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(54) **Title:** METHOD AND SYSTEM FOR AUTONOMOUS CLOUD SEEDING

(57) **Abstract:** The presently disclosed subject matter include a system and computer-implemented method of seeding a cloud using an autonomous vehicle. The method including: using an image sensor that is mounted on the autonomous vehicle for obtaining an image that includes at least a portion of the cloud; and using a computer for: determining a seeding location within the cloud to begin seeding of the cloud based on the image, wherein the determination is based at least in part on image processing identifying a characteristic of the cloud that is indicative of the cloud's suitability for seeding; and generating one or more flight instructions for directing the autonomous vehicle towards the determined seeding location.

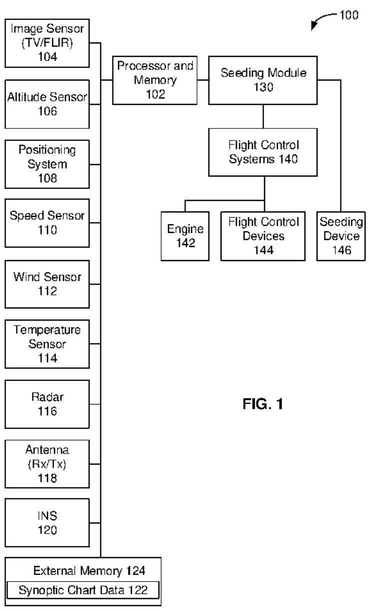

FIG. 1

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METHOD AND SYSTEM FOR AUTONOMOUS CLOUD SEEDING

TECHNICAL FIELD

The presently disclosed subject matter relates to a method and system for autonomous cloud seeding using an aircraft.

BACKGROUND

Cloud seeding is a way to change the amount or type of precipitation that falls from clouds. Cloud seeding is done by dispersing cloud seeding material into the air near the clouds. This cloud seeding material can serve as cloud condensation or ice nuclei that alter the microphysical processes that occur within the seeded cloud. Cloud seeding can be done to increase precipitation, such as for rain or snow. Cloud seeding can also be done to suppress precipitation, such as for hail or fog, for example near airports in order to prevent the delay or cancellation of flights due to weather conditions.

GENERAL DESCRIPTION

According to one aspect of the presently disclosed subject matter there is provided a computer-implemented method of seeding a cloud using an autonomous vehicle, including:

using an image sensor that is mounted on the autonomous vehicle for obtaining an image that includes at least a portion of the cloud; and

using a computer for performing the following:

determining a seeding location within the cloud to begin seeding of the cloud based on the image, wherein the determination is based at least in part on image processing identifying a characteristic of the cloud that is indicative of the cloud's suitability for seeding; and

generating one or more flight instructions for directing the autonomous vehicle towards the determined seeding location.

In addition to the above features, the method according to this aspect of the presently disclosed subject matter can include one or more of features (i) to (xv) listed below, in any desired combination or permutation which is technically possible:

(i). wherein the characteristic is a visual characteristic.

(ii). wherein the sensor is a thermal image sensor which provides thermal image data, and the characteristic includes a thermal characteristic.

(iii). wherein the determination is further based on one or more other types of data, including at least one of: radar data, data indicative of an environmental condition relating to the surroundings of the vehicle, position data, line of sight data, meteorological data, satellite picture data, and synoptic chart data.

(iv). wherein determining includes synchronizing the image data with the other type of data.

(v). wherein determining includes superpositioning a first type of data with a second type of data.

(vi). wherein determining includes: predicting a future location of the cloud; obtaining a desired location for precipitation to occur; and corresponding the predicted future location with the desired location to help determine the seeding location of the cloud.

(vii). wherein the seeding location is located at an area above or underneath the cloud.

(viii). seeding the cloud at the seeding location.

(ix). determining a location within the cloud to end seeding; and determining a flight path for seeding the cloud from the start seeding location to the end seeding location.

(x). selecting a cloud for seeding from among a plurality of clouds, based on cloud image data.

(xi). selecting a cloud from among the plurality of clouds based on one or more other types of data, including at least one of: cloud location data, cloud direction data, cloud precipitation potential data, and predicted future cloud location data.

(xii). identifying a potential dangerous cloud or portion of a cloud; and generating one or more flight instructions to avoid that cloud or cloud portion.

(xiii). wherein the determination is a real-time determination.

(xiv). automatically controlling the vehicle to direct the vehicle to the seeding location to perform cloud seeding.

(xv). wherein the vehicle is an unmanned aerial vehicle (UAV).

According to another aspect of the presently disclosed subject matter there is provided a non-transitory program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform the above method of seeding a cloud using an autonomous vehicle

This aspect of the disclosed subject matter can optionally include one or more of features (i) to (xv) listed above, mutatis mutandis, in any desired combination or permutation which is technically possible.

According to another aspect of the presently disclosed subject matter there is provided a system mountable on an aircraft for controlling the aircraft to perform seeding of a cloud, including:

an image sensor configured to obtain an image that includes at least a portion of the cloud; and

a processor operatively connected to the sensor and configured to perform the following:

determine a seeding location within the cloud to begin seeding of the cloud based on the image, wherein the determination is based at least in part on image processing that identifies a characteristic of the cloud that is indicative of the cloud's suitability for seeding; and

generate one or more flight instructions to direct the aircraft towards the determined seeding location.

This aspect of the disclosed subject matter can optionally include one or more of features (i) to (xv) listed above, mutatis mutandis, in any desired combination or permutation which is technically possible.

In addition to the above features, the system according to this aspect of the presently disclosed subject matter can include one or more of features (xvi) to (xvii) listed below, in any desired combination or permutation which is technically possible:

(xvi). an antenna mounted on the vehicle and configured to receive data.

(xvii). an anti-ice system mounted on the vehicle and configured to protect the vehicle in cold weather conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it can be carried out in practice, embodiments will be described, by way of non-limiting examples, with reference to the accompanying drawings, in which:

Fig. 1 illustrates a functional block diagram of a system for cloud seeding in accordance with certain examples of the presently disclosed subject matter;

Figs. 2-6 illustrate flow-charts of operations for cloud seeding in accordance with certain examples of the presently disclosed subject matter; and

Fig. 7 illustrates schematically an image of a cloud taken by a sensor on-board an aircraft in accordance with certain examples of the presently disclosed subject matter.

DETAILED DESCRIPTION

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the presently disclosed subject matter may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the presently disclosed subject matter.

Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "obtaining", " determining", "generating", "synchronizing", "superpositioning", "predicting", "corresponding", "selecting", "identifying", "controlling", or the like, refer to the action(s) and/or process(es) of a computer that manipulate and/or transform data into other data, said data represented as physical, such as electronic, quantities and/or said data representing the physical objects.

The term “computer” or "processor" or variations thereof should be expansively construed to cover any kind of hardware-based electronic device with data processing capabilities including, by way of non-limiting example a processing device (e.g. digital signal processor (DSP), microcontroller, field programmable circuit, application-specific integrated circuit (ASIC), etc.) or a device which comprises or is operatively connected to one or more processing devices. The terms "non-transitory memory", “non-transitory storage medium”, and "memory", used herein should be expansively construed to cover any volatile or non-volatile computer memory suitable to the presently disclosed subject matter. The above includes, by way of non-limiting example, processor and memory **102** disclosed in the present application.

The operations in accordance with the teachings herein may be performed by a computer specially constructed for the desired purpose or by a general-purpose computer specially configured for the desired purpose by a computer program stored in a non-transitory computer-readable storage medium.

The terms, "range", "proximity", "threshold", or the like, used herein includes variations that are equivalent for an intended purpose or function. These ranges, proximities, thresholds, etc., can be predetermined or calculated in real-time. In some examples a user can manually input a desired range, proximity, threshold, etc. In some examples the range, proximity, threshold, etc. is determined automatically by the system.

Bearing this in mind, attention is drawn to **Fig. 1** illustrating an autonomous cloud seeding system **100** in accordance with certain examples of the presently disclosed subject matter.

The autonomous cloud seeding system **100** can be mounted on an aircraft. The aircraft can be an unmanned aerial vehicle (UAV), also known as a, "drone", which can operate with various degrees of autonomy: either under remote control by a human operator, or fully or intermittently autonomously, e.g., by on-board computers.

The illustrated autonomous cloud seeding system **100** includes one or more processors and memory **102** configured to perform image processing and execute various operations as disclosed herein.

System **100** can include for example, processor and memory **102** operatively connected to various devices/elements including, for example: an image sensor **104**, an altitude sensor **106**, a position sensor **108**, a speed sensor **110**, a wind sensor **112**, a temperature sensor **114**, a radar **116**, an antenna **118**, an inertial navigation system (INS) **120**, an external memory **124** storing synoptic chart data **122**, and an automatic seeding module **130**.

