction opposite to the direction of the second leg, the first turn is aimed to increase the distance of the aircraft from the second leg; a second turn in a second direction toward the next leg, wherein the diameter of the second turn is such that the second turn ends at an ending point located beyond the next leg; and a third turn from the ending point of the second turn to the entry point of the next leg; and

in case diameter of the minimal effective turning is shorter than the distance crossing between the first leg and the second leg, performing a second turning maneuver that includes:

a first turn exiting the current leg in a direction of the next leg; a second turn toward the next leg, the second turn having a direction substantially opposite to the first turn and an extended section connecting between the first turn and the second turn.

(viii). wherein each turn in the first turning maneuver and the second turning maneuver is part of a circle characterized by a diameter that is equal to the minimal effective turning diameter.

(ix). The method further comprising operating the at least one processing circuitry for selecting a circling maneuver for repeating a traversed section within a current leg, the method comprising:

responsive to detection of a need to repeat a traversed section within a leg:

calculating the distance of a first circling maneuver that comprises a turn starting from about the end of the traversed section and circles back around to the beginning of traversed section along the current leg; and

calculating the distance of a second circling maneuver that comprises proceeding to an ending point of the current leg, performing a U-turn leading back to the ending point and into the current leg, and repeating the entire current leg a second time;

selecting a selected circling maneuver with the shorter length;

controlling the aircraft according to the selected circling maneuver for flying over the traversed section a second time, and activating a payload.

(x). wherein the aircraft is an unmanned aerial vehicle.

(xi). The method further comprising: operating the at least one processing circuitry for selecting a turning maneuver during transition from a first leg to a second leg, wherein flying direction along the first leg is substantially parallel and at an opposite direction to flying direction along the second leg, the method comprising:

for each one of a plurality of candidate turning maneuvers:

calculating predicted ground-speed along the candidate turning maneuvers, based on the wind velocity and flight directions along the course of the candidate turning maneuver;

calculating a time of travel for completing each of the candidate turning maneuvers; and

selecting a turning maneuver from a plurality of turning maneuvers characterized by the shortest time of travel.

(xii). The method further comprising: operating the at least one processing circuitry for selecting a circling maneuver for repeating a traversed section within a current leg; the method comprising:

calculating a predicted ground-speed along each one of a plurality of candidate circling maneuvers, based on the wind velocity and flight directions along the candidate circling maneuver;

calculating a time of travel for completing each of the candidate circling maneuvers; and

selecting a circling maneuver from a plurality of turning maneuvers characterized by the shortest time of travel.

According to another aspect of the presently disclosed subject matter there is provided a system mountable on an aircraft for autonomously maneuvering the aircraft over an area of interest during a scanning-mission, where the scanning-mission includes flying over the area of interest along a flight path that comprises multiple legs, wherein all legs traverse the area of interest in substantially the same direction and each two consecutive legs are connected by a turn, the system comprises a computer and a payload, the computer comprising one or more processing circuitries configured to:

obtain mapping data indicative of boundaries of the area of interest to be scanned by the aircraft;

process the mapping data to select a selected cross-section of the area of interest from a plurality of cross-sections, each cross-section from among the plurality of cross-sections is characterized by a different angle relative to a certain frame of reference (e.g. global coordinate system) and comprises a respective section confined by two projection points, each of the two projection points are a projection of a respective extreme vertex of a polygon representing the area of interest;

wherein the selected cross-section is characterized by the shortest respective section;

determine a selected flight direction to be substantially perpendicular to the selected cross-section;

generate the flight path comprising a plurality of legs, where all legs are aligned with the selected flight direction, thereby reducing the number of turns during the scanning-mission relative to other possible flight directions ; and

generate instructions dedicated for controlling the aircraft to fly along the flight path and instructions for operating the payload along the flight path.

According to another aspect of the presently disclosed subject matter there is provided a computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein for autonomously maneuvering an aircraft over an area of interest during a scanning-mission, where the scanning-mission includes flying over the area of interest along a flight path that comprises multiple legs, wherein all legs traverse the area of interest in substantially the same direction and each two consecutive legs are connected by a turn; the computer program product comprising:

computer readable program code for causing the computer to obtain mapping data indicative of boundaries of the area of interest to be scanned by the aircraft;

computer readable program code for causing the computer to process the mapping data and select a selected cross-section of the area of interest from a plurality of cross-sections, each cross-section from among the plurality of cross-sections is characterized by a different angle relative to a certain frame of reference (e.g. global coordinate system) and comprises a respective section confined by two projection points, each of the two projection points are a projection of a respective extreme vertex of a polygon representing the area of interest; wherein the selected cross-section is characterized by the shortest respective section;

computer readable program code for causing the computer to determine a selected flight direction to be substantially perpendicular to the selected cross-section;

computer readable program code for causing the computer to generate the flight path comprising a plurality of legs, where all legs are aligned with the selected flight direction, thereby reducing the number of turns during the scanning-mission relative to other possible flight directions; and

computer readable program code for causing the computer to generate instructions dedicated for controlling the aircraft to fly along the flight path.

According to another aspect of the presently disclosed subject matter there is provided an aircraft configured with autonomous flying capabilities (e.g. a UAV) that comprises a system for autonomously maneuvering the aircraft over an area of interest during a scanning-mission, as disclosed in the aspect above.

The method, the computer program product, and the aircraft disclosed in accordance with the presently disclosed subject matter can optionally comprise one or more of features (i) to (xii) listed above, mutatis mutandis, in any technically possible combination or permutation.

- According to another aspect of the presently disclosed subject matter there is provided a computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein for autonomously maneuvering an aircraft over an area of interest; the computer program product comprising:

  computer readable program code for causing the computer to select a turning maneuver during transition from a first leg to a second leg, wherein flying direction along the first leg is substantially parallel and at a substantially opposite direction to flying direction along the second leg; the computer program product further comprising:

  computer readable program code for causing the computer to determine a minimal effective turning diameter of the aircraft;

  computer readable program code for causing the computer to perform a first turning maneuver, in case the minimal effective turning diameter is greater than a distance crossing between the first leg and the second leg, the first turning maneuver comprises:

  a first turn exiting the current leg in a first direction opposite to the direction of the second leg, the first turn is aimed to increase the distance of the aircraft from the second leg; a second turn in a second direction toward the next leg, wherein the diameter of the second turn is such that the second turn ends at an ending point located beyond the next leg; and a third turn from the ending point of the second turn to the entry point of the next leg; and computer readable program code for causing the computer to perform a second turning maneuver, in case diameter of the minimal effective turning is shorter than the distance crossing between the first leg and the second leg, performing the second turning maneuver comprises:

a first turn exiting the current leg in a direction of the next leg; a second turn toward the next leg, the second turn having a direction substantially opposite to the first turn and an extended section connecting between the first turn and the second turn.

The presently disclosed subject matter further contemplates a method of autonomously controlling an aircraft (e.g. during a scanning-mission) and selecting a turning maneuver during transition from a first leg to a second leg as disclosed above, as well as a system mountable on an aircraft configured and operable for executing the method.

- According to another aspect of the presently disclosed subject matter there is provided a computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein, the computer program product comprising:

computer readable program code for causing the computer to select a turning maneuver during transition from a first leg to a second leg, wherein flying direction along the first leg is substantially parallel and at a substantially opposite direction to flying direction along the second leg; the computer program product further comprising:

computer readable program code for causing the computer to calculate a predicted ground-speed along each one of a plurality of candidate turning maneuvers, based on the wind velocity and flight directions along the candidate turning maneuver;

computer readable program code for causing the computer to calculate a time of travel for completing each of the candidate turning maneuvers; and

computer readable program code for causing the computer to select a selected turning maneuver from the plurality of turning maneuvers, the selected turning maneuver is characterized by the shortest time of travel.

According to some examples, the computer program product further includes a computer readable program code for causing the computer to generate instructions for controlling the aircraft according to the selected turning maneuver.

The presently disclosed subject matter further contemplates a method of autonomously controlling an aircraft (e.g. during a scanning-mission) and selecting a circling maneuver during transition from a first leg to a second leg as disclosed above, as well as a system mountable on an aircraft configured and operable for executing the method.

- According to another aspect of the presently disclosed subject matter there is provided a computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein; the computer program product comprising:

  computer readable program code for causing the computer to select a circling maneuver for repeating a traversed section within a current leg; the computer program product further comprising:

computer readable program code for causing the computer, responsive to detection of a need to repeat a traversed section within a leg to:

calculate the distance of a first circling maneuver that comprises a turn starting from about the end of the traversed section and circling back around to the beginning of traversed sections along the current leg; and

calculate the distance of a second circling maneuver that comprises proceeding to the end of the current leg, performing a U-turn leading back into the current leg, and repeating the entire current leg a second time;

computer readable program code for causing the computer to select the circling maneuver with the shorter length;

computer readable program code for causing the computer to control the aircraft according to the selected circling maneuver for flying over the traversed section a second time, and activating a payload.

The presently disclosed subject matter further contemplates a method of autonomously controlling an aircraft (e.g. during a scanning-mission) and selecting a circling maneuver during transition from a first leg to a second leg as disclosed above, as well as a system mountable on an aircraft configured and operable for executing the method.

- According to another aspect of the presently disclosed subject matter there is provided a computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein; the computer program product comprising:

computer readable program code for causing the computer to select a circling maneuver for repeating a traversed section within a current leg; the computer program product further comprising:

computer readable program code for causing the computer to calculate a predicted ground-speed along each one of a plurality of candidate circling maneuvers, based on the wind velocity and flight directions along the candidate circling maneuver;

computer readable program code for causing the computer to calculate a time of travel for completing each of the candidate circling maneuvers; and

computer readable program code for causing the computer to select a circling maneuver from a plurality of turning maneuvers characterized by the shortest time of travel.

According to some examples, the computer program product further includes a computer readable program code for causing the computer to generate instructions for controlling the aircraft according to the selected turning maneuver.

The presently disclosed subject matter further contemplates a method of autonomously maneuvering an aircraft over an area of interest (e.g. during a scanning-mission) and selecting a circling maneuver during transition from a first leg to a second leg as disclosed above, as well as a system mountable on an aircraft configured and operable for executing the method.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the presently disclosed subject matter and to see how it may be carried out in practice, the subject matter will now be described, by way of non-limiting examples only, with reference to the accompanying drawings, in which:

Fig. 1 is block diagram schematically illustrating a UAV system, according to some examples of the presently disclosed subject matter;

Fig. 2 is block diagram schematically illustrating a scanning-mission control unit, according to some examples of the presently disclosed subject matter;

Fig. 3 is a schematic illustration of a flight pattern of an aircraft executing a scanning-mission, according to some examples of the presently disclosed subject matter;

Fig. 4 is a generalized flowchart of operations carried out during a scanning-mission, according to some examples of the presently disclosed subject matter;

Fig. 5 is a flowchart of operations carried out during a scanning-mission, according to some examples of the presently disclosed subject matter;

Fig. 6a is a schematic illustration demonstrating the processing of AOI characterized by curved sides, according to some examples of the presently disclosed subject matter;

Fig. 6b is a schematic illustration demonstrating the process of selecting a flight direction in a scanning-mission, according to some examples of the presently disclosed subject matter;

Fig. 7 is a schematic illustration demonstrating sun direction relative to the aircraft, according to some examples of the presently disclosed subject matter;

Fig. 8 is a flowchart of operations carried out during selection of a turning maneuver, according to some examples of the presently disclosed subject matter;

Figs. 9a – 9d are schematic illustrations demonstrating different turning maneuvers, according to some examples of the presently disclosed subject matter;

Fig. 10 is a flowchart of operations carried out during selection of a circling maneuver, according to some examples of the presently disclosed subject matter; and

Figs. 11a – 11c are schematic illustrations demonstrating different circling maneuvers, according to some examples of the presently disclosed subject matter;.

DETAILED DESCRIPTION

In the drawings and descriptions set forth, identical reference numerals indicate those components that are common to different embodiments or configurations. Elements in the drawings are not necessarily drawn to scale.

Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "obtaining", "processing", "determining", "generating" or the like, include action and/or processes of a computer that manipulate and/or transform data into other data, said data represented as physical quantities, e.g. such as electronic quantities, and/or said data representing the physical objects.

The terms “computer”, "computerized device" or the like as used herein is meant to include any kind of electronic device that comprises one or more processing circuitries with data processing capability, that include a computer processor (e.g., a Central Processing Unit (CPU), a microprocessor, an electronic circuit, an Integrated Circuit (IC), firmware written for or ported to a specific processor such as digital signal processor (DSP), a microcontroller, a field programmable gate array (FPGA), an application specific integrated circuit (ASIC), etc.) configured for executing computer instructions readable for example from a computer memory, configured as part of the processing circuitry or operatively connected thereto.

It is appreciated that certain features of the presently disclosed subject matter, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the presently disclosed subject matter, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub-combination.

In embodiments of the presently disclosed subject matter, fewer, more and/or different stages than those shown in **Figs. 4**, **5**, **8** and **10** may be executed. In embodiments of the presently disclosed subject matter one or more stages illustrated in **Figs. 4**, **5**, **8** and **10** may be executed in a different order and/or one or more groups of stages may be executed simultaneously. For example, operations described with reference to block **1005** and **1007** can be executed substantially simultaneously, also illustrated in a sequential order.

Figs. 1 and **2** illustrate a high level schematic of the system architecture in accordance with an embodiment of the presently disclosed subject matter. Elements in **Figs. 1** and **2** can be made up of any combination of software and hardware and/or firmware that perform the functions as defined and explained herein. Elements in **Figs. 1** and **2** may be centralized in one location or dispersed over more than one location. In other embodiments of the presently disclosed subject matter, the system may comprise fewer, more, and/or different elements than those shown in **Figs. 1** and **2**.

