United States Patent Application Publication	20250252856
Kind Code	A1
Publication Date	August 07, 2025
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NAVIGATION SYSTEMS AND METHODS FOR OPERATION

Abstract

A navigation system for an aircraft includes a light source, a light sensor, one or more processors, and a computer readable medium storing instructions that, when executed by the one or more processors, cause the navigation system to perform functions. The functions include illuminating a surface using the light source to cause light to be reflected from the surface and detecting the light and generating data representing the light using the light sensor. The data maps intensities of the light to respective positions on the surface. The functions further include identifying within the data a subset of the data that corresponds to a border and causing navigation of the aircraft based on a position of the border indicated by the subset of the data.

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Family ID: **77626924**

Appl. No.: **19/087837**

Filed: **March 24, 2025**

Related U.S. Application Data

parent US continuation 17360828 20210628 parent-grant-document US 12307910 child US 19087837
us-provisional-application US 63068132 20200820

Publication Classification

Int. Cl.: **G08G5/50** (20250101); **B64D47/02** (20060101); **G01S17/88** (20060101); **G01S17/89** (20200101); **G05D1/437** (20240101); **G08G5/54** (20250101); **G08G5/55** (20250101)

U.S. Cl.:

CPC **G08G5/50** (20250101); **B64D47/02** (20130101); **G05D1/437** (20240101); **G05D1/439** (20240101); **G08G5/54** (20250101); **G08G5/55** (20250101); G01S17/88 (20130101); G01S17/89 (20130101)

Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 17/360,828, filed Jun. 28, 2021, which claims priority to U.S. Provisional Application No. 63/068, 132, filed on Aug. 20, 2020, the contents of which are hereby incorporated by reference in their entireties.

FIELD
[0002] The present disclosure generally relates to navigation systems and methods for operating them, and more specifically to aircraft navigation systems and methods for operating them.
BACKGROUND
[0003] Autonomous aerial vehicles generally include some kind of autonomous navigation system to maneuver in the air or on the ground (e.g., during taxiing). Some conventional autonomous navigation techniques include using visible light cameras to capture successive images of a runway or another surface that the aircraft is taxiing on and analyzing each pixel of those images to identify runways or taxiways within those images. This can be very time intensive and computationally demanding. Additionally, such techniques can be less reliable in inclement weather such as rain or snow or in low light conditions. As such, a need exists for more efficient and environmentally resistant systems and methods for autonomous navigation of an aircraft on a ground surface.
SUMMARY
[0004] One aspect of the disclosure is a navigation system for an aircraft comprising: a light source; a light sensor; one or more processors; and a computer readable medium storing instructions that, when executed by the one or more processors, cause the navigation system to perform functions comprising: illuminating a surface using the light source to cause light to be reflected from the surface; detecting the light and generating data representing the light using the light sensor, wherein the data maps intensities of the light to respective positions on the surface; identifying within the data a subset of the data that corresponds to a border; and causing navigation of the aircraft based on a position of the border indicated by the subset of the data.
[0005] Another aspect of the disclosure is a non-transitory computer readable medium storing instructions that, when executed by a navigation system of an aircraft, cause the navigation system to perform functions comprising: illuminating a surface to cause light to be reflected from the surface; detecting the light and generating data representing the light, wherein the data maps intensities of the light to respective positions on the surface; identifying within the data a subset of the data that corresponds to a border; and causing navigation of the aircraft based on a position of the border indicated by the subset of the data.
[0006] Another aspect of the disclosure is a method of operating a navigation system of an aircraft, the method comprising: illuminating a surface to cause light to be reflected from the surface; detecting the light and generating data representing the light, wherein the data maps intensities of the light to respective positions on the surface; identifying within the data a subset of the data that corresponds to a border; and causing navigation of the aircraft based on a position of the border indicated by the subset of the data.
[0007] By the term “about” or “substantially” with reference to amounts or measurement values described herein, it is meant that the recited characteristic, parameter, or value need not be achieved