Image sensor **104** is configured to capture image data. Image sensor **104** is located on-board the aircraft and its field of view can be pointed in a direction which allows capturing images of the area in front of the aircraft's nose. Image sensor **104** can be, for example, a thermal sensor configured to capture thermal image data. Image sensor **104** can include, for example, one or more of the following cameras/sensors: forward-looking infrared (FLIR), panoramic (pano), infrared (IR), mid-wavelength infrared (MWIR), short-wavelength infrared (SWIR), light detection and ranging (LIDAR), any other appropriate multiple spectral sensing device that can be used as a sensor during the daytime and/or night-time, etc. Optionally, image sensor **104** can have different selectable modes of operation. An appropriate mode of operation of image sensor **104** can be selected based on various real-time parameters including for example, time of day, weather, etc. For example, this selection can be made autonomously, and/or manually.

Altitude sensor **106** is configured to determine an altitude of the aircraft. Altitude sensor **106** can include, for example, one or more of the following sensors: altimeter, radar altimeter (RALT), barometer, or any other appropriate altitude sensing device.

Positioning system **108** is configured to determine a location of the aircraft. Positioning system **108** can include, for example, a Global Positioning System (GPS) configured to determine a geolocation of the aircraft, or any other appropriate location determining device.

Inertial navigation system (INS) **120** is configured to calculate the position, orientation, and/or velocity (direction and speed of movement) of the aircraft.

Speed sensor **110** is configured to determine a speed of the aircraft (e.g., the airspeed of the aircraft). Speed sensor **110** can include, for example, a pitot tube, or any other appropriate speed sensing device.

Wind sensor **112** is configured to determine a parameter related to wind. The wind parameter can include, for example, one or more of: wind speed, wind direction, etc. Wind sensor **112** can include, for example, an anemometer, a wind vane, or any other appropriate wind sensing device. As an example, wind sensor **112** can determine wind speed data based on speed data of the vehicle together with ground speed data (e.g., from INS **120**).

Temperature sensor **114** is configured to determine a temperature in the vicinity of the aircraft. Temperature sensor **114** can include, for example, a thermometer, or any other appropriate temperature sensing device.

Radar **116** is configured to determine the range, angle, and/or velocity of objects. Radar **116** can be mounted on the aircraft, and/or can be a ground radar communicatively connected to processor and memory **102**. Radar **116** can include one or more of, for example: a weather radar configured to detect weather formations, a cloud radar configured to monitor clouds, and/or a rain radar configured to monitor rain. Radar **116** can include, for example, a Doppler radar, or any other appropriate radar device.

Antenna **118** is configured to transmit and/or receive radio waves. Antenna **116** can be configured to facilitate communication between the aircraft and a satellite and/or a ground station. Antenna **116** can be configured to transmit/receive data and/or instructions. The aircraft can be configured to perform line-of sight (LOS) and/or beyond-line-of-sight (BLOS) communication. Antenna **118** can include, for example, a SATCOM antenna, or any other appropriate antenna.

Synoptic chart data **122** is weather map data that is indicative of weather related data. Synoptic chart data **122** can be data related to a map that is indicative of atmospheric conditions (temperature, precipitation, wind speed and direction, atmospheric pressure, cloud coverage, etc.) over an area at a certain time. Synoptic chart data **122** can indicate an overview of the weather conditions observed from many different sources (e.g., weather stations, aircraft, satellites, etc.). For example, synoptic chart data **122** can be generated and stored externally, e.g., in an external memory **124** that is communicatively connected to processor and memory **102**. The external memory **124** can be mounted on-board the aircraft or located elsewhere. For example, synoptic chart data **122** can uploaded and stored in computer memory before or during flight of the aircraft. Synoptic chart data **122** can be continuously updated, for example, during flight of the aircraft.

Altitude sensor **106**, positioning system **108**, speed sensor **110**, wind sensor **112**, temperature sensor **114**, antenna **118**, and INS **120**, can be mounted on-board the aircraft.

Seeding module **130** can be located on-board the aircraft as an aircraft control system operatively connected to flight control systems **140** of the aircraft and seeding device **146**. Seeding module **130** is configured to receive data (e.g. from processor and memory **102**, and/or over a real-time communication link via, e.g. from antenna **118**) and control the aircraft to perform cloud seeding accordingly. For example, seeding module **130** can control the aircraft to perform cloud seeding by generating flight commands/instructions that are used by one or more of the flight control systems **140** and seeding commands/instructions that are used by seeding device **146**. As an example, seeding module **130** can control the aircraft to perform cloud seeding by autonomously generating the flight commands/instructions.

Flight control systems **140** are operatively connected to various subsystems on-board the aircraft configured to enable maneuvering the aircraft. These subsystems can include, for example: engine **142**, flight control devices **144** (e.g., ailerons, elevator, rudder, spoilers, flaps, slats, air brakes, landing gear, etc.).

Seeding device **146** is configured to disperse the seeding material. Seeding device **146** can include, for example: a container for storing the seeding material, a dispersal pipe connected to the container, a fan connected to the dispersal pipe, or any other appropriate device for dispersing the seeding material.

Optionally, autonomous seeding system **100** can include an anti-ice system mounted on the aircraft that can be used to protect the aircraft, e.g., if the aircraft gets close to areas of the cloud that are relatively cold, or in other cold weather conditions.

It is noted that the teachings of the presently disclosed subject matter are not bound by the autonomous seeding system **100** described with reference to **Fig. 1**. Equivalent and/or modified functionality can be consolidated or divided in another manner and can be implemented in any appropriate combination of software with firmware and/or hardware and executed on a suitable device. For example, seeding module **130** which is shown as a module that is external from processor and memory **102** can be a module that is comprised in and executed by processor and memory **102**. As another example, data and/or images can be provided by other systems, including third party equipment, and at least part of the processing can be done remotely from the aircraft.

Reference is now made to **Figs. 2-6** which show flow charts of operations in accordance with certain examples of the presently disclosed subject matter.

It is noted that the teachings of the presently disclosed subject matter are not bound by the flow charts illustrated in **Figs. 2-6**, and the illustrated operations can occur out of the illustrated order. For example, operations **304** and **306**, or **408** and **410**, shown in succession in their respective Figures, can be executed substantially concurrently or in the reverse order. It is also noted that whilst the flow charts are described with reference to elements of autonomous seeding system **100**, this is by no means binding, and the operations can be performed by elements other than those described herein.

Fig. 2 illustrates a generalized flow-chart of a method for controlling an aircraft to perform autonomous cloud seeding in accordance with certain examples of the presently disclosed subject matter.

At block **202** one or more clouds is selected for seeding (e.g., by seeding module **130**). Examples of this selection will be described in greater detail below with reference to **Fig. 3**.

At block **204** a location to perform seeding is determined based at least partly on the obtained image of the cloud (e.g., by seeding module **130**, after the image was captured by image sensor **104**). Examples of this determination will be described in greater detail below with reference to **Fig. 4**. After the seeding location is determined, one or more flight instructions can then be generated for directing the aircraft to the determined seeding location (e.g., by seeding module **130**). Arrival at the seeding location can also be determined (e.g., by processor and memory **102**).

At block **206** cloud seeding is performed at the seeding location (e.g., by seeding device **146**). This can include the activation of the fan connected to the dispersal pipe, for the purpose of dispersing the cloud seeding material at the designated area. Examples of this seeding will be described in greater detail below with reference to **Fig. 5**.

Fig. 3 illustrates the process of selecting one or more clouds for seeding, described briefly above with connection to block **202**, in accordance with certain examples of the presently disclosed subject matter.

At block **302** a desired geographic location to be affected by the cloud seeding is obtained (e.g., by seeding module **130**). For example, the desired geographic location can be an area on the ground where it is desired for precipitation to occur, e.g., for rain to fall on.

At block **304** one or more candidate clouds for performing seeding on is determined (e.g., by seeding module **130**). The candidate cloud(s) can be chosen from a plurality of clouds. For example, the candidate clouds can be determined based on an obtained location of the clouds. The location of the candidate clouds can be obtained based on data from one or more of the following, for example: air weather radar data, ground weather radar data, cloud radar data, other meteorological data, etc. For example, candidate cloud(s) are clouds that are determined to be within a predetermined range of the obtained desired geographic location to be affected by the cloud seeding. The predetermined range can be according to a determination of the ability of the cloud(s) to provide precipitation at the desired geographic location after the cloud(s) are seeded. The candidate clouds can also be determined using any other appropriate data, for example, data determined by the systems and devices described above with reference to **Fig. 1**.