For the sake of clarity the term "substantially" is used herein to imply the possibility of variations in values within an acceptable range. According to one example, the term "substantially" used herein should be interpreted to imply possible variation of up to 10% over or under any specified value. According to another example, the term "substantially" used herein should be interpreted to imply possible variation of up to 5% over or under any specified value. According to a further example, the term "substantially" used herein should be interpreted to imply possible variation of up to 2.5% over or under any specified value. According to yet a further example, the term "substantially" used herein should be interpreted to imply possible variation of up to 1.0% over or under any specified value. The specified value can be absolute value (e.g. substantially not exceeding 45°, substantially perpendicular, etc.) or relative (e.g. substantially not exceeding the height of x, etc.).

Fig. 1 is a block diagram of a UAV system **100** that includes a UAV **120** operatively connected to a control unit **110**, according to an example of the presently disclosed subject matter. UAV **120** comprises an airborne system **125** comprising, for example: mission payload **131**, mission computer **133**, flight computer **135** and sensors **137**.

Mission payload **131** can include for example an imaging system which can be used in aerial photography missions. The imaging system can include one or more types of imaging devices such as color camera, black & white camera, infra-red camera, hyperspectral camera, etc. Mission payload can further include other types of data acquisition devices such as a RADAR or LIDAR as well as other types of payloads such as crop dusting or water irrigation systems.

In some examples, a payload such as a camera can be mounted on a gimbal assembly configured to move the camera around one or more gimbal axes to provide a scanning motion around an axis (e.g. in a sweeping motion across the flight direction) in order to increase the range which is covered by the camera. Multiple images of the ground terrain which are captured can be synthetically combined into a single continuous image.

Mission computer **133** is configured, *inter alia*, to generate instructions dedicated for controlling the UAV (e.g. flight instructions) and/or the payload. For example, mission computer can generate instructions directing the UAV to a desired location along a dedicated flight path or to fly over an AOI along a certain path, and generate instructions for operating an imaging system for capturing images as further discussed herein below.

Airborne system **125** also comprises various sensing devices **137** such as altimeters, pitot tubes, navigation devices such as GPS sub-systems and inertial navigation systems, cameras, etc.

Flight computer **135** is configured and operable to generate specific instructions for controlling various flight control devices in order to control the operation of the aircraft, e.g. according to instructions received from the mission computer. Flight control devices include for example, ailerons, flaps, throttle, rudder, wheels, etc. In some examples, flight computer **135** can include, or be otherwise operatively connected to, various control units, each dedicated for controlling a specific flight control device.

According to some examples, mission computer **133** comprises or is otherwise operatively connected to a communication unit configured and operable to establish a down-link (DNK) communication link (line of sight (LOS) and/or beyond line of sight/line of sight (B/LOS)) between the UAV and other remote entities such as control system **110** and provide data such as telemetry and imaging data over the communication link.

Control system (CS) **110** is located remotely from UAV (e.g. on the ground) and comprises communication unit **113** and control mission computer **115**. Communication unit **113** is configured to establish a communication up-link (UPL; line of sight (LOS) and/or beyond line of sight/line of sight (B/LOS)) with airborne system **125**. Communication between UAV **120** and CS **110** can be realized by any suitable communication infrastructure and protocol known in the art. Communication unit **113** can comprise or be otherwise operatively connected to a ground data terminal (B/LOS GDT) as known in the art. Likewise, communication unit in airborne system **125** can comprise or be otherwise operatively connected to an aerial data terminal (B/LOS ADT) as known in the art.

Control mission computer **115** is configured and operable in general to monitor and control the operation of the UAV. More specifically, in some examples control mission computer **115** is configured to generate control data and transmit the control data to the UAV. Control data incudes for example flight instructions dedicated for directing the UAV to fly to a certain location or in a certain manner as well as payload operational instructions, specifying how and when to operate the payloads onboard the UAV.

Control system (CS) **110** can further include a user interface for enabling interaction of an operator with the system. The user interface can comprise one or more display devices for displaying control data (e.g. telemetry received from the UAV and imaging data captured by an imaging system onboard the UAV). The user interface can further include one or more input devices (e.g. keyboard, mouse, touchpad, etc.) and appropriate computer software executed by a computer, as is well known in the art.

According to the presently disclosed subject matter system **100** further includes a scanning-mission control unit that includes one or more processing circuitries configured and operable to generate flight instructions dedicated for controlling the UAV during a scanning-mission for the purpose of improving the efficiency and autonomous operation of the scanning-mission execution. According to some examples, as illustrated in Fig. **1**, scanning-mission control unit **140** is designed as part of mission computer **133** or as a dedicated processing device operatively connectible to mission computer **133**. According to other examples, scanning-mission control unit is designed as a distributed unit that comprises various sub-units each dedicated for performing a different task, where in some examples, part or all of the sub-units of scanning-mission control unit are implemented remotely from the UAV, e.g. at control system **110**. Placing the scanning-mission control-unit (**140**) onboard the aircraft has the advantage that calculations can be done faster as they are not hindered by communication link delays and breakdown, which may be significant. This helps to safeguard the autonomous operation of the aircraft and augment its efficiency during execution of the scanning-mission.

The term "scanning-mission" is used herein to include an aerial mission where a UAV is required to fly over a certain area of interest (AOI) with the purpose of scanning or covering the entire area. One example of a scanning-mission is an aerial imaging mission where a UAV is required to capture images of an entire area of interest. The UAV flies over the area of interest and uses its onboard imaging payload to continuously capture images of the area below. As mentioned above, in some examples, the captured images can be later processed and stitched together to provide a composite image of the entire area of interest.

Fig. **3** is a schematic illustration in top view of flight progress of an aircraft during an imaging (scanning) mission. According to the illustrated example, the area of interest is divided into legs, in the current example four legs, a, b, c and d. The arrows illustrated along the legs indicate the flight path of the aircraft during the mission. As the aircraft flies along each leg, the camera system onboard the aircraft is operated to capture images of the area beneath the aircraft. Assuming a gimbaled camera is used, during each pass, the camera system moves the camera along a scanning line from side to side. Horizontal lines in section **'a'** and the beginning of section **'b'** represent scanning lines. In the illustrated example aircraft (e.g. UAV) **200** has finished the pass over leg **'a'** and is now in the initial part of the pass over leg **'b'**. Although not shown in **Fig. 3**, in some cases some overlap may exist between two adjacent legs and between consecutive scanning lines.

As illustrated in Fig. **3**, a turning maneuver (**T** Fig. **3**) connects between consecutive legs along the flight path, where both legs are aligned with the same azimuth and are generally traversed by the aircraft in opposite directions. According to one example, scanning-mission control unit **140** is configured and operable (e.g. using a scanning direction determination module as illustrated in Fig. **2**) to generate a flight plan that comprises flight instructions directing the aircraft during execution of a scanning-mission that reduces (e.g. minimizes) the number of turns that the UAV is required to make during the scanning-mission. Turns are executed outside the polygon and enable the aircraft to enter the next leg following the turn in a roll angle that allows to continue operation of the payload. The specific roll angle is dependent on the type of payload, and in general is substantially equal to zero i.e. the aircraft being leveled (possibly with tolerance of a few degrees). A turning maneuver is a wasteful operation, since, while turning, the aircraft is not positioned over the AOI and thus is unable to operate the payload for completing the mission (e.g. activate an imaging system for capturing images of the AOI). Accordingly, it would be advantageous to reduce the number of turns which are made during the execution of a scanning-mission. Reducing the number of turns would help to shorten the execution time needed for completing the mission, and also to reduce consumption of various resources such as fuel.

The shape of the AOI is in many cases characterized by uneven sides. For example, an operator can interact with aerial images of an area, which are displayed on a display device at the control system **110**, and mark on the displayed images points indicating the boundaries of an AOI. The points marked by the operator, when connected, may construct a polygon with sides of unequal length. For instance assuming the area of interest is a field, the shape of the field, which may be characterized by sides of unequal length, prescribes the shape of the AOI. An example of an AOI with uneven sides is illustrated in Fig. **3**.

According to examples disclosed herein a flight direction that reduces (e.g. minimizes) the number of turns made during a scanning-mission is calculated. Fig. **4** is a flowchart of operations carried out according to some examples of the presently disclosed subject matter. Operations described with reference to Fig. **4** (as well as Figs. **5**, **8** and **10** below) can be executed, for example, with the help of a system **100** (and more specifically by scanning-mission control unit **140**) configured according to the principles described above with reference to Figs. **1** and **2**. It is noted however that any description of operations, which is made with reference to elements in Figs. **1** and **2** , is done by way of example only and should not be construed as limiting in any way.

At block **401** data on an area of interest (AOI) is obtained. The data includes for example, the location of the AOI (e.g. relative to a global coordinates system). The location of the area can be indicated by two or more points representing vertices located on the perimeter of the AOI. By connecting the points, a shape (e.g. polygon) bounding the area of interest is obtained. Connection of the vertices to obtain the AOI can be done automatically (e.g. by scanning-mission control unit) or by an operator. In some examples the data can include two vertices and a corresponding length for each of the vertices thus essentially providing information pertaining to a rectangle delineating the AOI. In other examples, an entire shape of the AOI can be provided.

At block **403** the mapping data is processed in order to determine a selected flight direction (e.g. a certain azimuth) that enables to reduce (e.g. minimize) the number of turns required to be made by the UAV during the scanning-mission. A more detailed description of an example of determining the flight direction is described below with reference to Fig. **5**.

At block **405**, once the selected flight direction is known, instructions for directing the UAV to fly over the AOI and execute the mission (e.g. capture images of the ground) are generated. For example, a continuous flight path directing the aircraft for scanning the entire AOI and instructions for following the flight path are generated.

As illustrated in Fig. **3**, the flight path comprises a plurality of legs, each leg extending across the AOI in the selected flight direction and each pair of consecutive legs are connected by a turn. The UAV is controlled so it follows the generated flight path. The number of legs, and consequentially the number of turns connecting between each two legs, depends, *inter alia*, on the width of the cross-section of the AOI that is perpendicular to the flight direction of the UAV and on the width of each leg. The width of each leg depends on the operational requirement of the specific payload which is being used and the type of mission. For example, in an image acquisition mission, the width of each leg depends on the sensor size, exposure time, scan orientation (Forward/Side), resolution, etc., as these parameters determine the FOV of the camera.

If the camera is mounted in a static position, the camera field of view (FOV) defines the width of the leg. The FOV can be determined based on required image resolution and resolution of the sensor of the camera device. Assuming for example that required pixel resolution range is 0.5 meters (requiring 0.5 meters width for each pixel), and sensor resolution is 500 pixels, the FOV is calculated by 0.5 * 500 = 250 meters, which represent the distance on the ground covered by each frame.

In some cases the camera is mounted on a gimbal device configured during operation to move the camera around one or more gimbal axes to provide a scanning motion from side to side (e.g. in a sweeping motion across the flight direction, parallel to the cross-section) in order to increase the range which is covered by the camera. In such cases, an offset range from frame to frame is determined. The offset range is the range of new ground covered in each new frame. According to one example, it can be equal to the FOV. According to other examples, in order to enable the successful stitching of the captured images into one combined image, an overlap is maintained between consecutive frames. The offset range depends on the overlapping range and equals the FOV minus the overlapping range. For example, if the overlapping range is 20% of the FOV and FOV is 250 meters, the overlap range equals 20% of 250 which equals 50 meters. In this case, the offset range equals 250 – 50 = 200.

Turning to Fig. **5**, this shows a flowchart of a sequence of operations carried out for determining a selected flight direction, according to some examples of the presently disclosed subject matter. Fig. **5** is a more detailed example of the operations mentioned above with reference to block **403**. Operations described with reference to Fig. **5** can be executed for example by scanning-mission control unit.

At block **510** a plurality of different candidate flight directions are analyzed, where the analysis includes, for each candidate flight direction:

determining a respective cross-section of the AOI substantially perpendicular to the particular candidate flight direction of the plurality of flight direction (block **503**);

determining projection points of the vertices of the AOI on the particular cross-section, including at least the two vertices that are projected on projection points located on the cross-section at the farthest distance, one from the other (block **505**). In case of an AOI having a polygon shape, vertices of the polygon are projected on the cross-section. As illustrated in Fig. **6a**, In case the AOI is characterized by curved sides, a circumgon (a polygon tangential to the AOI that represents the AOI) can be drawn around the AOI. For example scanning-mission control unit **140** can determine a circumgon around the AOI.

At block **507**, the distance between the two farthest apart projection points on the particular cross section is calculated.

At block **515** a cross-section that accommodates the two farthest apart projection points with the shortest distance one from the other, is selected. At block **520**, the selected direction of flight (azimuth) is determined as the direction perpendicular (or substantially perpendicular) to the selected cross-section. The selected direction is the direction of flight that requires the least number of turns during the execution of a scanning operation. A flight path is generated that comprises a plurality of legs, where all legs are aligned with (are substantially parallel to) the selected flight direction.

Fig. **6b** is a schematic illustration demonstrating the operations described with reference to Fig. **5** above. Fig. **6b** includes three states, state a, state b and state c. In each state a cross-section (**65**) at a different angle relative to the AOI is shown. In state 'a' the cross section is in the west-east direction, which is perpendicular to a north oriented flight direction (azimuth 0; or south, azimuth 180). As shown, vertices of the polygon representing the AOI are projected (90° projection of the vertices onto the cross-section) on the cross-section (indicated by the broken lines). The two projected points of the two vertices located farthest away from each other in the west-east direction of the AOI are indicated by circles (5).

Likewise, in states 'b' and 'c' a similar calculation is performed, where in state 'b' the cross-section is in the north-south direction perpendicular to the west-east flight direction, and in state 'c' the cross-section is in the northeast-southwest direction perpendicular to the northwest-southeast flight direction.