exactly, but that deviations or variations, including for example, tolerances, measurement error, measurement accuracy limitations and other factors known to those of skill in the art, may occur in amounts that do not preclude the effect the characteristic was intended to provide.
[0008] The features, functions, and advantages that have been discussed can be achieved independently in various examples or may be combined in yet other examples further details of which can be seen with reference to the following description and drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0009] The novel features believed characteristic of the illustrative examples are set forth in the appended claims. The illustrative examples, however, as well as a preferred mode of use, further objectives and descriptions thereof, will best be understood by reference to the following detailed description of an illustrative example of the present disclosure when read in conjunction with the accompanying Figures.
[0010] FIG. **1** is a schematic diagram of an aircraft, according to an example.
[0011] FIG. **2** is a schematic block diagram of an aircraft, according to an example.
[0012] FIG. **3** is a schematic block diagram of a computing system, according to an example.
[0013] FIG. **4** is a schematic diagram of an aircraft positioned on a surface, according to an example.
[0014] FIG. **5**A is a schematic diagram of data corresponding to a surface, according to an example.
[0015] FIG. **5**B is a schematic diagram of data corresponding to a surface, according to an example.
[0016] FIG. **6** is a schematic diagram of data corresponding to a surface, according to an example.
[0017] FIG. **7**A is a schematic diagram of data corresponding to a surface, according to an example.
[0018] FIG. **7**B is a schematic diagram of data corresponding to a surface, according to an example.
[0019] FIG. **8** is a block diagram of a method, according to an example.
[0020] FIG. **9** is a block diagram of a method, according to an example.
[0021] FIG. **10** is a block diagram of a method, according to an example.
[0022] FIG. **11** is a block diagram of a method, according to an example.
[0023] FIG. **12** is a block diagram of a method, according to an example.
[0024] FIG. **13** is a block diagram of a method, according to an example.
DETAILED DESCRIPTION
[0025] As discussed above, a need exists for more efficient and environmentally resilient systems and methods for autonomous navigation of an aircraft on a surface (e.g., a ground surface). Within examples, a navigation system for an aircraft includes a light source, a light sensor, one or more processors, and a computer readable medium storing instructions that, when executed by the one or more processors, cause the navigation system to perform functions. The functions include illuminating a surface using the light source to cause light to be reflected from the surface and detecting the light and generating data representing the light using the light sensor. The data maps intensities of the light to respective positions on the surface. The functions further include identifying within the data a subset of the data that corresponds to a border between roadway and non-roadway, such as a runway border, and causing navigation of the aircraft based on a position of the border indicated by the subset of the data.
[0026] The functionality of the aforementioned navigation system can yield better response time and more efficient use of computational resources when compared to conventional navigation

systems, as explained in more detail below. Additionally, the disclosed navigation system can help improve performance in low light conditions and in inclement weather.

[0027] Disclosed examples will now be described more fully hereinafter with reference to the accompanying Drawings, in which some, but not all of the disclosed examples are shown. Indeed, several different examples may be described and should not be construed as limited to the examples set forth herein. Rather, these examples are described so that this disclosure will be thorough and complete and will fully convey the scope of the disclosure to those skilled in the art.

[0028] FIGS. **1-7**B are schematic diagrams of a navigation system and related functionality.

[0029] FIG. **1** is an example schematic view of an aircraft **10**, according to an example. The aircraft **10** may be or include a fixed wing aircraft, a helicopter, a rotorcraft, an unmanned aerial vehicle (e.g., a drone or a satellite), a spacecraft, and the like. The aircraft **10** includes a navigation system **100**, which further includes a computing system **150** that is described in more detail below.

[0030] FIG. **2** is a schematic block diagram of the aircraft **10**. The navigation system **100** includes a light source **102** (e.g., one or more lasers) and a light sensor **104** (e.g., one or more photodetectors or photosensors). The light source **102** and the light sensor **104** are operationally in communication with other components of the navigation system **100** and are generally part of a light detection and ranging system (e.g., LIDAR). The light source **102** and/or the light sensor **104** can be forward facing or rearward facing with respect to the aircraft **10**, but other examples are possible.