At block **306** a direction and/or vector of progression of the candidate clouds is determined (e.g., by seeding module **130**). The direction and/or vector of progression of the candidate clouds can be determined based on data from one or more of the following, for example: air weather radar data, ground weather radar data, wind direction data sensed by sensors on the vehicle or external sensors, wind speed data determined based on data sensed by sensors on the vehicle or external sensors, cloud image data, etc. The direction and/or vector of progression of the candidate clouds is indicative of the ability of the cloud(s) to reach the desired geographic location after the cloud(s) are seeded and provide precipitation at that location. In some examples, a future location of the cloud(s) can be predicted; e.g., based on cloud direction, wind conditions, etc.

At block **308** a precipitation potential of the candidate cloud(s) is determined (e.g., by seeding module **130**). The precipitation potential can be calculated as a score or a grade, e.g., on a predetermined scale. For example, the precipitation potential can be based on data that is indicative of the cloud(s) likelihood to produce a desired amount or type of precipitation. For example, the precipitation potential can be determined based on a thermal characteristic of the cloud that is indicated by one or more of the following, for example: a thermal image of the cloud(s), air weather radar data, ground weather radar data, etc. Precipitation potential can also be referred to according to the type of desired precipitation; e.g., rain potential, snow potential, etc.

At block **310** one or more clouds are selected to perform seeding on (e.g., by seeding module **130**). The selected cloud(s) can be selected from a plurality of candidate clouds. For example, the cloud(s) can be selected based on a parameter related to the one or more clouds. This parameter can include one or more of the following, for example: the location of the cloud(s), the direction/vector of progression of the cloud(s), the precipitation potential of the cloud(s), a visual parameter of the cloud(s) obtained from a cloud image, a predicted future location of the cloud(s), etc.

The obtained data can also be indicative of a type of cloud(s) and the selection of the cloud(s) for cloud seeding can be based on the type of cloud(s). The type of cloud can be one or more of the following, for example: stratus, cumulus, cirrus, etc.

At block **312** the vehicle is directed towards the selected cloud(s) (e.g., by flight control systems **140**). For example, one or more flight instructions can be generated (e.g., by seeding module **130**) for directing the vehicle towards the selected cloud(s).

Fig. 4 illustrates determining a location to release the seeding material in relation to the selected cloud(s), described briefly above with connection to block **204**, in accordance with certain examples of the presently disclosed subject matter.

Fig. 4 is described with reference to **Fig. 7** which schematically illustrates an image **700** taken by image sensor **104** on-board the aircraft in accordance with certain examples of the presently disclosed subject matter.

At block **402** arrival of the vehicle at an area within a range/proximity of the selected cloud(s) is determined (e.g., by processor and memory **102**). Arrival at the area in proximity of the cloud(s) can be determined based on one or more of the following, for example: an obtained image of the cloud(s), location data of the vehicle (e.g. obtained by positioning system **108**), radar data, etc.

As described above with reference to block **202** of **Fig. 2**, an image in the FOV of the aircraft can be received at the system to be processed. For example, processor and memory **102** receives an image **700** captured by image sensor **104** located on-board the aircraft. Processor and memory **102** (e.g. with the help of an image processing module operatively connected to the processor) can be configured to process the received image and identify a cloud **702** in the image **700**.

At block **404**, when the aircraft reaches the designated area within the range/proximity of the selected cloud(s), an image of at least a portion of the selected cloud(s) is obtained (e.g., by seeding module **130**) for further image processing. For example, the determined image **700** of the cloud(s) **702** or portion of the cloud(s) **702** can be a thermal image (e.g., obtained by a thermal image sensor **104**, such as, a FLIR camera). For example, seeding module **130** (e.g. with the help of an image processing module operatively connected to seeding module **130**) can be configured to process the received image and identify a visual characteristic of cloud **702** in the image **700**.

At block **406** a seeding location, within the cloud, to begin the seeding of the selected cloud(s) is determined based at least in part on the obtained image of the cloud(s)/portion of the cloud(s) (e.g., by seeding module **130**). Optionally, at block **408** the seeding location is determined based at least in part on a visual characteristic of the cloud(s)/portion of the cloud(s). The visual characteristic is indicative of the suitability of the cloud(s)/portion of the cloud(s) for cloud seeding. For example, the visual characteristic is a thermal characteristic. The thermal characteristic can be indicative of an area of the cloud that is particularly suited for cloud seeding, and that will increase the effectiveness of the cloud seeding. For example, this area within the cloud can be the coldest part of the cloud that was identified. In the example of image **700** of cloud **702**, there are several different portions of cloud **702** with different temperatures: portion **708** is the coldest portion of cloud **702** characterized in image **700** by a first visual characteristic (e.g. a red color indicating a relatively low temperature), portion **704** is the warmest portion of cloud **702** characterized in image **700** by a second visual characteristic (e.g. a blue color indicating a relatively high temperature), portion **706** is a portion of cloud **702** with a medium temperature, between the temperature of portion **704** and portion **708**, characterized in image **700** by a third visual characteristic (e.g. a green color indicating a relatively medium temperature).

In some examples, the determination can be based on a plurality of images, e.g., simultaneously taken from a plurality of sensors at substantially the same time, and of substantially the same FOV.

Optionally, at block **410** the seeding location is determined based at least in part on other data related to the cloud(s). The other data is also indicative of the suitability of the cloud(s)/portion of the cloud(s) for cloud seeding. The other data can be indicative of an area of the cloud that is particularly suited for cloud seeding, and that will increase the effectiveness of the cloud seeding. The other data can include, for example, one or more of: radar data (e.g. obtained from radar **116**), such as, weather and/or cloud radar data, data indicative of an environmental condition relating to the surroundings of the vehicle, such as wind strength and/or wind direction (e.g. obtained from wind sensor **112**), barometric pressure (e.g. obtained from the barometer), position data (e.g. obtained from positioning system **108**), line of sight data, meteorological data, satellite picture data, synoptic chart data (e.g. obtained from synoptic chart data **122**), etc. For example, seeding module **130** can be configured to analyze the data and determine suitability.

In the present subject matter the various types of data can be synchronized in order to help in the determination of the seeding location, and/or the selection of the cloud(s) for seeding. For example, weather radar map data obtained from ground radar, weather radar map data obtained from radar mounted on the aircraft, synoptic chart data, image sensor data, etc., can all be synchronized or consolidated together in order to determine a seeding location within the cloud that will help optimize the cloud seeding of the cloud. In some examples, a weather radar map indicative of selected cloud(s) for seeding in a certain location can be superpositioned or superimposed with a synoptic map of that location to better determine the seeding location. As another example, weather radar data indicative of a particularly desirable cloud seeding location can be correlated with the image sensor data in order to optimize the determination of the seeding location. Also as an example, ground radar data, determined by a radar on the ground, can be synchronized or consolidated with air radar data, determined by a radar mounted on the vehicle, to optimize the selection of the cloud(s) for seeding and/or the determination of the seeding location.

In some examples, the seeding location is located at an area above or underneath the cloud in an area that is relatively dangerous for a manned flight to fly towards. For example, the seeding location can be located at the center of the selected cloud(s) and reached by flying underneath, and/or above the cloud(s). Flying underneath, and/or above clouds to perform cloud seeding is typically not done when cloud seeding is carried out by a manned flight, due to the danger it poses to the aircraft and pilot. In the present subject matter, the aircraft is able to get relatively close to the cloud and take an image of the cloud that a manned aircraft would generally not be able to take due to the danger posed. However, in the present subject matter a flight vector or flight path is determined which protects the aircraft, that also optimizes cloud seeding. An example of the generation of a flight path is described further below.

At block **412** the vehicle is directed towards the seeding location (e.g., by flight control systems **140**). For example, one or more flight instructions can be generated (e.g., by seeding module **130**) for directing the vehicle towards the start seeding location.

Fig. 5 illustrates a flow-chart of a method for performing cloud seeding at the seeding location, described briefly above with connection to block **206**, in accordance with certain examples of the presently disclosed subject matter.

At block **502** arrival of the vehicle at an area within a range/proximity of the seeding location is determined (e.g., by processor and memory **102**). Arrival at the area in proximity of the cloud(s) can be determined based on one or more of the following, for example: an obtained image of the cloud(s), location data of the vehicle (e.g. obtained by positioning system **108**), radar data, etc. For example, the predetermined range can be according to a determination of the ability of the cloud(s) to provide precipitation at the desired geographic location after the cloud(s) are seeded, to increase the effectiveness of the cloud seeding. As an example, the location data of the vehicle can be compared to the determined end location data in order to determine arrival at the designated area to begin seeding.