As is apparent from the illustration, in state 'b' the section confined between the two farthest away projection points is the shortest from among the three illustrated states, and accordingly state 'b' would be selected out of the 3 states. Of course the process of determining a selected flight direction can include the analysis of additional cross-sections in relative angles. For example, the analysis can include a cross-section for every angle in a 360° resolution around the AOI for a total of 360 cross-sections, or a cross-section for every other angle for a total of 180 cross-sections or a cross-section for every half an angle for a total of 720 cross sections or a cross-section for every 4 angles for a total of 90 cross-section, or the like.

As illustrated in Fig. **3**, during execution of the mission, the aircraft is controlled to fly over the AOI in the selected direction along a first leg, make a turn at the edge of the AOI, and fly over the next leg in a direction opposite to the selected direction.

According to some examples, other conditions and constraints are taken into consideration in order to increase the quality of the scanning output. For example, in case the scanning-mission involves operation of an electro optic imaging system (e.g. a hyperspectral imaging system) over the AOI, the direction of the sun may also be taken into consideration when selecting a flight direction. As schematically illustrated in Fig. **7**, in order to improve the output of a hyperspectral imaging system, it is desirable to operate the imaging system substantially in parallel to the direction of the sun. Direction of the sun can be determined based on the current date and time, as is well known in the art.

Thus, according to some examples, the direction of flight during a scanning-mission that involves the operation of an imaging (payload e.g. hyperspectral imaging system) depends on the direction of the sun, and is selected such that the direction of flight is aligned with the direction of the sun.

In some cases, in order to reduce the number of turns as discussed above and increase the efficiency of the scanning-mission, alignment of the flight direction with the direction of the sun is maintained within a certain tolerance, for example, a ±40° offset from the real-time estimated sun direction. In such cases, the possible flight direction is within the tolerance window. The specific direction of the UAV within the tolerance window is determined as discussed above with reference to Figs. **4** and **5**, so as to reduce the number of turns to the minimal possible, while not deviating from the allowed tolerance window determined according to the direction of the sunlight.

Another example is related to the wind direction, where a flight direction is limited to a certain tolerance window relative to the estimated wind direction. In this case the possible flight direction is within the tolerance window determined as discussed above with reference to Figs. **4** and **5**, so as to reduce the number of turns to the minimal possible, while not deviating from the allowed tolerance window determined according to the direction of the wind (e.g. aligned with or perpendicular to the wind direction).

The presently disclosed subject matter further contemplates a method and system for controlling a UAV aimed to improve efficiency of the UAV operation when executing turns. As explained above, during turns the position of the UAV relative to the AOI does not permit to operate the payload for completing the mission, and accordingly it is desired to reduce the time spent for turning. According to the presently disclosed subject matter, specific UAV control logic is implemented, which helps to reduce the time spent for performing turns.

Fig. **8** is a flowchart of a sequence of operations carried out according to some examples of the presently disclosed subject matter. Operations described with reference to Fig. **8** can be executed for example by scanning-mission control unit (e.g. by turning maneuver control module illustrated in fig. **2**). At block **801**, the minimal-effective (actual) turning diameter of the aircraft is calculated or obtained e.g. from computer memory. In some examples, the minimal-effective (or actual) turning diameter of the aircraft is calculated in real-time e.g. at the beginning of the flight, or right before a turn. The minimal-effective turning diameter is calculated based on the minimal-mechanical turning diameter (i.e. the minimal turning diameter possible in optimal conditions) and other environmental conditions, such as for example true airspeed and direction (obtained for example from pitot tubes).

At block **803** it is determined whether the minimal-effective turning diameter is smaller than the spacing between two consecutive legs. In general, the spacing is related to the width of a current leg on which the aircraft is located and the next leg to which the aircraft is about to turn. As explained above, the leg width depends on the operational requirement of the specific payload used during a mission. An example of calculation of the leg width is provided above. Notably, in some missions the width of different legs may not be equal, and in some cases the width is calculated in real-time.

In case the minimal-effective turning diameter (D) is smaller than the spacing between legs (R), a turning maneuver (or transition between legs) is constructed as illustrated in Fig. **9a** (block **805**). According to this example, the turning maneuver includes a sequence comprising: a first turn exiting the current leg **90** and turning to a first direction (arrow 5) toward the next leg, the first direction substantially perpendicular to the direction of the current leg (arrow 3); a second turn **92** towards the entry point to the next leg **93**, in a direction substantially perpendicular to the first direction (arrow 7); and an extended section **9** connecting between the end of the first turn **91** and the beginning of the second turn **92** covering the distance between the legs, where the length of the line depends on the difference between the minimal-effective turning diameter (D) and the distance between the two legs (R). Notably, the turning maneuver according to the example illustrated in Fig. **9a** is comprised of a first section of a first complete turn (section **90**-**91**) and a second section of a second complete turn (section **92**- **93**) and another section connecting the two sections, and tangential to the two complete turns (section **91**-**92**).

In case the minimal-effective turning diameter (D) is larger than the spacing between two consecutive legs (R), a turning maneuver (or transition between legs) is constructed as illustrated in Fig. **9b** (block **807**). According to this example the turning maneuver includes three consecutive turns: a first turn exiting the current leg in a first direction away from the next leg **95** to thereby provide sufficient distance for executing a full turn towards the next leg; a second turn in a second direction towards the next leg **96**, wherein the diameter of the second turn is such that the second turn ends at an ending point **97** located beyond the entry point to next leg **98** (the diameter of the second turn ≥ D); and a third turn from the ending point of the second turn **97**, directing the UAV towards the entry point to the next leg **98**. Notably, the turning maneuver according to the example illustrated in Fig. **9b** is comprised of a first section of a first complete turn (section **95**-**96**) and a second section of a second complete turn (section **97**- **98**) and another section of a third complete turn connecting the two sections (section **96**-**97**).

As an alternative to block **807**, in some examples, in case the minimal-effective turning diameter (D) is larger than the spacing between two consecutive legs (R) a turning maneuver (or transition between legs) is constructed as illustrated in Fig. **9c**. According to this example the turning maneuver includes a first turn exiting the current leg **901** in a first direction (arrow **9**) away from the next leg to thereby provide sufficient distance for executing a full turn towards the next leg; a second turn **903** in a second direction towards the next leg, wherein the diameter of the second turn is such that the second turn ends at an ending point **905** with the aircraft pointing in the direction of the next leg; and an extended section (section **905** -**907**), substantially aligned with the next leg, leading the aircraft to the next leg. The turning maneuver according to the example illustrated in Fig. **9c** is comprised of a first section of a complete turn (section **901**-**903**) and a second section of a complete turn (section **903**-**907**).

Notably, as illustrated in Fig. **9d**, the maneuver according to Fig. **9c** can be alternatively made in the opposite direction i.e. a turning maneuver that starts with an extended section, substantially aligned with the next leg and followed by a first turn in the direction (arrow **15**) of the next leg, the first turn ending at an ending point **913** located beyond the entry point to next leg **915** and followed by a second turn leading to the entry point to the next leg **915**.

According to some examples, upon determining that the minimal-effective turning diameter (D) is larger than the spacing between two consecutive legs (R) the process according to Fig. **8** includes a decision stage for selecting between two or more possible maneuvers, e.g. selecting between a maneuver according to Fig. **9b**, a maneuver according to Fig. **9c** and a maneuver according to Fig. **9d**. According to this example a maneuver that would take the shortest time for the aircraft to travel from the exit point of the current leg to entry point of the next leg is selected. Selection is performed for example based on a calculation of a predicted ground-speed in each of the maneuvers.

The predicted ground-speed is calculated based on the airspeed and the wind velocity along each turn. Assuming the airspeed is constant along the turning maneuver, the ground-speed depends on the wind velocity along a certain turning maneuver. The ground-speed along the turning maneuver is calculated by taking the different directions assumed by the aircraft along the turning maneuver, determining the wind velocity and calculating the ground-speed in each of the different directions and integrating the calculated ground-speed to obtain an integrated ground-speed along the entire turning maneuver. Wind velocity can be determined based on airspeed (received for example from pitot tubes), heading (e.g. obtained from INS) which give together an first (inertial) vector. A second vector is received from the GPS sub-system. The subtraction between the first and second vectors provides the wind velocity.

For each of the candidate turning maneuvers, an estimated time for completing the turning maneuver is calculated based on the length of the turning maneuver and the integrated ground-speed. The turning maneuver that would take the shortest time to complete is selected. Notably, in some cases the selected maneuver may not be the one with the shortest distance. According to some examples, while executing a certain scanning-mission, different turning maneuvers can be used during the transition between different legs. This can result for example in a change in wind direction and/or wind velocity that occurs during the mission execution or in variation in the spacing between consecutive legs.

The presently disclosed subject matter further contemplates a method and system for controlling a UAV aimed to improve efficiency of the UAV operation when executing mission operation. As explained above, during a scanning-mission the UAV is controlled to fly along a certain flight path that comprises a plurality of legs for the purpose of covering an AOI and operating a payload while traveling along the flight path. In some cases, it may be desired to repeat a certain section, e.g. in case of operational failure of the payload over a certain section. For example, in an imaging mission, images which are captured by an imaging payload onboard the UAV undergo quality assessment. To this end, system **100** can comprise an automatic quality assessment sub-system which can be implemented for example as part of the imaging system or the mission computer **133** or the control mission computer **115**. Automatic quality assessment executed onboard the UAV can be used to determine, immediately after an image is generated, whether the image complies with certain quality measures. Such quality measures can include for instance, smearing of the image due to a movement which is above the allowed exposure speed. In another example, in a camera operated in a fixed position (not gimbaled), movement of the aircraft may cause a deviation from the required overlap between legs.

In case images captured along a certain section along a leg are found to be incompliant with some prescribed quality measure, the UAV may be required (e.g. according to instructions generated by scanning-mission control unit **140**) to repeat and fly over the same section a second time in order to obtain images in sufficient quality. Likewise, in the example of crop dusting or irrigation, a UAV may be required to fly a second time over a certain section for repeatedly applying the material.

According to examples of the presently disclosed subject matter, the UAV is controlled to reduce the time and/or distance travelled when executing a circling maneuver for the purpose of repeating and flying over the same section. Fig. **10** is a flowchart of a sequence of operations carried out according to some examples of the presently disclosed subject matter. Operations described with reference to Fig. **10** can be executed for example by scanning-mission control unit **140** (e.g. by mission correction control module illustrated in fig. **2**). At block **1001**, data indicative of a need to fly over a section of a leg currently being traversed, is detected. According to the example illustrated in Figs. **11a** and **11b** while a UAV is executing a mission (e.g. operating an imaging system) along leg **L**, a payload operation failure is detected along a certain section **X** (referred to herein as a "bad section" or "traversed section").

In case it is decided that repeating of a payload operation over the bad section is required, a type of circling maneuver is selected from of at least two different types of candidate circling maneuvers.

Fig. **11a** is a schematic illustration of a first type of circling maneuver (referred to herein as "circling back maneuver") where the UAV turns back, as close as possible, to the end of the bad section, to reach the beginning of the bad section, and then flies over the bad section a second time while operating the payload (e.g. repeats image acquisition to obtain images in a sufficient quality). **Fig. 11b** is a schematic illustration of a second type of circling maneuver (referred to herein as "leg repeating maneuver"), where the UAV proceeds until the end of the leg, makes a U-turn at the end of the leg, and flies over the entire leg a second time while repeating the mission over the bad section. Notably, the leg repeating maneuver may result in a change in the direction of flight along the following legs, switching to the opposite direction.

At block **1005** the flight distance and flight time added by two or more types of circling maneuvers is calculated. To this end the following operations may be carried out for each candidate circling maneuver:

the flight distance of each circling maneuver is calculated.

the integrated ground-speed of each maneuver is calculated, based on the wind velocity relative to various directions of the aircraft during the maneuver.

The time needed for completing each maneuver is calculated based on the distance of the maneuver and the integrated ground-speed.

In some examples, calculation of the distance of the first circling maneuver (CM) can be based on:

First CM = X + Y

where:

X is the length of the bad section.

The length of the bad section can be determined by monitoring the performance of the scan (e.g. using an on-board quality assessment sub-system) regarding the examples above. For example, this may be the area over which poor quality image output was obtained.

Y is the estimated length of the maneuver required for circling back from the current position of the UAV along the leg to the beginning of the bad section. The circling maneuver **Y** according to the example illustrated in Fig. **11a** is similar to the turning maneuver shown in Fig. **9a** and comprises a first section of a first complete turn (section **1103 -1105**) and a second section of a second complete turn (section **1107 -1101**) and another section connecting and tangential to the two sections (section **1105 -1107**). According to some examples, the length of **Y** can be determined based on the calculation of the minimal-effective turning radius calculated as described above. Notably, minimal-effective turning radius is based on airspeed and can be calculated in real-time. In some case the radius of the two circles may not be the same.

Calculation of the distance of the second circling maneuver (CM) can be based on:

Second CM = $\mathbf{L_R}$ + U1

where:

$\mathbf{L_R}$ is the length of the leg which is repeated; and

U1 is the length of the U-turn.

The turning maneuver **U**1 according to the example illustrated in Fig. **11b** is comprised of a first section extending in the general direction of the current leg (section **1111** -**1113**) and a second section of a first complete turn (section **1113 - 1117**) and another section of a second complete turn turning back to the current leg (section **1115 -1111**). Notably, the maneuver illustrated in Fig. **11b** can be alternatively executed in the opposite direction, i.e. with a first turn exiting the current leg, followed by a turn in the other direction that ends with an extended section substantially aligned with the current leg.

Another alternative for a circling maneuver is illustrated in Fig. **11c**. This maneuver includes a first turn exiting the current leg **1121** in a first direction that provides sufficient distance for executing a full turn back towards the entry to the current leg; a second turn **1123** pointing the aircraft back towards the current leg; and a third turn **1125** starting from the end of the second turn and directing the aircraft back towards the current leg. According to this example, the U-turn comprises a full turn, with its center substantially aligned with the current leg.

According to some examples a maneuver that would require the shortest time for the aircraft to travel from the exit point of the current leg, to entry point of the next leg, is selected. Selection is performed for example, based on a calculation of a predicted ground-speed in each of the maneuvers. The predicted ground-speed is calculated based on the airspeed and the wind velocity along each turn. As explained above with respect to the turning maneuver, the ground-speed along the circling maneuver is calculated by taking the different directions assumed by the aircraft along the turning maneuver, determining the wind velocity, and calculating the ground-speed in each of the different directions and integrating the calculated ground-speed to obtain an integrated ground-speed along the entire circling maneuver. For each of the candidate turning maneuvers, an estimated time for completing the circling maneuver is calculated based on the length (distance) of the circling maneuver and the integrated ground-speed. The circling maneuver that is determined to take the shortest time to complete is selected. Notably, in some cases the selected maneuver may not be the one with the shortest distance. According to some examples, while executing a certain scanning-mission, different circling maneuvers can be used during the transition between different legs. This can result for example in a change in wind direction and/or wind velocity that occurs during the mission execution.

The UAV is controlled to fly according to the selected maneuver and repeat the mission over the bad section (block **1010**).

It will also be understood that the system according to the presently disclosed subject matter may be a suitably programmed computer. Likewise, the presently disclosed subject matter contemplates a computer program being readable by a computer for executing the method of the presently disclosed subject matter. The presently disclosed subject matter further contemplates a machine-readable non-transitory memory tangibly embodying a program of instructions executable by the machine for executing the method of the presently disclosed subject matter.

It is to be understood that the presently disclosed subject matter is not limited in its application to the details set forth in the description contained herein or illustrated in the drawings. The presently disclosed subject matter is capable of other embodiments and of being practiced and carried out in various ways. Hence, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting. As such, those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for designing other structures, methods, and systems for carrying out the several purposes of the present presently disclosed subject matter.

Claims:

1. A method of autonomously maneuvering an aircraft over an area of interest during a scanning-mission, where the scanning-mission includes flying over the area of interest along a flight path that comprises multiple legs, wherein all legs traverse the area of interest in substantially the same direction and each two consecutive legs are connected by a turn, the method comprising:

operating at least one processing circuitry for:

obtaining mapping data indicative of boundaries of the area of interest to be scanned by the aircraft;

processing the mapping data to select a selected cross-section of the area of interest from a plurality of cross-sections, each cross-section from among the plurality of cross-sections is characterized by a different angle relative to a certain frame of reference and comprises a respective section confined by two projection points, each of the two projection points are a projection of a respective extreme vertex of a polygon representing the area of interest;

wherein the selected cross-section is characterized by the shortest respective section;

determining a selected flight direction to be substantially perpendicular to the selected cross-section;

generating the flight path comprising a plurality of legs, where all legs are aligned with the selected flight direction, thereby reducing the number of turns during the scanning-mission relative to other possible flight directions ; and

generating instructions dedicated for controlling the aircraft to fly along the flight path.

2. The method of claim 1 further comprising operating the payload while proceeding along the flight path.

3. The method of claim 1, wherein the polygon representing the AOI is the area of interest.

4. The method of claim 1, wherein the polygon representing the AOI is a polygon tangential to the AOI.

5. The method of any one of the preceding claims further comprising:

for each cross-section of the plurality of cross-sections, calculating the length of the respective section, comprising:

projecting a plurality of vertices of the polygon on the cross-section; and determining the greatest distance between two points projected on the cross-section.

6. The method of any one of the preceding claims further comprising:

obtaining information indicative of a range of angles limiting the allowed flying direction; and

selecting the selected cross-section from a plurality of cross-sections characterized by an angle substantially perpendicular to an angle that resides within the range of angles.

7. The method according to claim 6, wherein the scanning-mission includes operating a hyperspectral imaging system over the AOI, and wherein the range of angles is determined according to the position of the sun relative to the AOI.

8. The method of any one of preceding claims further comprising: operating the at least one processing circuitry for selecting a turning maneuver during transition from a first leg to a second leg, wherein flying direction along the first leg is substantially parallel and at an opposite direction to flying direction along the second leg, the selecting comprising:

determining a minimal effective turning diameter of the aircraft;

in case the minimal effective turning diameter is greater than a distance crossing between the first leg and the second leg, performing a first turning maneuver that includes:

a first turn exiting the current leg in a first direction opposite to the direction of the second leg, the first turn is aimed to increase the distance of the aircraft from the second leg; a second turn in a second direction toward the next leg, wherein the diameter of the second turn is such that the second turn ends at an ending point located beyond the next leg; and a third turn from the ending point of the second turn to the entry point of the next leg; and

in case diameter of the minimal effective turning is shorter than the distance crossing between the first leg and the second leg, performing a second turning maneuver that includes:

a first turn exiting the current leg in a direction of the next leg; a second turn toward the next leg, the second turn having a direction substantially opposite to the first turn, and an extended section connecting between the first turn and the second turn.

9. The method according to claim 8, wherein each turn in the first turning maneuver and the second turning maneuver is part of a circle characterized by a diameter that is equal to the minimal effective turning diameter.

10. The method of any one of the proceeding claims, further comprising operating the at least one processing circuitry for selecting a circling maneuver for repeating a traversed section within a current leg, the selecting comprising:

responsive to detection of a need to repeat a traversed section within a leg:

calculating the distance of a first circling maneuver that comprises a turn starting from about the end of the traversed section and circling back around to the beginning of traversed sections along the current leg; and calculating the distance of a second circling maneuver that comprises proceeding to the end of the current leg, performing a U-turn leading back into the current leg, and repeating the entire current leg a second time;

selecting the circling maneuver with the shorter length;

controlling the aircraft according to the selected circling maneuver for flying over the traversed section a second time, and activating a payload.

11. The method of any one of the preceding claims wherein the aircraft is an unmanned aerial vehicle.

12. A system mountable on an aircraft for autonomously maneuvering the aircraft over an area of interest during a scanning-mission, where the scanning-mission includes flying over the area of interest along a flight path that comprises multiple legs, wherein all legs traverse the area of interest in substantially the same direction and each two consecutive legs are connected by a turn, the system comprises a computer and a payload, the computer comprising one or more processing circuitries configured to:

obtain mapping data indicative of boundaries of the area of interest to be scanned by the aircraft;

process the mapping data to select a selected cross-section of the area of interest from a plurality of cross-sections, each cross-section from among the plurality of cross-sections is characterized by a different angle relative to a certain frame of reference and comprises a respective section confined by two projection points, each of the two projection points are a projection of a respective extreme vertex of a polygon representing the area of interest;

wherein the selected cross-section is characterized by the shortest respective section;

determine a selected flight direction to be substantially perpendicular to the selected cross-section;

generate the flight path comprising a plurality of legs, where all legs are aligned with the selected flight direction, thereby reducing the number of turns during the scanningmission relative to other possible flight directions; and

generate instructions dedicated for controlling the aircraft to fly along the flight path and instructions for operating the payload along the flight path.

13. The system of claim 12 wherein the payload is an imaging system configured for capturing images of the area of interest.

14. The system of claim 12, wherein the at least one processing circuitry is further configured to operate the payload while proceeding along the flight path.

15. The system of claim 12 wherein the at least one processing circuitry is further configured to:

obtain information indicative of a range of angles limiting the allowed flying direction; and select the selected cross-section from a plurality of cross-sections characterized by an angle substantially perpendicular to an angle that resides within the range of angles.

16. The system of claim 15, wherein the scanning-mission includes operating a hyperspectral imaging system over the AOI, and wherein the range of angles is determined according to the position of the sun relative to the AOI.

17. The system of claim 12, wherein the at least one processing circuitry is further configured to:

select a turning maneuver during transition from a first leg to a second leg, wherein flying direction along the first leg is substantially parallel and at an opposite direction to flying direction along the second leg, the selecting comprising:

determining a minimal effective turning diameter of the aircraft;

in case the minimal effective turning diameter is greater than a distance crossing between the first leg and the second leg, performing a first turning maneuver that includes:

a first turn exiting the current leg in a first direction opposite to the direction of the second leg, the first turn is aimed to increase the distance of the aircraft from the second leg; a second turn in a second direction toward the next leg, wherein the diameter of the second turn is such that the second turn ends at an ending point located beyond the next leg; and a third turn from the ending point of the second turn to the entry point of the next leg; and

in case diameter of the minimal effective turning is shorter than the distance crossing between the first leg and the second leg, performing a second turning maneuver that includes:

a first turn exiting the current leg in a direction of the next leg; a second turn toward the next leg, the second turn having a direction substantially opposite to the first turn and an extended section connecting between the first turn and the second turn.

18. The system of claim 17, wherein each turn in the first turning maneuver and the second turning maneuver is part of a circle characterized by a diameter that is equal to the minimal effective turning diameter.

19. The system of claim 12, wherein the at least one processing circuitry is further configured to:

select a circling maneuver for repeating a traversed section within a current leg, the selecting comprising:

responsive to detection of a need to repeat a traversed section within a leg:

calculating the distance of a first circling maneuver that comprises a turn starting from about the end of the traversed section and circling back around to the beginning of traversed sections along the current leg; and

calculating the distance of a second circling maneuver that comprises proceeding to the end of the current leg, performing a U-turn leading back into the current leg, and repeating the entire current leg a second time;

selecting the circling maneuver with the shorter length;

controlling the aircraft according to the selected circling maneuver for flying over the traversed section a second time, and activating a payload.

20. An unmanned aerial vehicle comprising the system according to any one of claims 12 to 19.

21. A computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein for autonomously maneuvering an aircraft over an area of interest during a scanning-mission, where the scanning-mission includes flying over the area of interest along a flight path that comprises multiple legs, wherein all legs traverse the area of interest in substantially the same direction and each two consecutive legs are connected by a turn; the computer program product comprising:

computer readable program code for causing the computer to obtain mapping data indicative of boundaries of the area of interest to be scanned by the aircraft;

computer readable program code for causing the computer to process the mapping data and select a selected cross-section of the area of interest from a plurality of cross-sections, each cross-section from among the plurality of cross-sections is characterized by a different angle relative to a certain frame of reference and comprises a respective section confined by two projection points, each of the two projection points are a projection of a respective extreme vertex of a polygon representing the area of interest; wherein the selected cross-section is characterized by the shortest respective section;

computer readable program code for causing the computer to determine a selected flight direction to be substantially perpendicular to the selected cross-section;

computer readable program code for causing the computer to generate the flight path comprising a plurality of legs, where all legs are aligned with the selected flight direction, thereby reducing the number of turns during the scanning-mission relative to other possible flight directions; and

computer readable program code for causing the computer to generate instructions dedicated for controlling the aircraft to fly along the flight path.

22. A computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein; the computer program product comprising:

computer readable program code for causing the computer to select a turning maneuver during transition from a first leg to a second leg, wherein flying direction along the first leg is substantially parallel and at a substantially opposite direction to flying direction along the second leg; the computer program product further comprising:

computer readable program code for causing the computer to calculate a predicted ground-speed along each one of a plurality of candidate turning maneuvers, based on the wind velocity and flight directions along the candidate turning maneuver;

computer readable program code for causing the computer to calculate a time of travel for completing each of the candidate turning maneuvers; and computer readable program code for causing the computer to select a turning maneuver from a plurality of turning maneuvers characterized by the shortest time of travel.

23. A computer program product comprising a non-transitory computer useable medium having computer readable program code embodied therein; the computer program product comprising:

computer readable program code for causing the computer to select a circling maneuver for repeating a traversed section within a current leg; the computer program product further comprising:

computer readable program code for causing the computer to calculate a predicted ground-speed along each one of a plurality of candidate circling maneuvers, based on the wind velocity and flight directions along the candidate circling maneuver;

computer readable program code for causing the computer to calculate a time of travel for completing each of the candidate circling maneuvers; and

computer readable program code for causing the computer to select a circling maneuver from a plurality of turning maneuvers characterized by the shortest time of travel.