At block **504** cloud seeding is initiated by the vehicle upon arrival at the area within a range/proximity of the seeding location (e.g., by seeding module **130**). For example, seeding module **130** can activate seeding device **146** to begin dispersing the cloud seeding material at the desired location for seeding.

At block **506** a location to end the seeding of the selected cloud(s) is determined based at least in part on an obtained image of the cloud(s)/portion of the cloud(s) (e.g., by seeding module **130**). For example, the end location can be determined based at least in part on a visual characteristic of the cloud(s)/portion of the cloud(s). The visual characteristic is indicative of the suitability of the cloud(s)/portion of the cloud(s) for cloud seeding. For example, the visual characteristic is a thermal characteristic. The thermal characteristic can be indicative of an area of the cloud that is not particularly suited for cloud seeding, and that will decrease the effectiveness of the cloud seeding. For example, this area within the cloud can be a relatively warm part of the cloud(s), e.g., within a predefined temperature range at which the effectiveness of seeding is lowered.

Optionally, at block **508** a flight path from the start seeding location to the end seeding location is determined (e.g., by seeding module **130**). For example, the flight path can be determined based on optimizing the effectiveness of the cloud seeding. As another example, the flight path can be determined as to avoid potential dangers that might harm the vehicle while performing cloud seeding, e.g. avoiding ice or other dangerous portions in the cloud(s). For example, if a potentially dangerous area is identified, then one or more flight instructions can be generated for avoiding that area. In some examples, the flight path will be updated in real-time based on obtained data, e.g. captured by the sensors on the aircraft and/or obtained by processor and memory **102**.

Optionally, at block **510** the cloud(s) are seeded along the determined flight path (e.g., by seeding device **146**).

At block **512** arrival of the vehicle at an area within a range/proximity of the end location is determined (e.g., by processor and memory **102**). Arrival at the area in proximity of the end location can be determined, for example, based on one or more of: an obtained image of the cloud(s), location data of the vehicle (e.g. obtained by the positioning system **108**), radar data, etc. As an example, the location data of the vehicle can be compared to the determined end location data in order to determine arrival at the designated area to end seeding.

At block **514** cloud seeding is ceased by the vehicle upon arrival at the area within a range/proximity of the end location (e.g., by seeding module **130**). For example, seeding module **130** can de-activate seeding device **146** to stop dispersing the cloud seeding material at the determined end seeding location.

According to some examples, the present subject matter is able to autonomously perform cloud seeding at specific selected areas of the cloud, and to avoid performing cloud seeding on other areas of the cloud. Thus, the present subject matter is able to selectively perform accurate cloud seeding only on the desired portions of the clouds, e.g., those areas that are particularly effective for cloud seeding. For example, the present subject matter can be used to perform cloud seeding only on portions of the cloud within a certain temperature range (e.g., relatively cold temperatures), and avoid cloud seeding on portions of the cloud that are not within that temperature range (e.g., relatively warm temperatures) or that are potentially dangerous to the aircraft (e.g., extremely cold temperatures that would present a danger to the aircraft). In some examples, the system can autonomously monitor environmental conditions and toggle the cloud seeding (start seeding and end seeding) based on detected changes in the environmental conditions. Meaning, there can be multiple start seeding and end seeding locations along a single flight path, even for a single cloud.

Fig. 6 illustrates a flow-chart of a method for automatically controlling an aircraft to perform autonomous cloud seeding in accordance with certain examples of the presently disclosed subject matter.

At block **602** a cloud location is determined (e.g., by seeding module **130**). For example, the cloud location is a location of selected cloud(s) that were selected according to processes described above with reference to **Fig. 3**.

At block **604** one or more flight instructions are generated to direct the vehicle towards the cloud location (e.g., by seeding module **130**). For example, after the flight instruction(s) are generated they can be transmitted to flight control systems **140** which control engine **142** and/or flight control devices **144** accordingly.

At block **606** a distance/proximity to the cloud location is determined (e.g., by seeding module **130**). The determination can be based on one or more of the following, for example: an obtained image of the cloud(s), location data of the vehicle, e.g. obtained by positioning system **108**, air radar data, ground radar data, etc. In some examples, the determination is based on a distance to the cloud, and/or direction of the cloud that is determined based on the cloud image.

Optionally, at block **608** a height of the vehicle relative to one or more clouds at the cloud location is determined (e.g., by seeding module **130**). The determination can be based on one or more of the following, for example: an obtained image of the cloud(s), location data of the vehicle, e.g. obtained by the positioning system **108**, air radar data, ground radar data, etc. For example, the determined height of the vehicle can be used to generate flight instructions, e.g., to help ensure that the aircraft does not get too close to certain areas of the cloud(s) (either from above or below).

At block **610** a decision whether or not the vehicle has reached an area within a range/proximity of the cloud location is made (e.g., by seeding module **130**). This decision can be based on one or more of the following, for example: the obtained cloud location, the determined distance/proximity to the cloud location, the determined height of the vehicle relative to one or more clouds, etc.

If at block **610** the decision is that the vehicle is not in sufficient proximity of the cloud location, then the process returns to block **604**, and further flight instructions, directing the vehicle towards the cloud location, are generated.

If at block **610** the decision is that the vehicle is in a sufficient proximity of the cloud location, then the process continues to block **612**, and the process of seeding the cloud begins.

Optionally, in some example the process returns to block **602** and the system can re-obtain/re-determine the cloud location, for example, in real-time, based on new data received by the system. In other examples, the cloud location can be determined in parallel to directing the vehicle, and the updating of the cloud location at block **602** can be synchronized with the generating of a new flight instruction at block **604**, e.g., after the decision is made at block **610** that the vehicle is not in the proximity of the previously determined cloud location, which was determined in a previous cycle.

For example, the decision at block **610** can be made at predetermined intervals of time.

At block **612** a seeding location is determined (e.g., by seeding module **130**). For example, the determination of the seeding location can be done using processes described above with reference to **Fig. 4**.

At block **614** one or more flight instructions are generated to direct the vehicle towards the cloud location (e.g., by seeding module **130**). For example, after the flight instruction(s) are generated, they can be transmitted to flight control systems **140** which control engine **142** and/or flight control devices **144** accordingly.

At block **616** a distance/proximity to the seeding location is determined (e.g., by seeding module **130**). The determination can be based on one or more of the following, for example: an obtained image of the cloud(s), location data of the vehicle (e.g. obtained by positioning system **108**), air radar data, ground radar data, etc. In some examples, the determination is based on a distance to the cloud and/or direction of the cloud that is determined based on the cloud image.

Optionally, at block **618** a height of the vehicle relative to one or more clouds is determined (e.g., by seeding module **130**). The determination can be based on one or more of the following, for example: an obtained image of the cloud(s), location data of the vehicle (e.g. obtained by positioning system **108**), air radar data, ground radar data, etc. For example, the determined height of the vehicle can be used to generate flight instructions, e.g., to help ensure that the aircraft does not get too close to certain areas of the cloud(s) (either from above or below).

At block **620** a decision whether or not the vehicle has reached an area within a range/proximity of the seeding location is made (e.g., by seeding module **130**). This decision can be based on one or more of the following, for example: the determined seeding location, the determined distance/proximity to the seeding location, the determined height of the vehicle relative to one or more clouds, etc.

If at block **620** the decision is that the vehicle is not in a sufficient proximity of the seeding location, then the process returns to block **614**, and further flight instructions directing the vehicle towards the seeding location are generated.

Optionally, in some examples the process returns to block **612** and the system can re-determine the seeding location, for example, in real-time, based on new data received by the system. In other examples, the seeding location can be determined in parallel to directing the vehicle, and the updating of the seeding location at block **612** can be synchronized with the generating of a new flight instruction at block **614**, e.g., after the decision is made at block **620** that the vehicle is not in the proximity of the previously determined seeding location, which was determined in a previous cycle.

If at block **620** the decision is that the vehicle is in a sufficient proximity of the seeding location, then the process continues to block **622** to begin the seeding of the cloud.

For example, the decision at block **620** can be made at predetermined intervals of time.

At block **622** the cloud is seeded (e.g., by seeding device **146**). For example, seeding instruction(s) are generated (e.g., by seeding module **130**) and transmitted to control seeding device **146** accordingly. For example, one or more seeding instructions/commands can be generated for and instructed/transmitted to seeding device **146** to release/disperse the cloud seeding material into the atmosphere in the vicinity of the seeding location. For example, cloud seeding can be performed from a start seeding location to an end seeding location using processes described above with reference to **Fig. 5**.

In some examples, some or all of the above processes will be repeated or iterated multiple times, for example, in order to direct the aircraft more accurately/optimally towards a particularly effective cloud location, and/or seeding location.

As an example, the processes can be repeated until the aircraft has finished seeding the clouds.