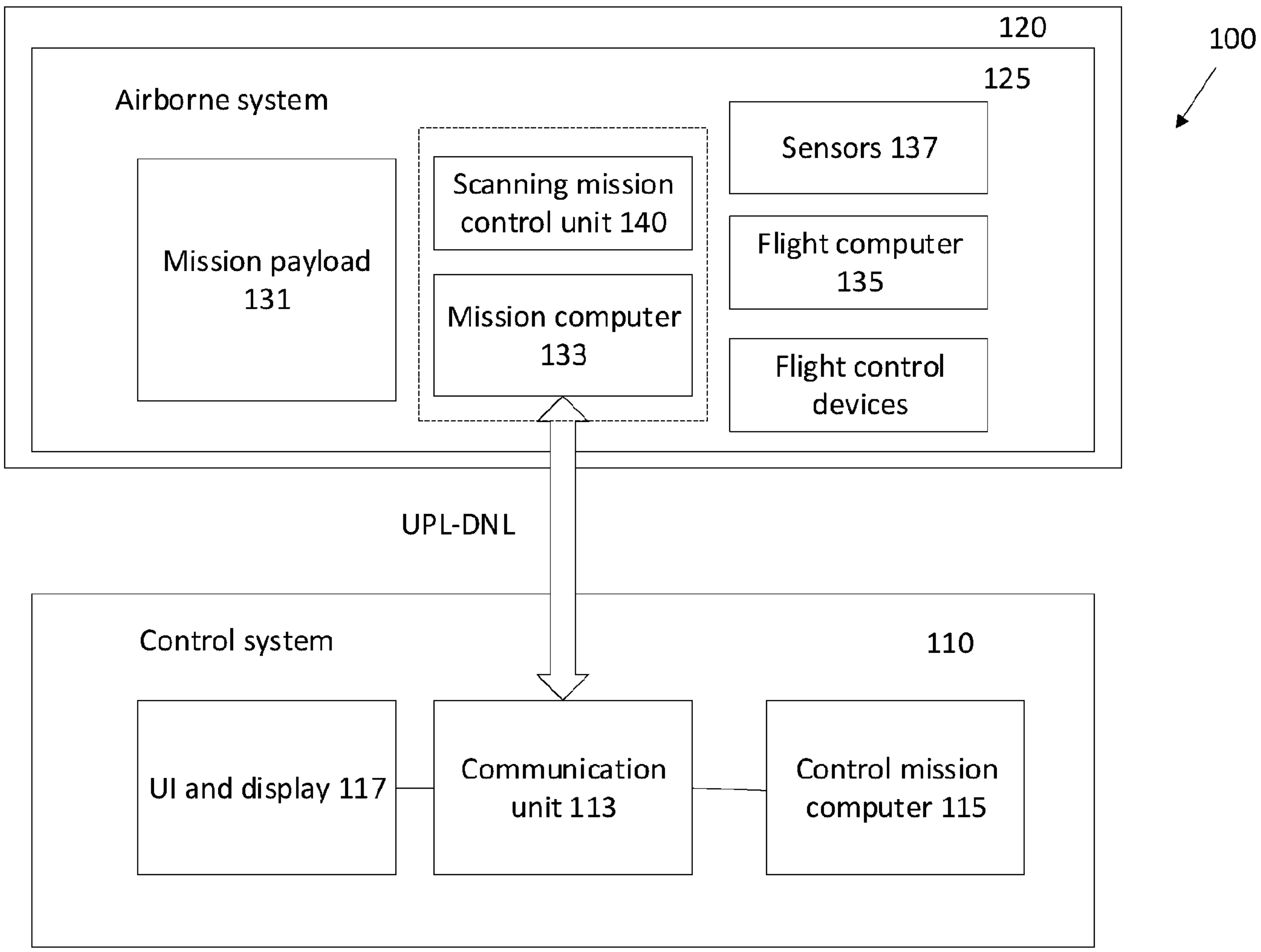
120
100
125
Airborne system
Sensors 137
Scanning mission control unit 140
Mission payload 131
Flight computer 135
Mission computer 133
Flight control devices
UPL-DNL
Control system
110
UI and display 117
Communication unit 113
Control mission computer 115

Fig. 1

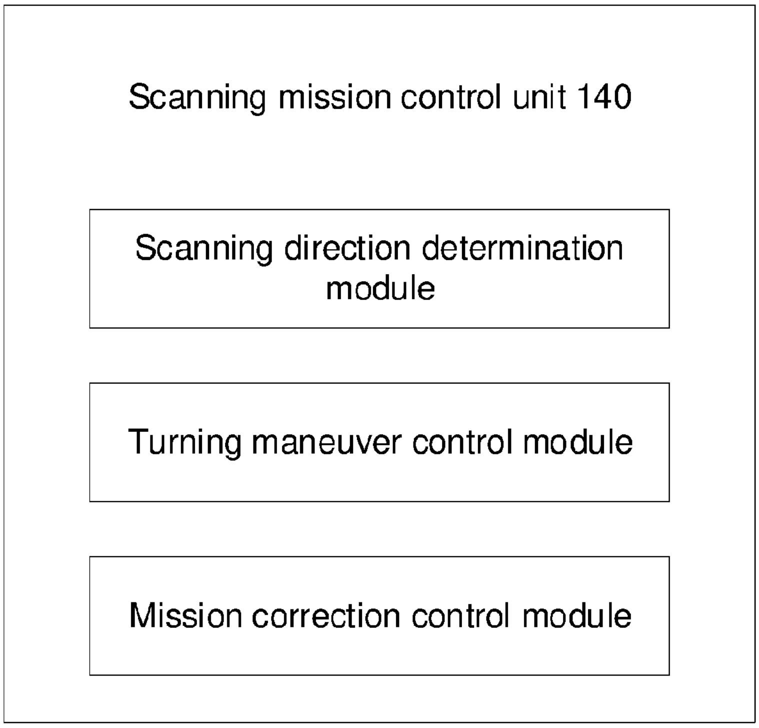
Scanning mission control unit 140
Scanning direction determination module
Turning maneuver control module
Mission correction control module

Fig. 2

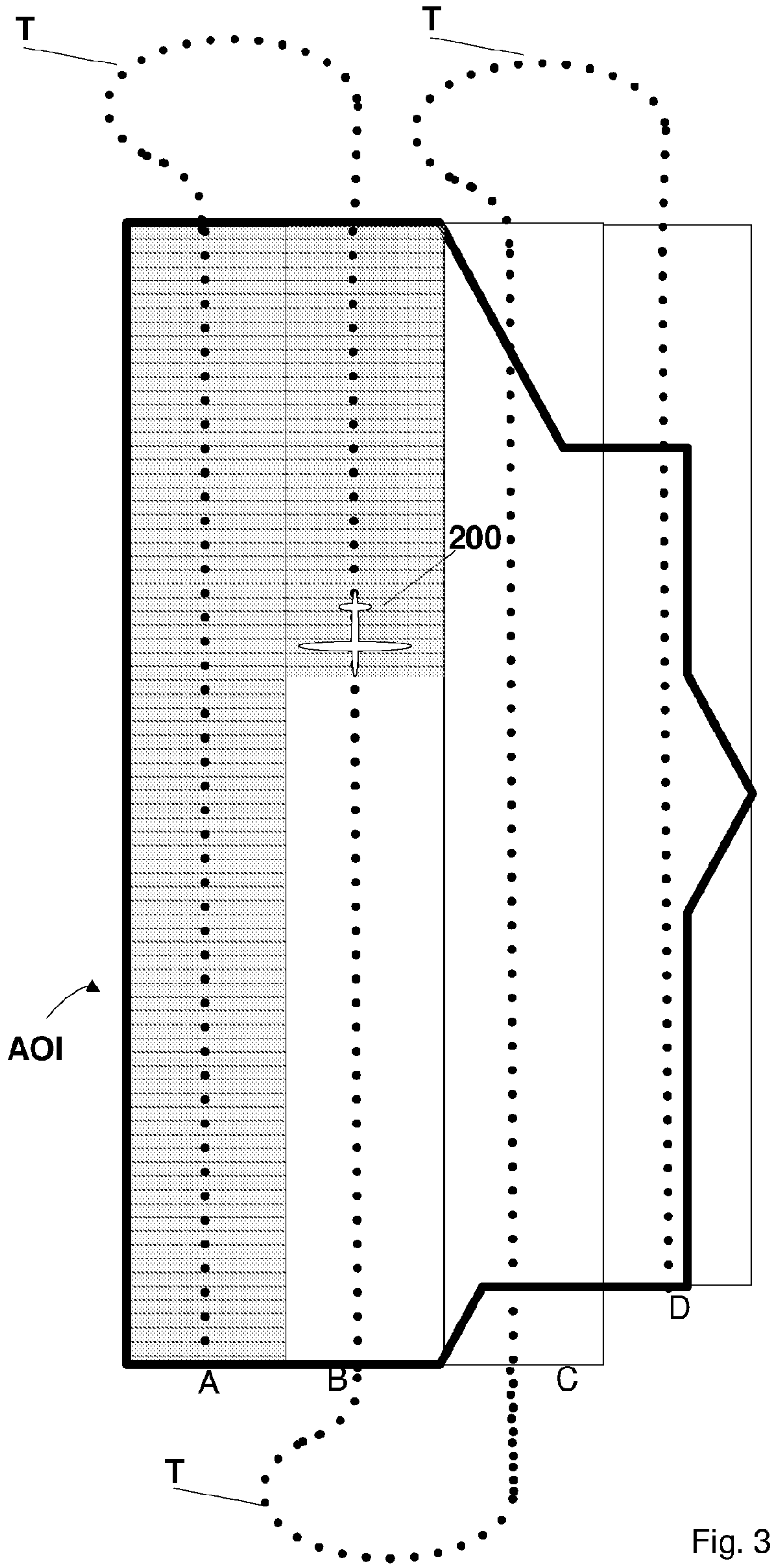

Fig. 3

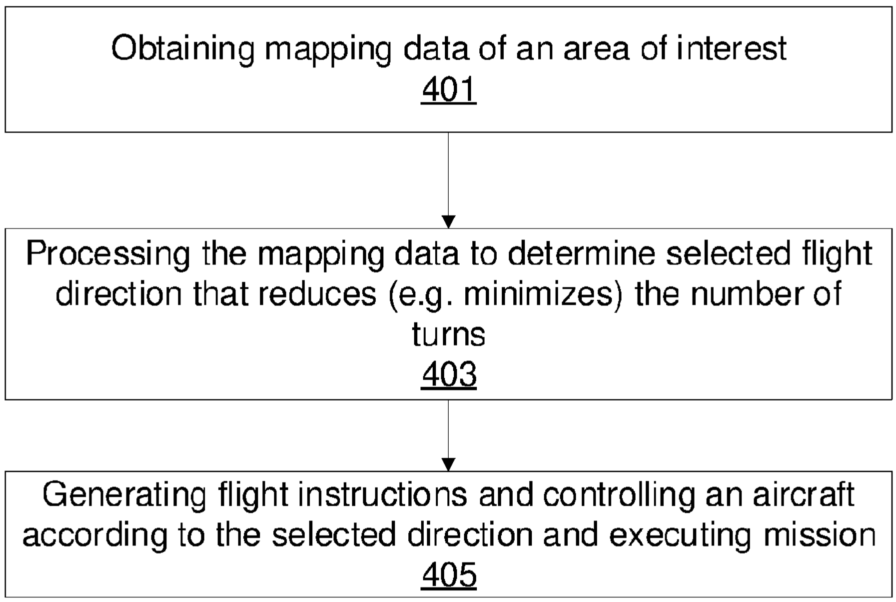
Obtaining mapping data of an area of interest
401
Processing the mapping data to determine selected flight direction that reduces (e.g. minimizes) the number of turns
403
Generating flight instructions and controlling an aircraft according to the selected direction and executing mission
405

Fig. 4

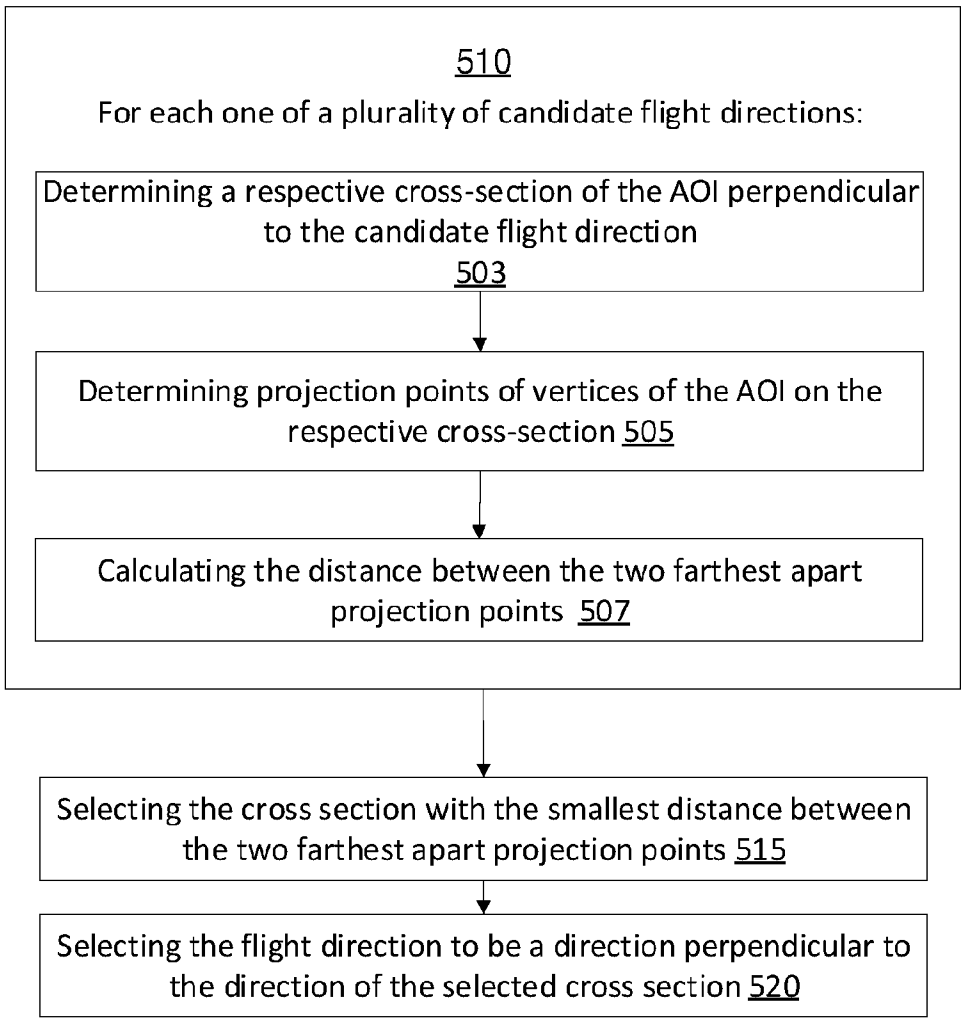
510
For each one of a plurality of candidate flight directions:
Determining a respective cross-section of the AOI perpendicular to the candidate flight direction
503
Determining projection points of vertices of the AOI on the respective cross-section 505
Calculating the distance between the two farthest apart projection points 507
Selecting the cross section with the smallest distance between the two farthest apart projection points 515
Selecting the flight direction to be a direction perpendicular to the direction of the selected cross section 520