As mentioned above, in some examples, multiple start seeding locations and end seeding locations can be generated. For example, a plurality of start seeding locations and end seeding locations can be generated for one or more clouds.

The above subject matter facilitates optimization of the cloud seeding process, since the cloud seeding is targeted to specific clouds and specific areas of those clouds. As a result, the amount of seeding material that goes to waste is lowered. Furthermore, the location for cloud seeding can be determined and updated in real-time, and an optimized flight path of the vehicle can be determined and updated in real-time accordingly. As such, in some examples the cloud seeding can be tailored depending on the particular cloud(s) to be seeded, e.g. based on a visual characteristic of the cloud(s).

Additionally, as explained above, in some examples of the present subject matter the determination of the seeding location and/or flight path can take into account a plurality of different types of data that are synchronized together, for example, image sensor data (e.g. indicative of the vehicle's line of sight and/or distance to objects), weather/meteorological data, flight data (e.g. the vehicle's speed/velocity and/or height), cloud parameter data (e.g. based on image data and/or radar data), etc. The synchronization of this plurality of different types of data can help ensure that the determination of the seeding location and/or flight path is optimized in terms of efficiency of cloud seeding, and safety of the vehicle.

It is to be understood that the invention is not limited in its application to the details set forth in the description contained herein or illustrated in the drawings. The invention is capable of other examples 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 presently disclosed subject matter.

It will also be understood that the system according to the invention may be, at least partly, implemented on a suitably programmed computer. Likewise, the invention contemplates a computer program being readable by a computer for executing the method of the invention. The invention further contemplates a non-transitory computer-readable memory tangibly embodying a program of instructions executable by the computer for executing the method of the invention.

Those skilled in the art will readily appreciate that various modifications and changes can be applied to the embodiments of the invention as hereinbefore described without departing from its scope, defined in and by the appended claims.

CLAIMS

1. A computer-implemented method of seeding a cloud using an autonomous vehicle, comprising:

using an image sensor that is mounted on the autonomous vehicle for obtaining an image that includes at least a portion of the cloud; and

using a computer for performing the following:

determining a seeding location within the cloud to begin seeding of the cloud based on the image, wherein the determination includes:

image processing identifying a characteristic of the cloud that is indicative of the cloud's suitability for seeding;

predicting a future location of the cloud;

obtaining a desired location for precipitation to occur;

corresponding the predicted future location with the desired location to help determine the seeding location of the cloud; and

generating one or more flight instructions for directing the autonomous vehicle towards the determined seeding location.

2. The method of claim **1**, wherein the characteristic is a visual characteristic.

3. The method of claim **1**, wherein the sensor includes a thermal image sensor which provides thermal image data, and the characteristic includes a thermal characteristic.

4. The method of any one of the preceding claims, wherein the determination is further based on one or more other types of data, including at least one of: radar data, data indicative of an environmental condition relating to the surroundings of the vehicle, position data, line of sight data, meteorological data, satellite picture data, and synoptic chart data.

5. The method of claim **4**, wherein determining includes synchronizing the image data with the other type of data.

6. The method of claim **4**, wherein determining includes superpositioning a first type of data with a second type of data.

7. The method of any one of the preceding claims, wherein the seeding location is located at an area above or underneath the cloud.

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

seeding the cloud at the seeding location.

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

determining a location within the cloud to end seeding; and

determining a flight path for seeding the cloud from the start seeding location to the end seeding location.

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

selecting a cloud for seeding from among a plurality of clouds, based on cloud image data.

11. The method of claim **10**, further comprising:

selecting a cloud from among the plurality of clouds based on one or more other types of data, including at least one of: cloud location data, cloud direction data, cloud precipitation potential data, and predicted future cloud location data.

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

identifying a potential dangerous cloud or portion of a cloud; and

generating one or more flight instructions to avoid that cloud or cloud portion.

13. The method of any one of the preceding claims, wherein the determination is a real-time determination.

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

automatically controlling the vehicle to direct the vehicle to the seeding location to perform cloud seeding.

15. The method of any one of the preceding claims, wherein the vehicle is an unmanned aerial vehicle (UAV).

16. A system mountable on an aircraft for controlling the aircraft to perform seeding of a cloud, comprising:

an image sensor configured to obtain an image that includes at least a portion of the cloud; and

a processor operatively connected to the sensor and configured to:

determine a seeding location within the cloud to begin seeding of the cloud based on the image, wherein the determination includes:

image processing that identifies a characteristic of the cloud that is indicative of the cloud's suitability for seeding;

predicting a future location of the cloud;

obtaining a desired location for precipitation to occur;

corresponding the predicted future location with the desired location to help determine the seeding location of the cloud; and

generate one or more flight instructions to direct the aircraft towards the determined seeding location.

17. The system of claim **16**, wherein the characteristic is a visual characteristic.

18. The system of claim **16**, wherein the sensor is a thermal image sensor which provides thermal image data, and the characteristic includes a thermal characteristic.

19. The system of any one of claims **16** to **18**, wherein the determination is further based on one or more other types of data, including at least one of: radar data, data indicative of an environmental condition relating to the surroundings of the vehicle, position data, line of sight data, meteorological data, satellite picture data, and synoptic chart data.

20. The system of claim 19, wherein the processor is configured to synchronize the image data with the other type of data.

21. The system of claim 19, wherein the processor is configured to superposition a first type of data with a second type of data.

22. The system of any one of claims **16** to **21**, wherein the seeding location is located at an area above or underneath the cloud.

23. The system of any one of claims 16 to 22, further comprising a seeding device configured to seed the cloud at the seeding location.

24. The system of any one of claims **16** to **23**, wherein the processor is configured to:

determine a location within the cloud to end seeding; and

determine a flight path for seeding the cloud from the start seeding location to the end seeding location.

25. The system of any one of claims **16** to **25**, wherein the processor is configured to:

select a cloud for seeding from among a plurality of clouds, based on cloud image data.

26. The system of claim **25**, wherein the processor is configured to:

select a cloud from among the plurality of clouds based on one or more other types of data, including at least one of: cloud location data, cloud direction data, cloud precipitation potential data, and predicted future cloud location data.

27. The system of any one of claims **16** to **26**, wherein the processor is configured to:

identify a potential dangerous cloud or portion of a cloud; and

generate one or more flight instructions to avoid that cloud or cloud portion.

28. The system of any one of claims **16** to **28**, wherein the determination is a real-time determination.

29. The system of any one of claims **16** to **28**, wherein the processor is configured to:

automatically control the vehicle to direct the vehicle to the seeding location to perform cloud seeding.

30. The system of any one of claims **16** to **29**, wherein the vehicle is an unmanned aerial vehicle (UAV).

31. The system of any one of claims **16** to **30**, further comprising an antenna mounted on the vehicle and configured to receive data.

32. The system of any one of claims **16** to **28**, further comprising an anti-ice system mounted on the vehicle and configured to protect the vehicle in cold weather conditions.

33. A non-transitory program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform a method of seeding a cloud using an autonomous vehicle, comprising:

using a processor for performing the following:

obtaining an image that includes at least a portion of the cloud;

determining a seeding location within the cloud to begin seeding of the cloud based on the image, wherein the determination includes:

image processing identifying a characteristic of the cloud that is indicative of the cloud's suitability for seeding;

predicting a future location of the cloud;

obtaining a desired location for precipitation to occur;

corresponding the predicted future location with the desired location to help determine the seeding location of the cloud; and

generating one or more flight instructions for directing the autonomous vehicle towards the determined seeding location.