Fig. 5

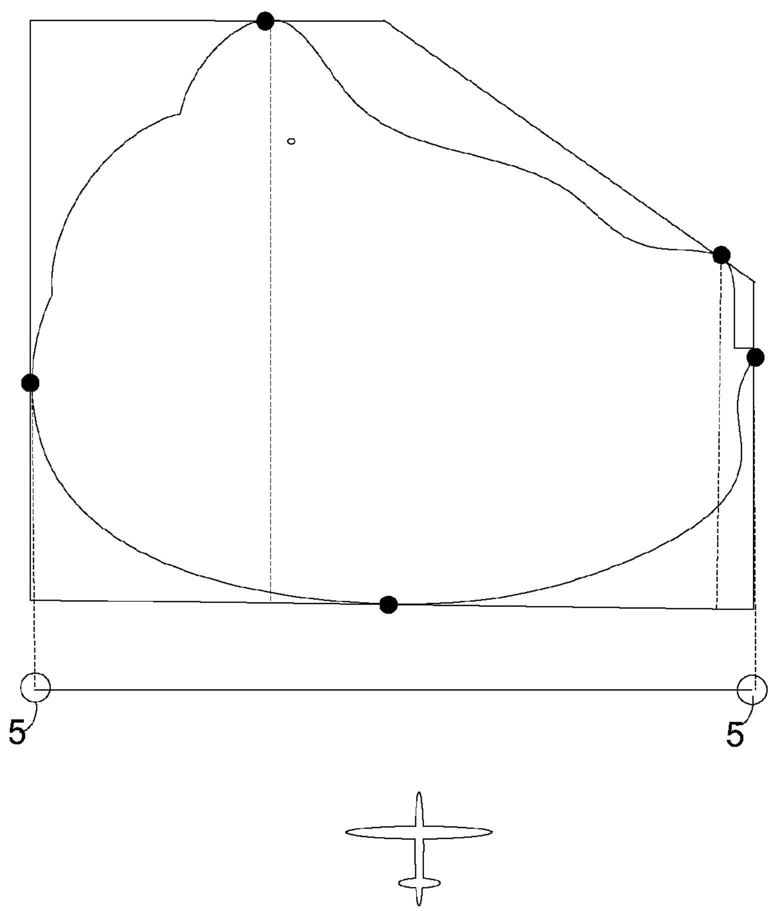

Fig. 6a

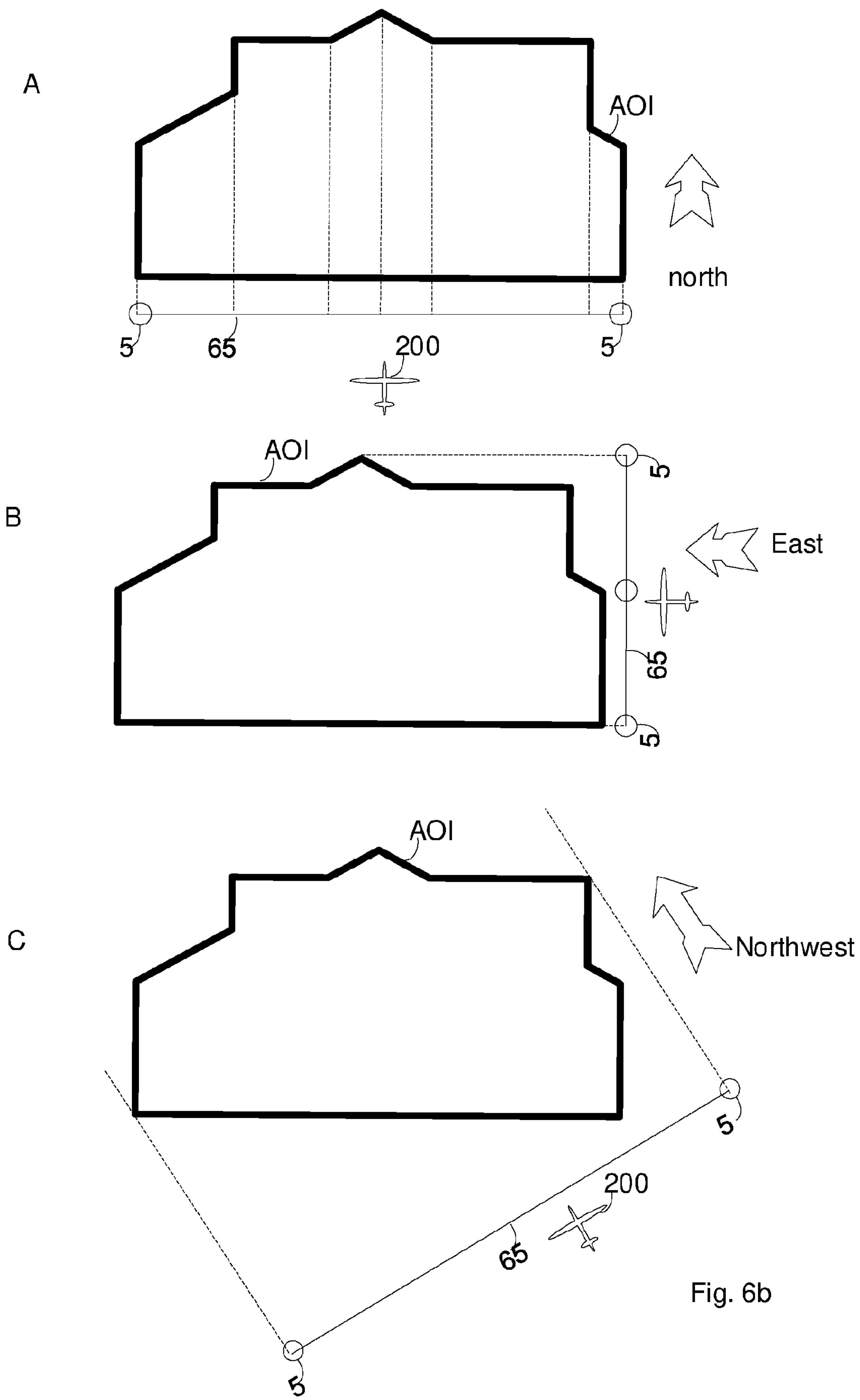

Fig. 6b

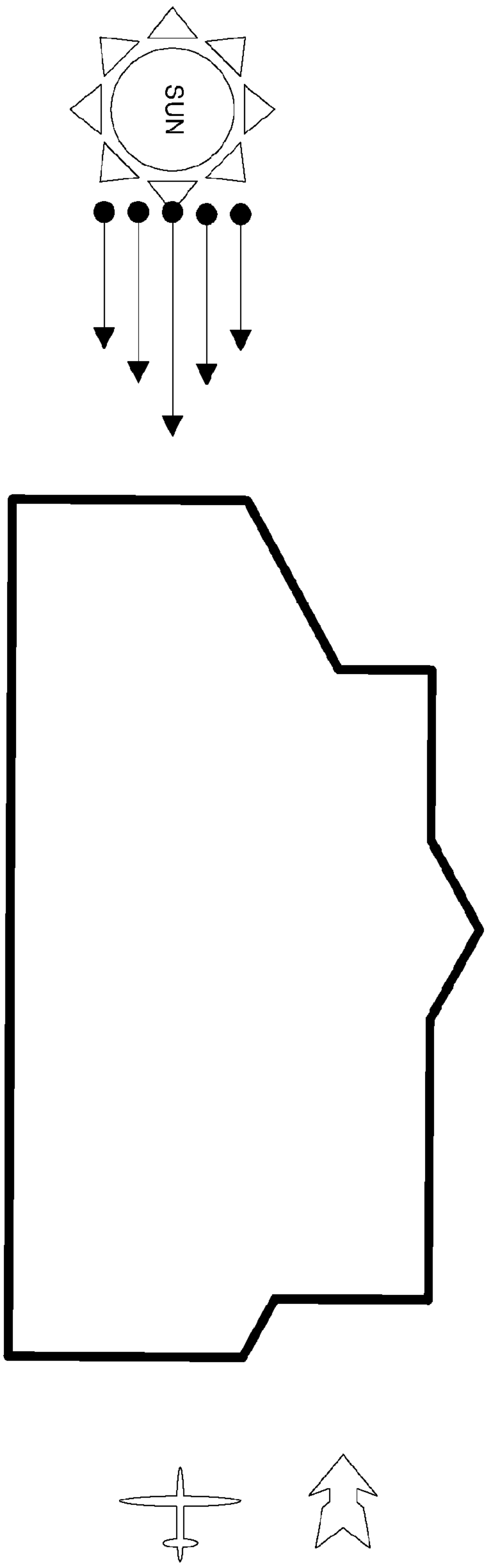

Fig. 7

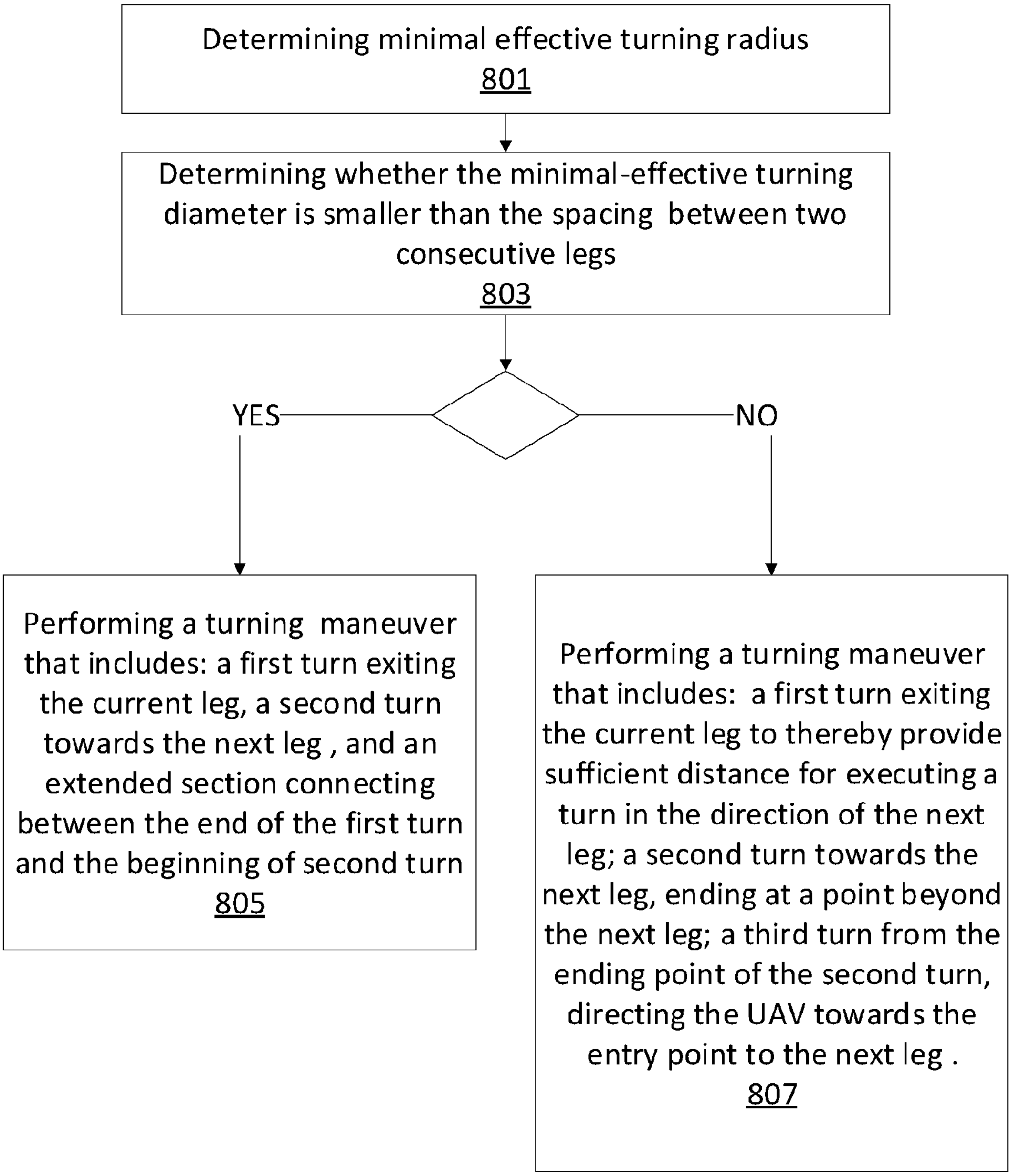
Determining minimal effective turning radius
801
Determining whether the minimal-effective turning diameter is smaller than the spacing between two consecutive legs
803
YES
NO
Performing a turning maneuver that includes: a first turn exiting the current leg, a second turn towards the next leg , and an extended section connecting between the end of the first turn and the beginning of second turn
805
Performing a turning maneuver that includes: a first turn exiting the current leg to thereby provide sufficient distance for executing a turn in the direction of the next leg; a second turn towards the next leg, ending at a point beyond the next leg; a third turn from the ending point of the second turn, directing the UAV towards the entry point to the next leg .
807