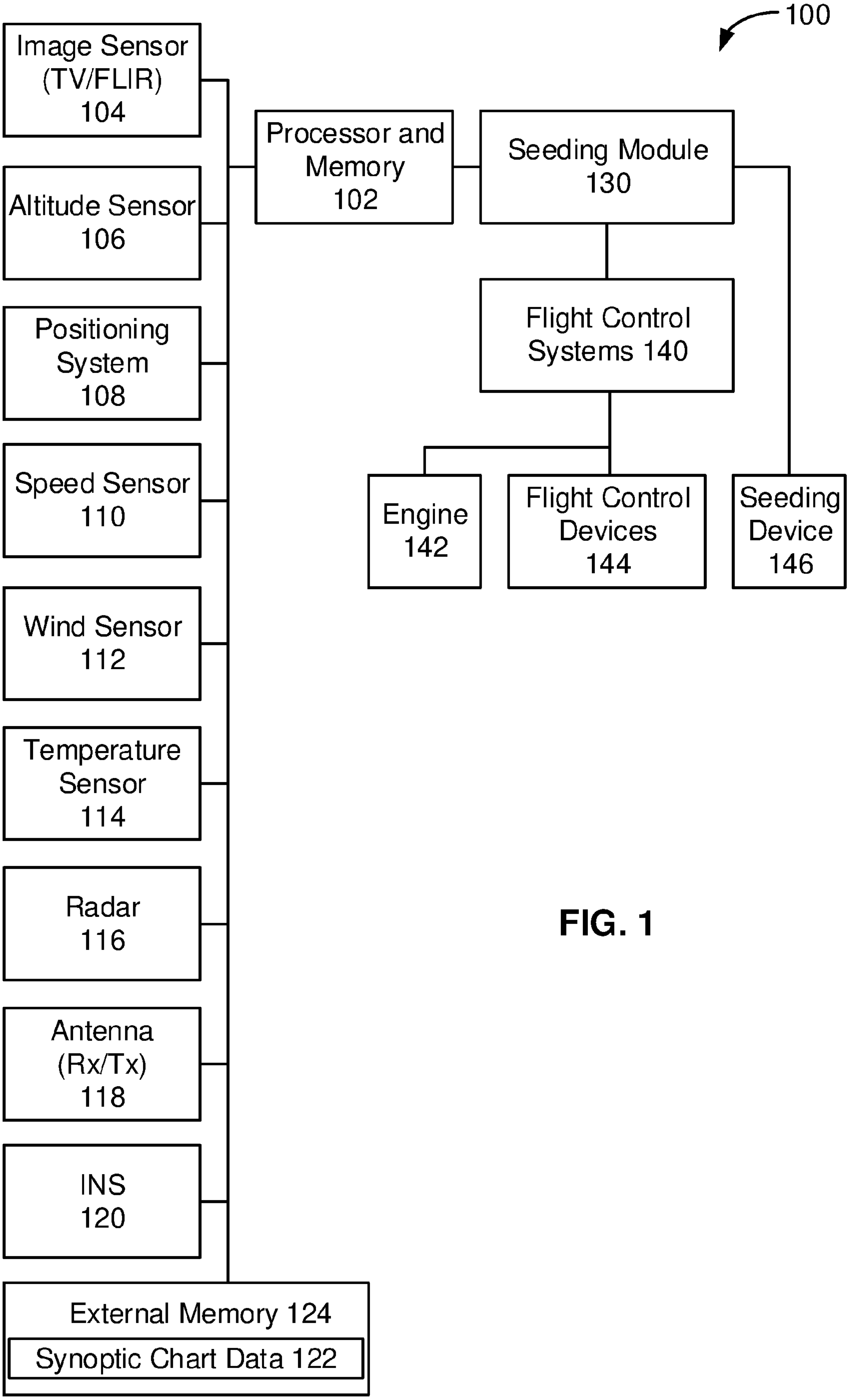
100
Image Sensor (TV/FLIR) 104
Altitude Sensor 106
Positioning System 108
Speed Sensor 110
Wind Sensor 112
Temperature Sensor 114
Radar 116
Antenna (Rx/Tx) 118
INS 120
External Memory 124
Synoptic Chart Data 122
Processor and Memory 102
Seeding Module 130
Flight Control Systems 140
Engine 142
Flight Control Devices 144
Seeding Device 146

FIG. 1

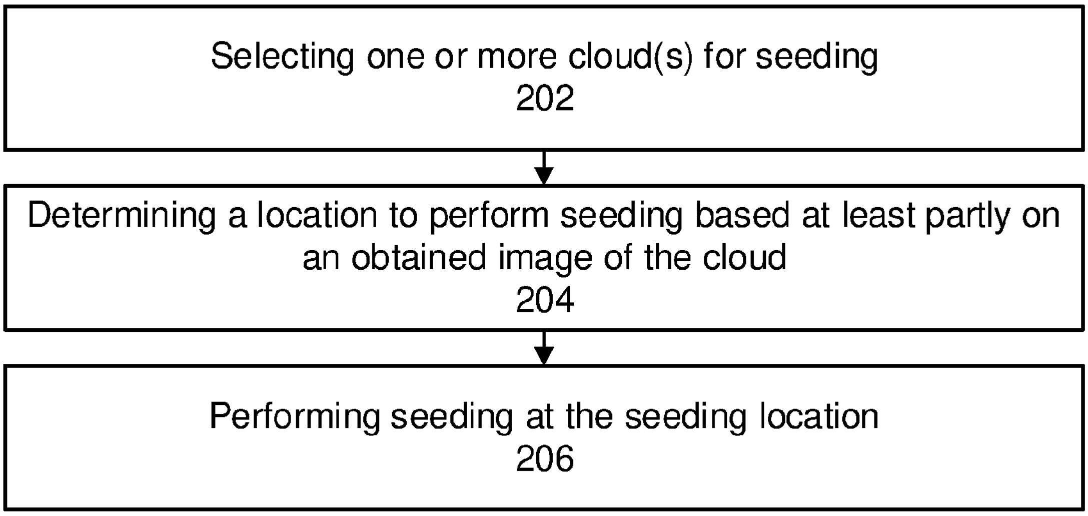
Selecting one or more cloud(s) for seeding
202
Determining a location to perform seeding based at least partly on an obtained image of the cloud
204
Performing seeding at the seeding location
206

FIG. 2

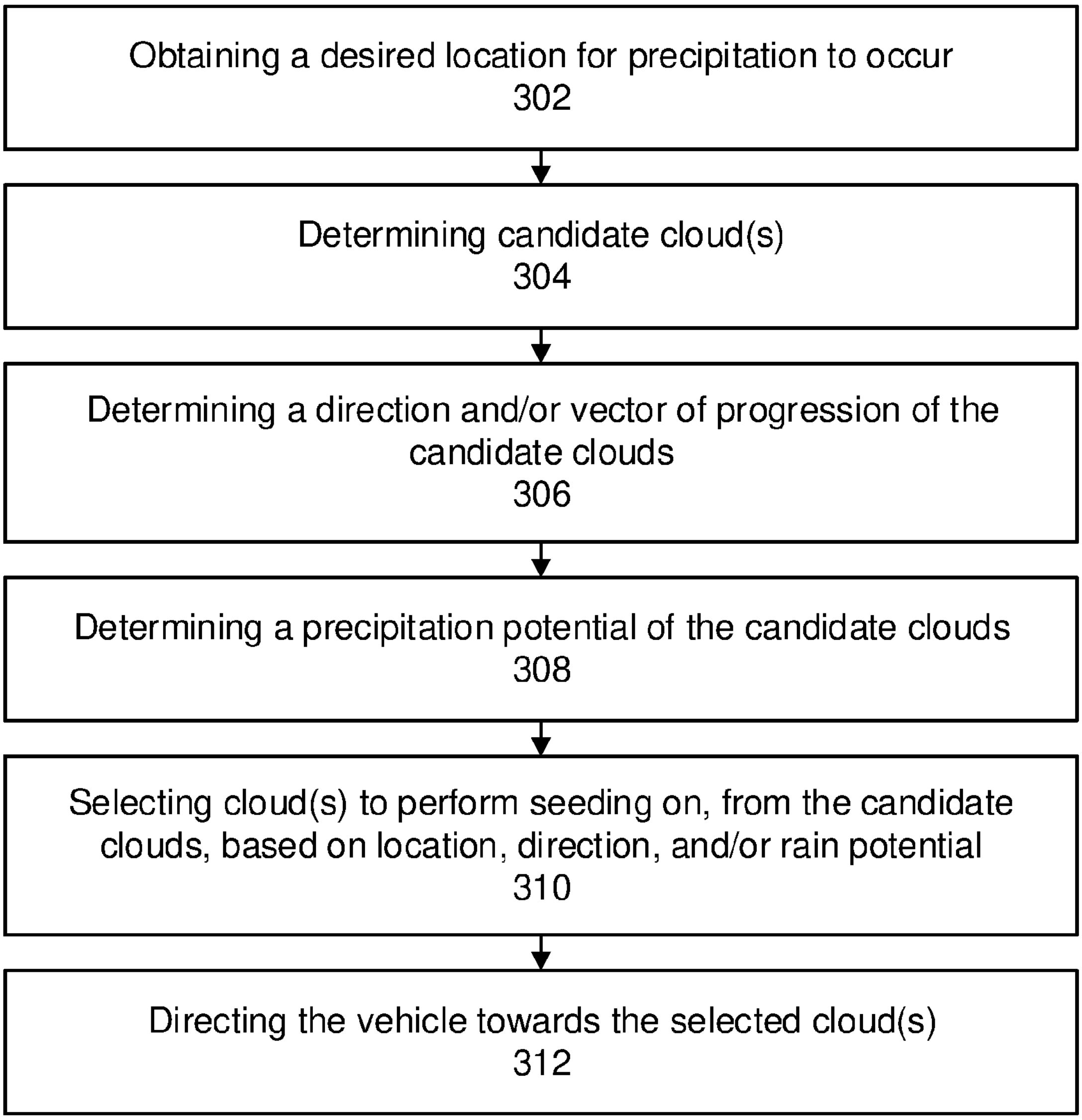
Obtaining a desired location for precipitation to occur
302
Determining candidate cloud(s)
304
Determining a direction and/or vector of progression of the candidate clouds
306
Determining a precipitation potential of the candidate clouds
308
Selecting cloud(s) to perform seeding on, from the candidate clouds, based on location, direction, and/or rain potential
310
Directing the vehicle towards the selected cloud(s)
312

FIG. 3

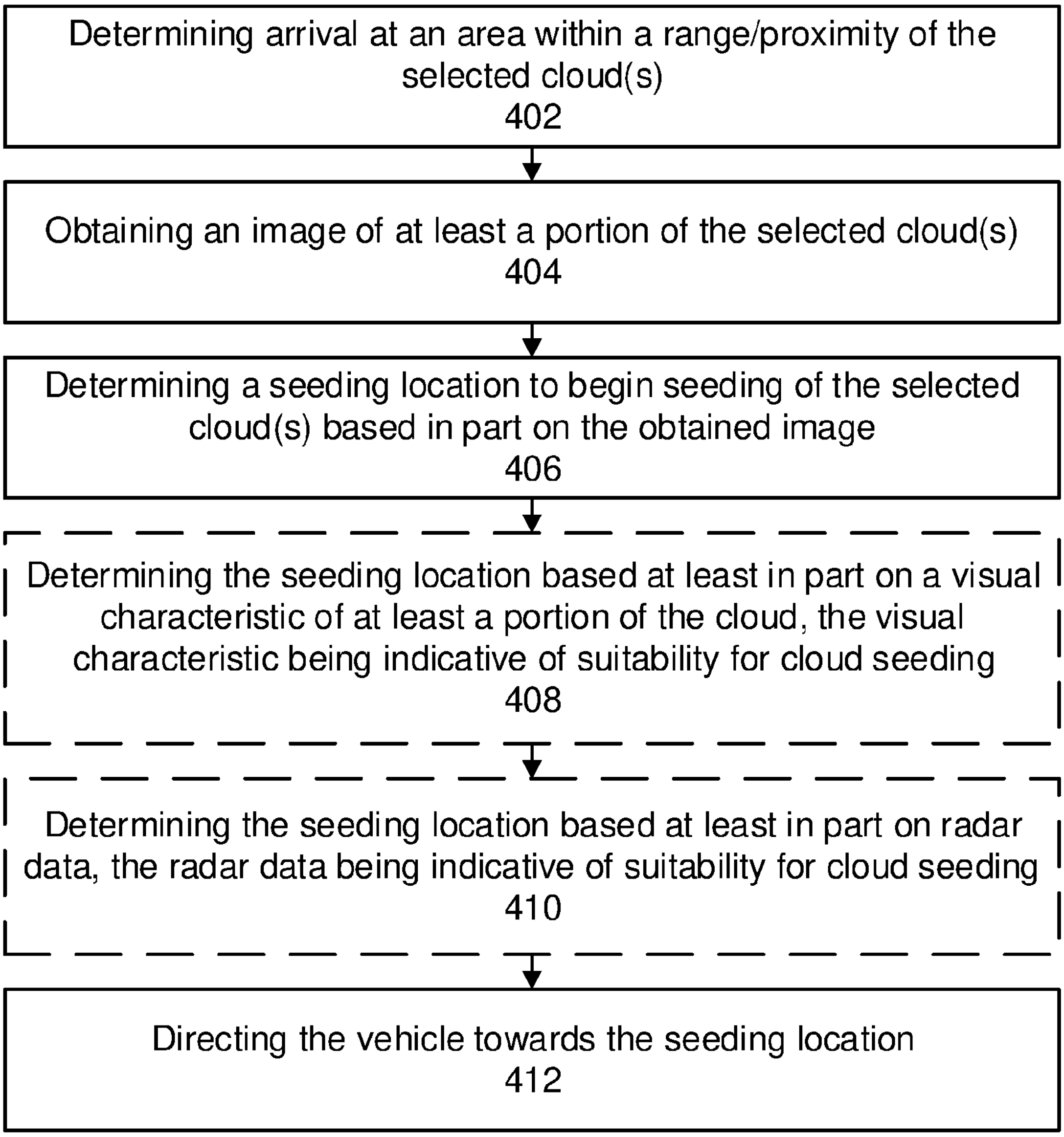
Determining arrival at an area within a range/proximity of the selected cloud(s)
402
Obtaining an image of at least a portion of the selected cloud(s)
404
Determining a seeding location to begin seeding of the selected cloud(s) based in part on the obtained image
406
Determining the seeding location based at least in part on a visual characteristic of at least a portion of the cloud, the visual characteristic being indicative of suitability for cloud seeding
408
Determining the seeding location based at least in part on radar data, the radar data being indicative of suitability for cloud seeding
410
Directing the vehicle towards the seeding location
412

FIG. 4

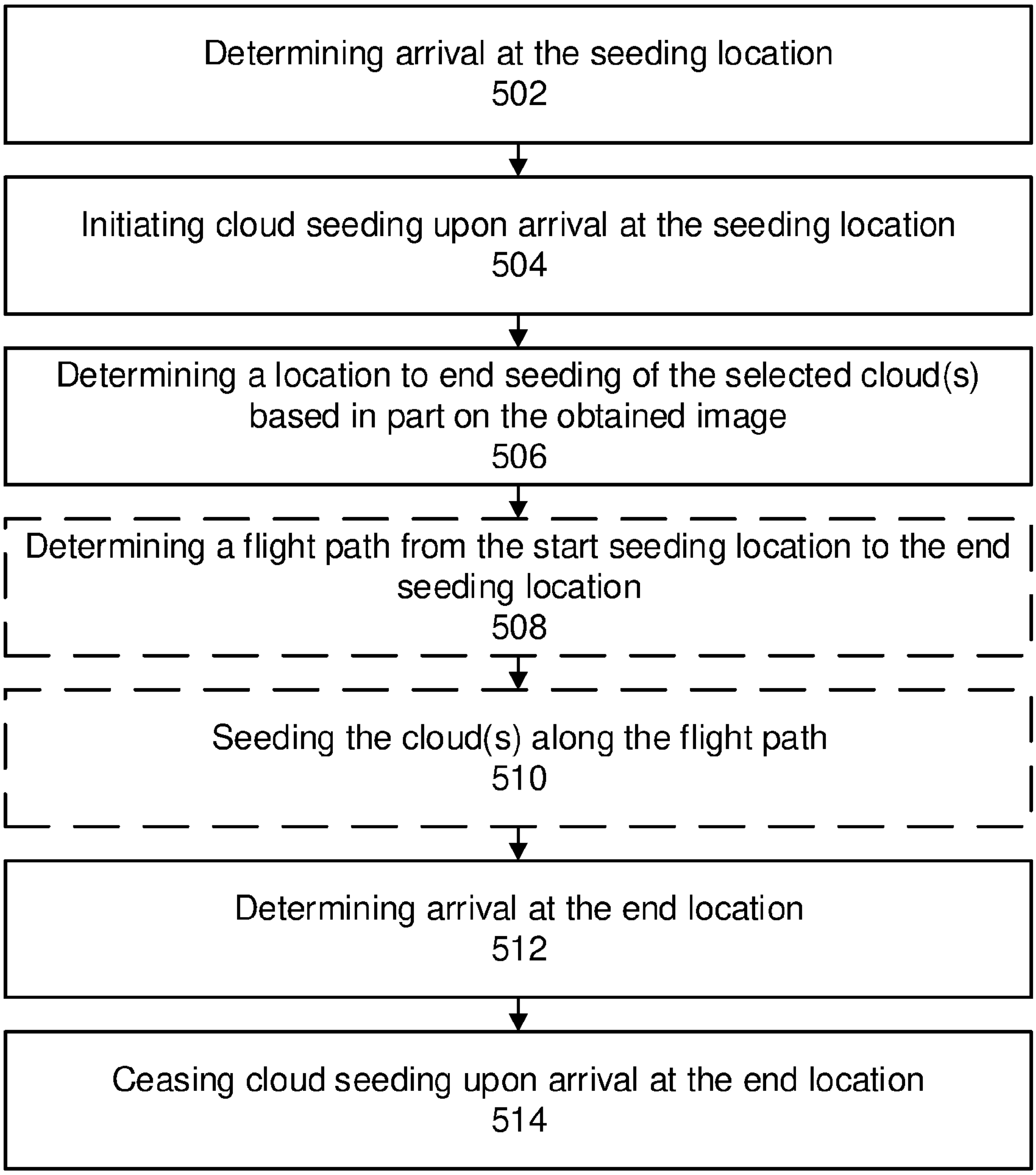
Determining arrival at the seeding location
502
Initiating cloud seeding upon arrival at the seeding location
504
Determining a location to end seeding of the selected cloud(s) based in part on the obtained image
506
Determining a flight path from the start seeding location to the end seeding location
508
Seeding the cloud(s) along the flight path
510
Determining arrival at the end location
512
Ceasing cloud seeding upon arrival at the end location
514