Fig. 8

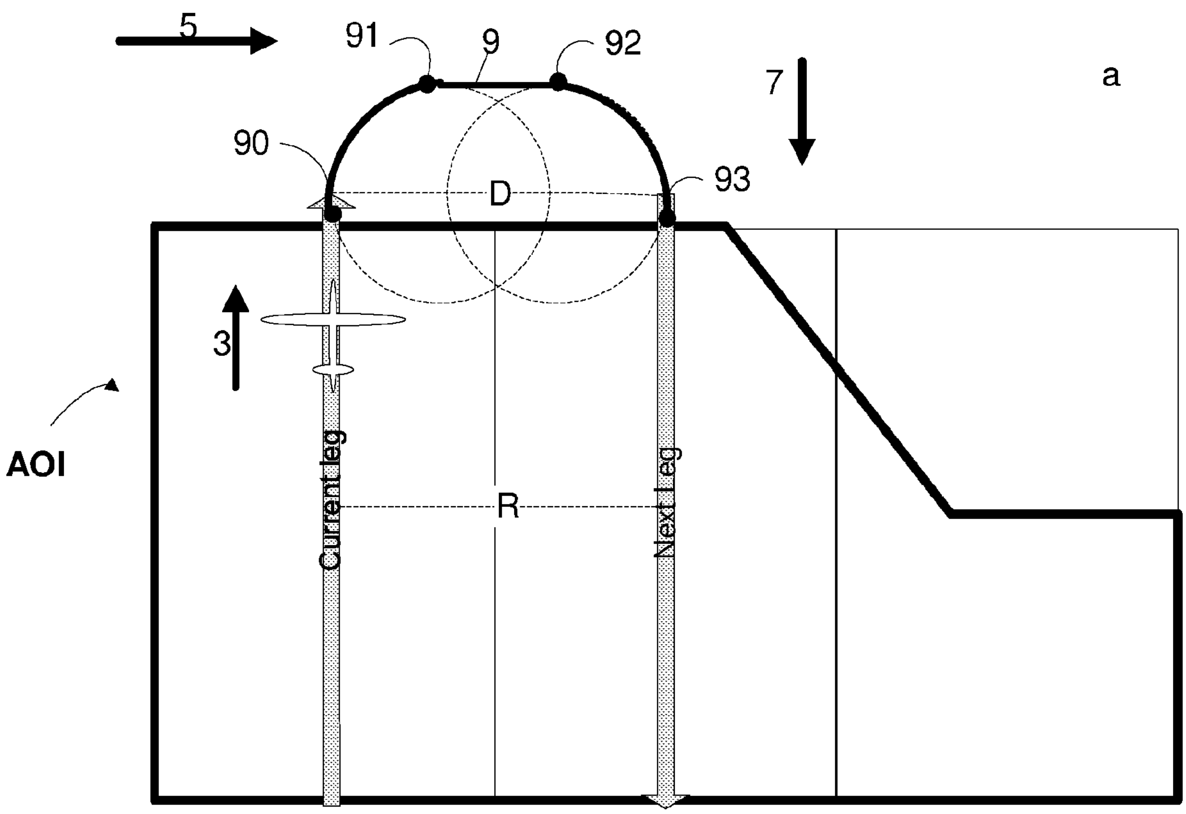

Fig. 9a

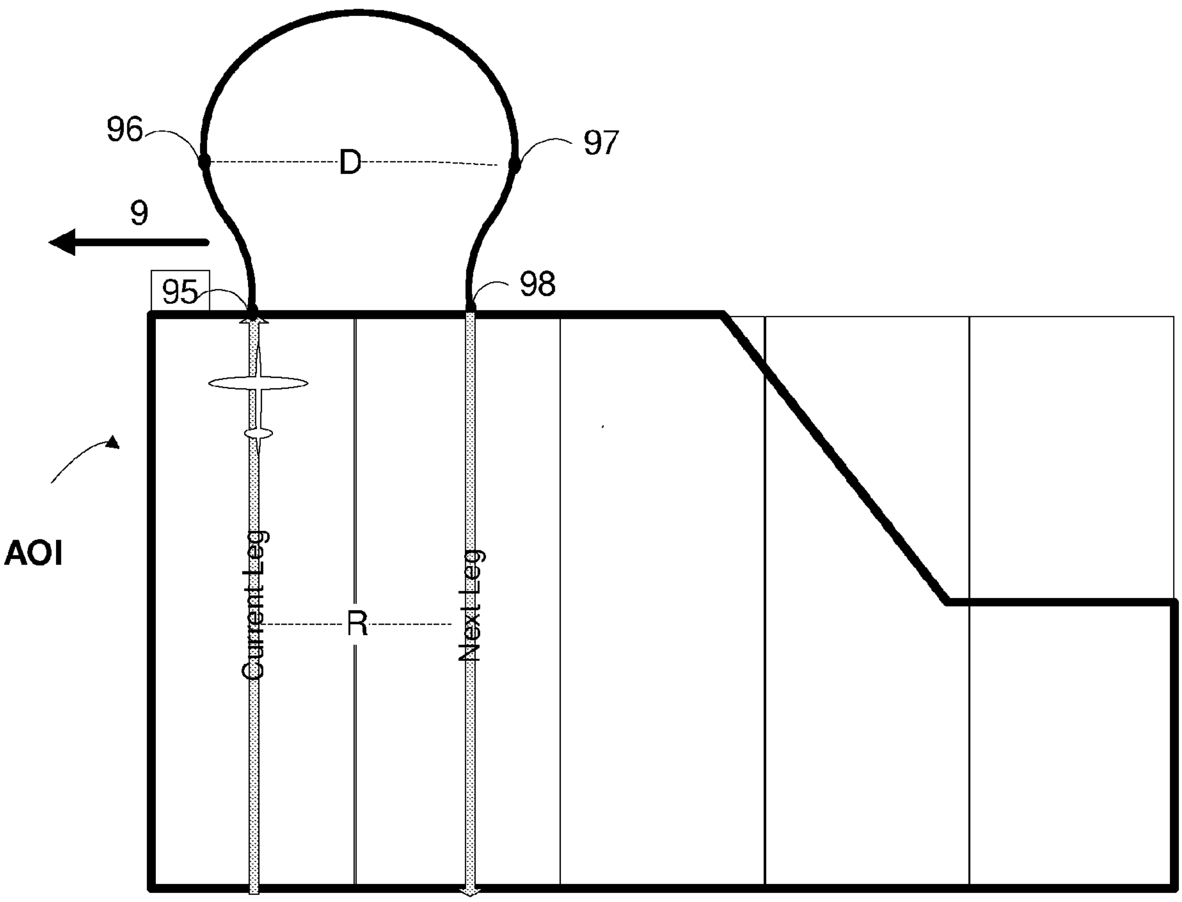

Fig. 9b

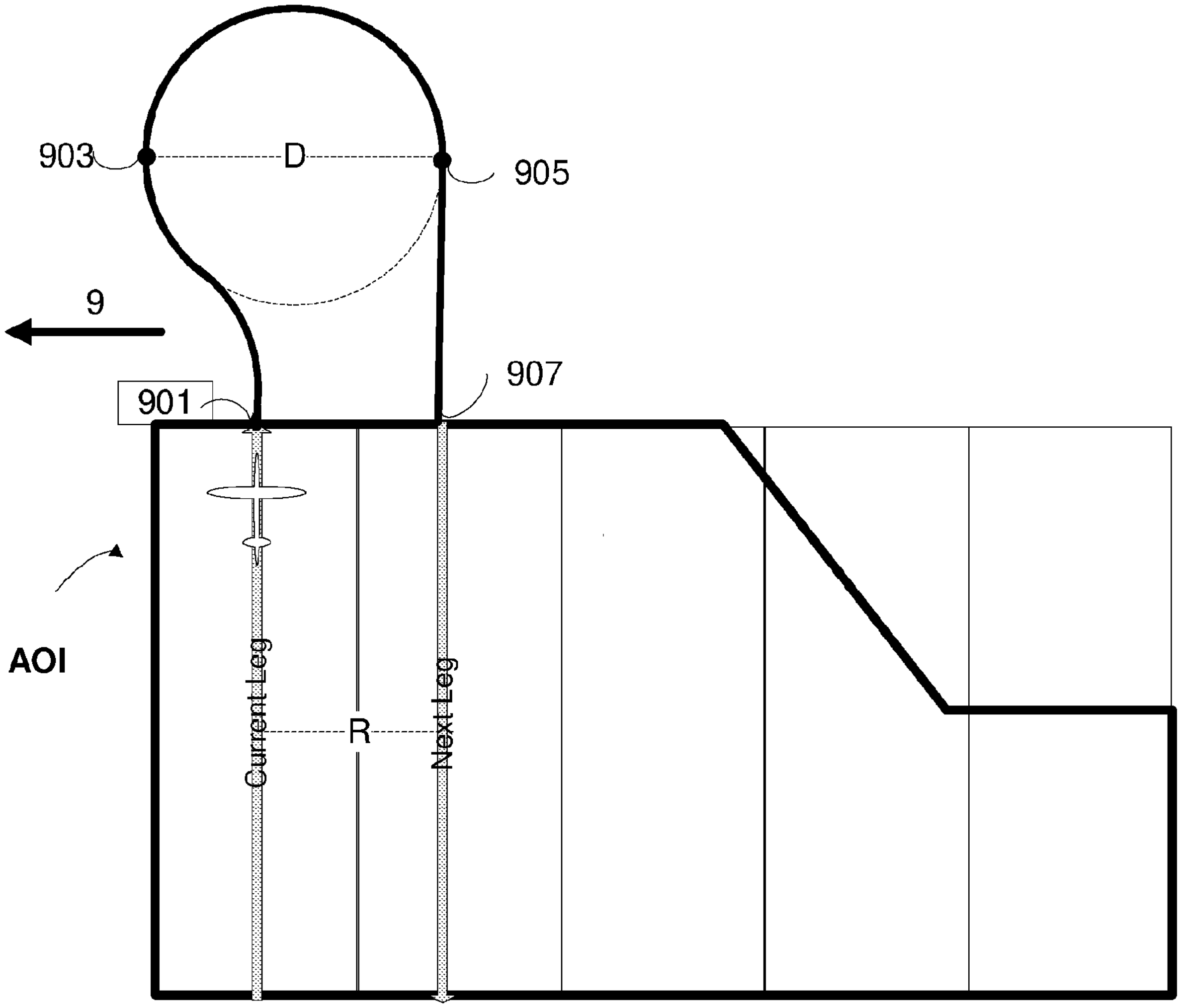

Fig. 9c

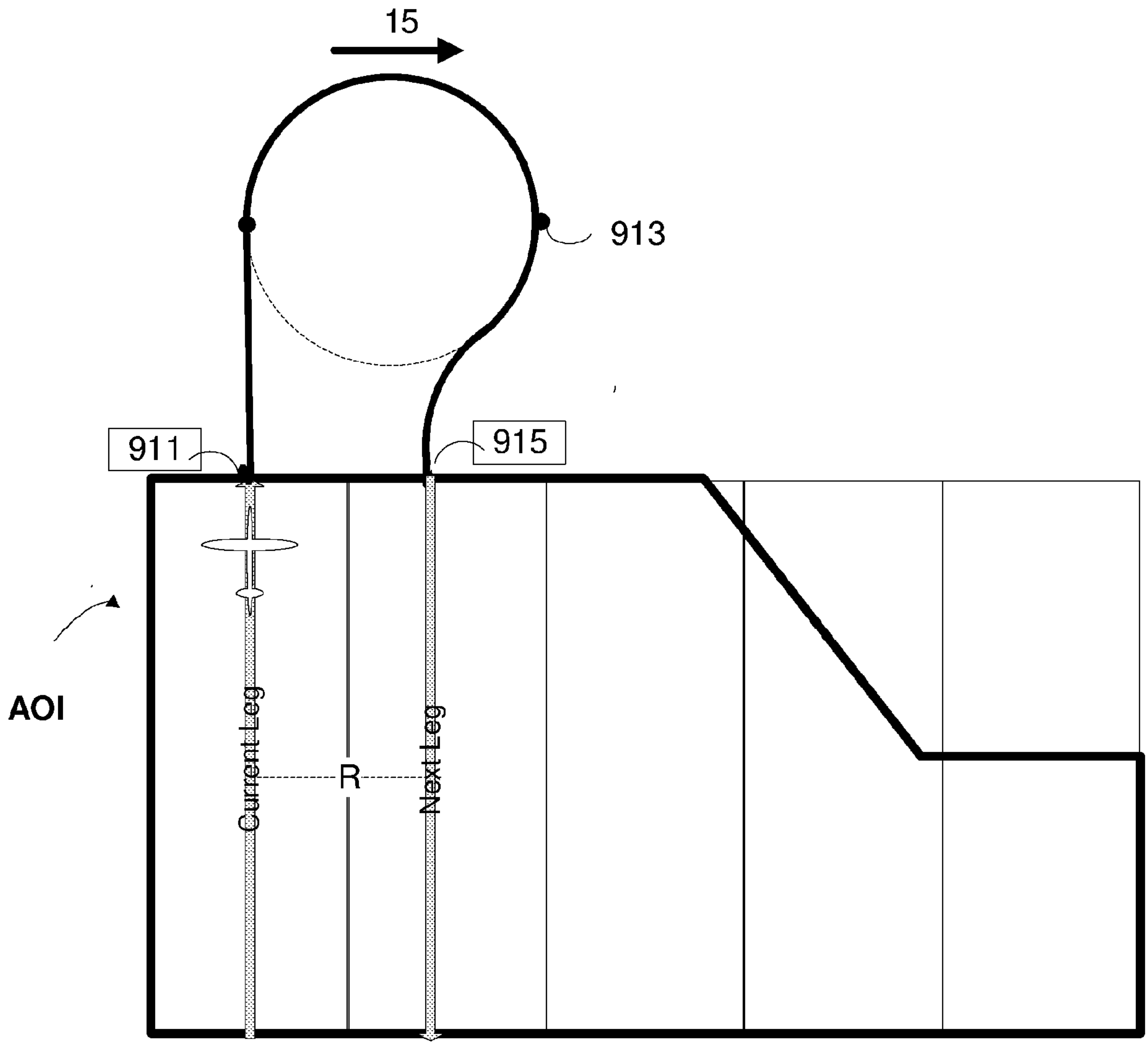

Fig. 9d

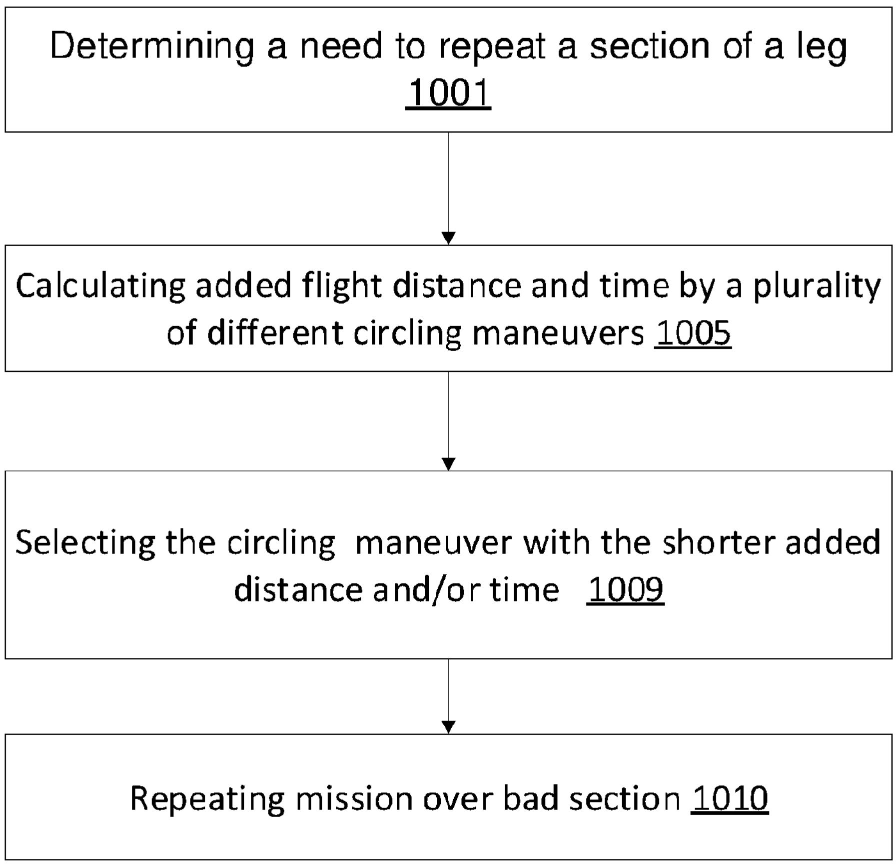
Determining a need to repeat a section of a leg 1001
Calculating added flight distance and time by a plurality of different circling maneuvers 1005
Selecting the circling maneuver with the shorter added distance and/or time 1009
Repeating mission over bad section 1010

Fig. 10

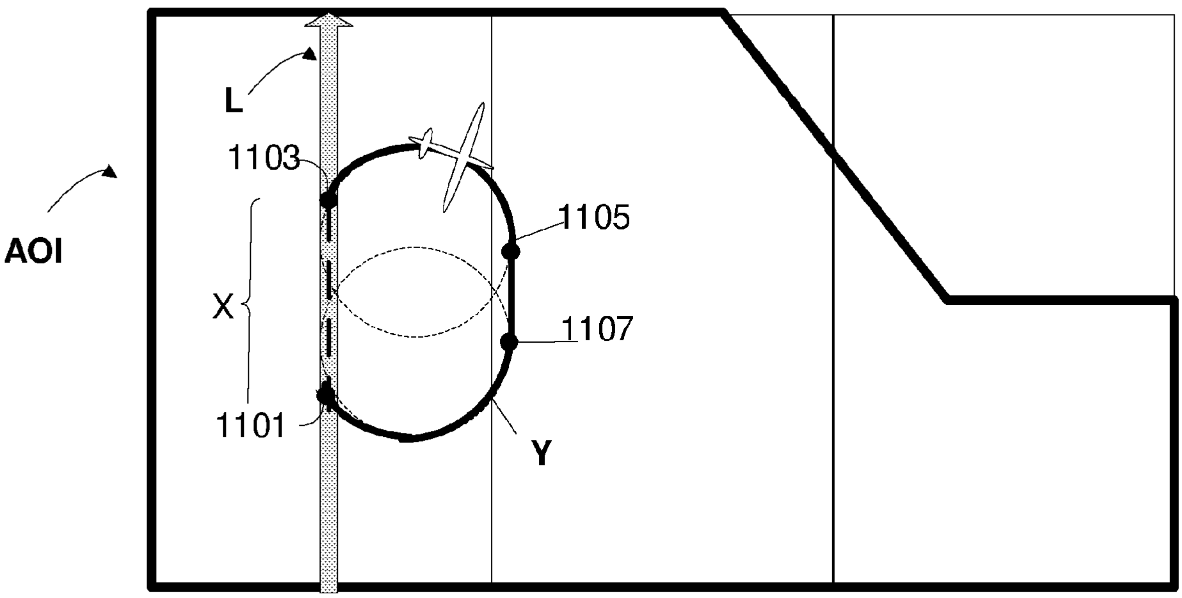

Fig. 11a

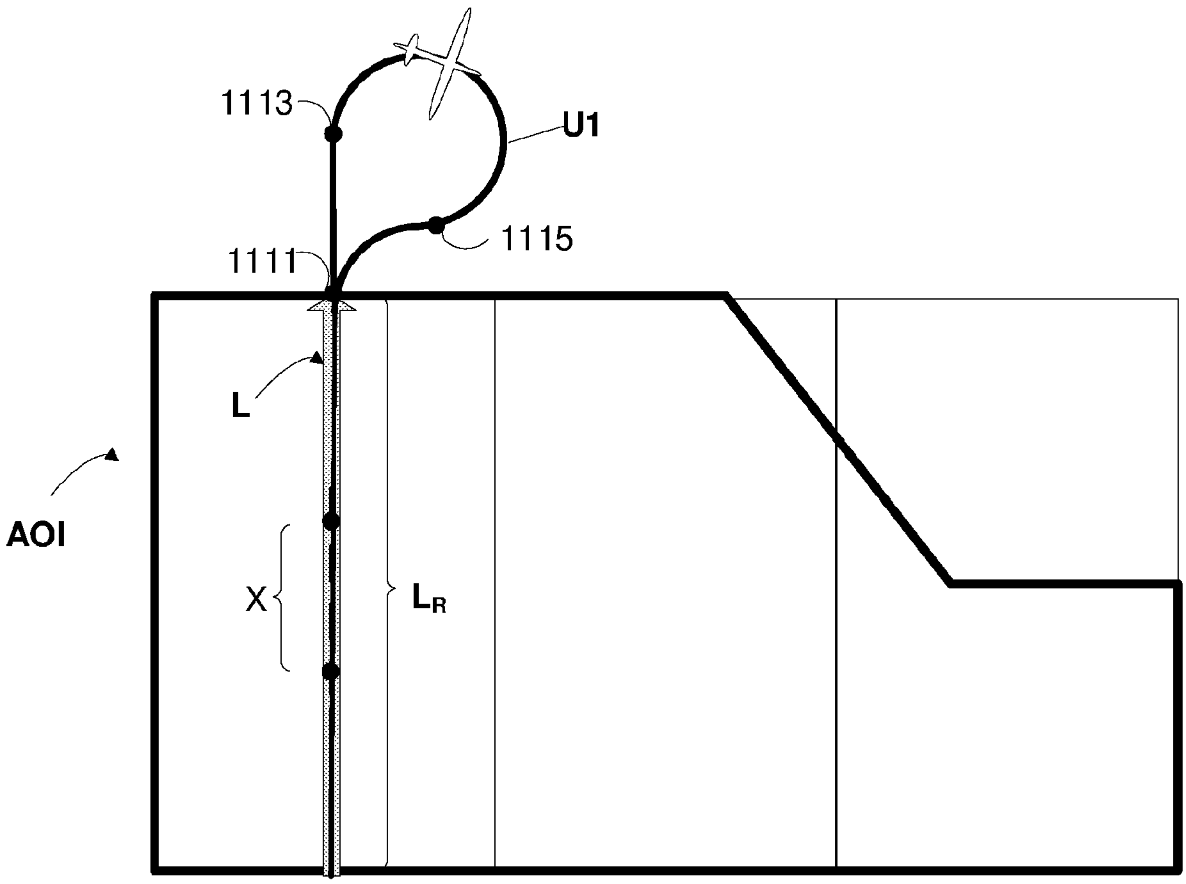

Fig. 11b

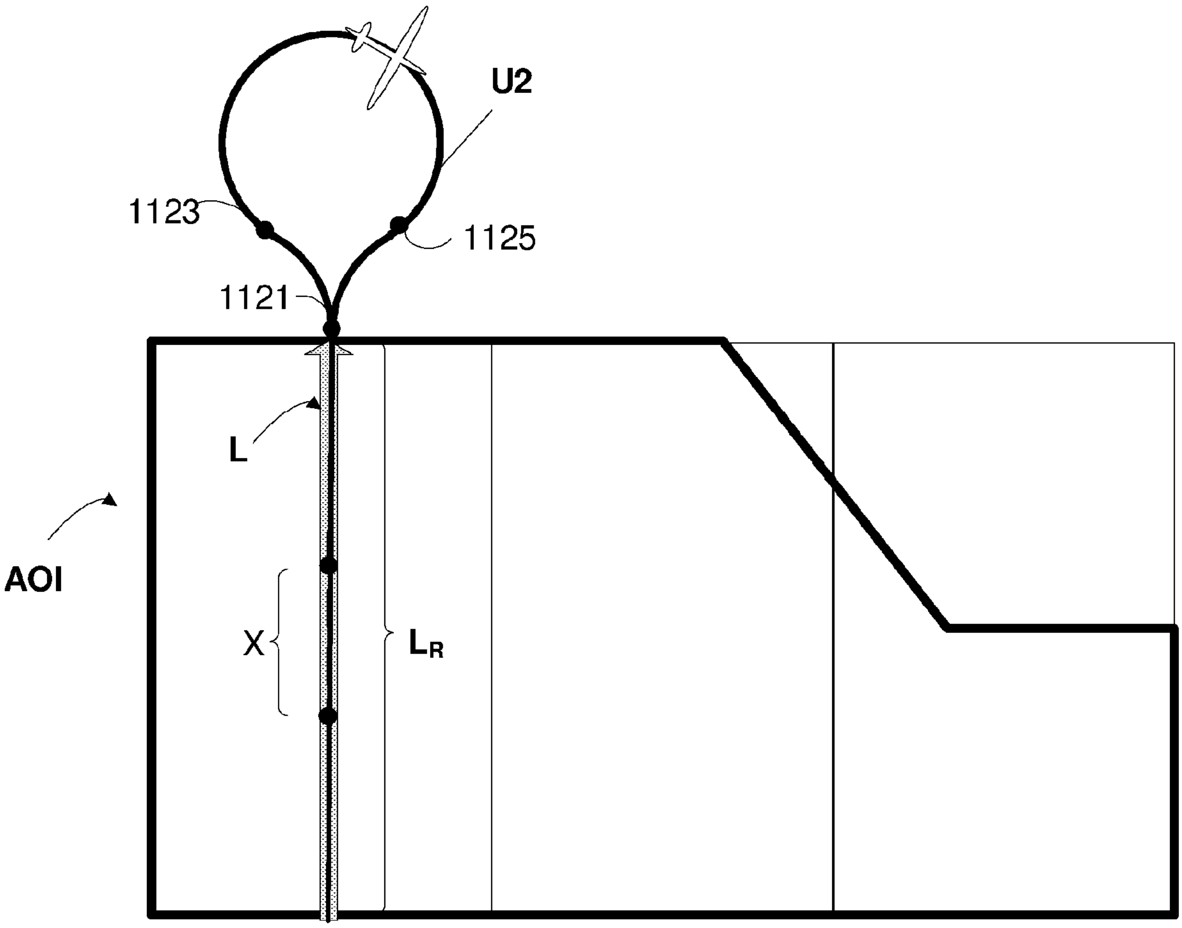

Fig. 11c

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2019/051396

A. CLASSIFICATION OF SUBJECT MATTER
IPC (20200101) G05D 1/00, B64C 39/02, G08G 5/00
CPC (20130101) G05D 1/0094, B64C 39/024, G08G 5/0013, G08G 5/0026
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)
IPC (20200101) G05D 1/00, B64C 39/02, G08G 5/00
CPC (20130101) G05D 1/0094, B64C 39/024, G08G 5/0013, G08G 5/0026

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)
Databases consulted: Esp@cenet, Google Patents, Google Scholar, Orbit