FIG. 5

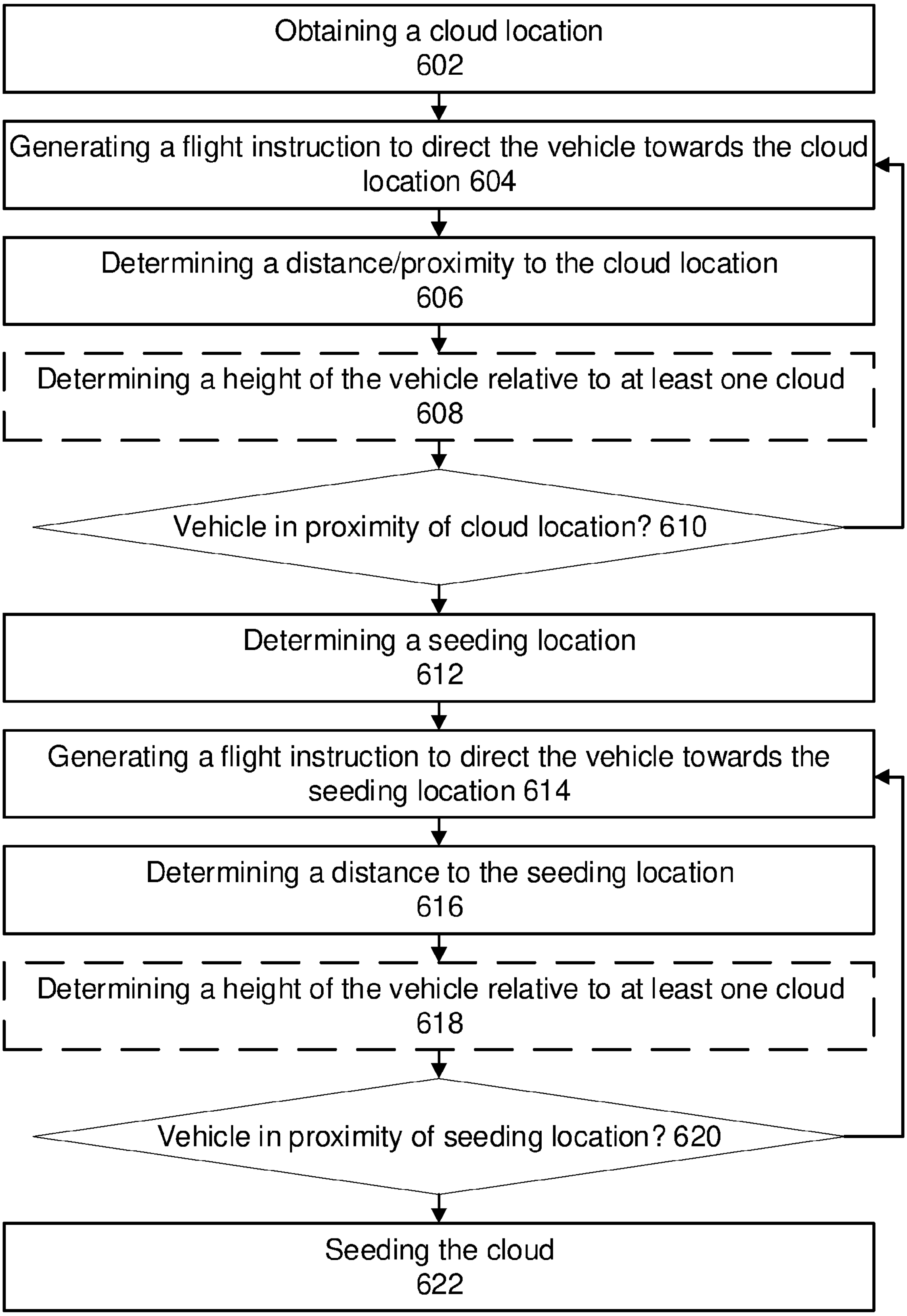
Obtaining a cloud location
602
Generating a flight instruction to direct the vehicle towards the cloud location 604
Determining a distance/proximity to the cloud location
606
Determining a height of the vehicle relative to at least one cloud
608
Vehicle in proximity of cloud location? 610
Determining a seeding location
612
Generating a flight instruction to direct the vehicle towards the seeding location 614
Determining a distance to the seeding location
616
Determining a height of the vehicle relative to at least one cloud
618
Vehicle in proximity of seeding location? 620
Seeding the cloud
622

FIG. 6

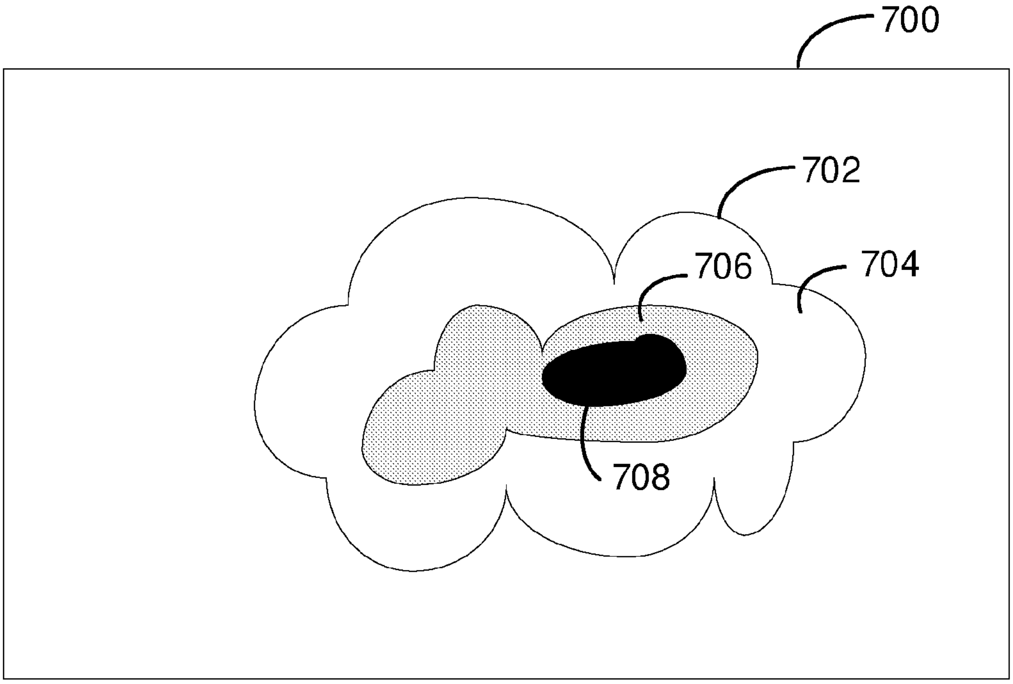

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2019/051347

A. CLASSIFICATION OF SUBJECT MATTER
IPC (20200101) G01W 1/00, G05D 1/00, G08G 5/00
CPC (20130101) G01W 1/00, B64C 2201/00, G05D 1/0088, G05D 1/0094, G08G 5/0091
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) G01W 1/00, G05D 1/00, G08G 5/00
CPC (20130101) G01W 1/00, B64C 2201/00, G05D 1/0088, G05D 1/0094, G08G 5/0091

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: Google Patents, Orbit

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016299254 A1 MART?NEZ DE LA ESCALERA LORENZO MARTINEZ?[MX] 13 Oct 2016 (2016/10/13) The whole document	1-33
Y	US 2018292826 A1 DEFELICE THOMAS PETER?[US] 11 Oct 2018 (2018/10/11) The whole document	1-33

☐ 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
15 Jan 2020	20 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	LESHINSKY Miriam Josepha Telephone No. 972-73-3927184

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2019/051347

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
US 2016299254 A1	13 Oct 2016	US 2016299254 A1	13 Oct 2016
		US 9715039 B2	25 Jul 2017
US 2018292826 A1	11 Oct 2018	US 2018292826 A1	11 Oct 2018
		WO 2018191134 A1	18 Oct 2018

Form PCT/ISA/210 (patent family annex) (revised January 2019)