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Coombes, M., Fletcher, T., Chen, W. H., & Liu, C. (2018). Optimal polygon decomposition for UAV survey coverage path planning in wind. Sensors, 18(7), 2132. M., Fletcher 18 Jul 2018 (2018/07/18) THE WHOLE DOCUMENT	1-23
A	US 2017334559 A1 Patrick Michael Bouffard 23 Nov 2017 (2017/11/23) THE WHOLE DOCUMENT	1-23
A	US 9852639 B2 Yifei Teng 26 Dec 2017 (2017/12/26) THE WHOLE DOCUMENT	1-23

☐ 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
"D" document cited by the applicant in the international application
"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	Date of mailing of the international search report
23 Jan 2020	27 Jan 2020

Name and mailing address of the ISA:	Authorized officer
Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Email address: pctoffice@justice.gov.il	SUBHI Suhaib Telephone No. 972-73-3927191

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2019/051396

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
US 2017334559 A1	23 Nov 2017	US 2017334559 A1	23 Nov 2017
US 9852639 B2	26 Dec 2017	US 2017110014 A1	20 Apr 2017
		US 9852639 B2	26 Dec 2017
		US 9508263 B1	29 Nov 2016
		US 2017337824 A1	23 Nov 2017
		US 10008123 B2	26 Jun 2018
		US 2018301041 A1	18 Oct 2018