[0031] The navigation system **100** also includes control surfaces **182** and landing gear **184**. The control surfaces **182** can include flaps, rudders, and ailerons, for example. The landing gear **184** includes one or more wheels that are motorized and can propel the aircraft **10** during ground travel, such as taxiing.

[0032] The navigation system **100** also includes an inertial navigation system **190** which can create data **192**. The inertial navigation system **190** can include one or more accelerometers and/or gyroscopes.

[0033] FIG. **3** is a schematic block diagram of the computing system **150**.

[0034] The computing system **150** includes one or more processors **152**, a non-transitory computer readable medium **154**, a communication interface **156**, a display **158**, and a user interface **160**. Components of the computing system **150** illustrated in FIG. **3** are linked together by a system bus, network, or other connection mechanism **162**.

[0035] The one or more processors **152** can be any type of processor(s), such as a microprocessor, a digital signal processor, a multicore processor, etc., coupled to the non-transitory computer readable medium **154**.

[0036] The non-transitory computer readable medium **154** can be any type of memory, such as volatile memory like random access memory (RAM), dynamic random access memory (DRAM), static random access memory (SRAM), or non-volatile memory like read-only memory (ROM), flash memory, magnetic or optical disks, or compact-disc read-only memory (CD-ROM), among other devices used to store data or programs on a temporary or permanent basis.

[0037] Additionally, the non-transitory computer readable medium **154** can be configured to store instructions **157**. The instructions **157** are executable by the one or more processors **152** to cause the computing system **150** to perform any of the functions or methods described herein.

[0038] The non-transitory computer readable medium **154** also stores data **206**. The data **206** includes a subset **210**, a subset **216**, and a subset **222** of the data **206**, as described in more detail below.

[0039] The communication interface **156** can include hardware to enable communication within the computing system **150** and/or between the computing system **150** and one or more other devices. The hardware can include transmitters, receivers, and antennas, for example. The communication interface **156** can be configured to facilitate communication with one or more other devices, in accordance with one or more wired or wireless communication protocols. For example, the communication interface **156** can be configured to facilitate wireless data communication for the computing system **150** according to one or more wireless communication standards, such as one or more Institute of Electrical and Electronics Engineers (IEEE) 801.11 standards, ZigBee standards, Bluetooth standards, etc. As another example, the communication interface **156** can be configured to facilitate wired data communication with one or more other devices.

[0040] The display **158** can be any type of display component configured to display data. As one example, the display **158** can include a touchscreen display. As another example, the display **158** can include a flat-panel display, such as a liquid-crystal display (LCD) or a light-emitting diode (LED) display.

[0041] The user interface **160** can include one or more pieces of hardware used to provide data and control signals to the computing system **150**. For instance, the user interface **160** can include a mouse or a pointing device, a keyboard or a keypad, a microphone, a touchpad, or a touchscreen, among other possible types of user input devices. Generally, the user interface **160** can enable an operator to interact with a graphical user interface (GUI) provided by the computing system **150** (e.g., displayed by the display **158**).

[0042] FIG. **4** is a schematic diagram of the aircraft **10** positioned on a surface **202**. A horizon **213** is pictured for clarity. The surface **202** can include combinations of many different types of surfaces such as runways, taxiways, or unpaved ground such as dirt or grass. The unpaved ground can help define borders of the runways or taxiways in that the unpaved ground is not considered part of the generally paved runways or taxiways.

[0043] The light source **102** of the aircraft **10** is used to illuminate the surface **202** with a light **203** (e.g., a laser light) to cause a light **204** to be reflected from the surface **202**. The light sensor **104** detects the light **204** that reflects from the surface **202**. Generally, paved surfaces such as runways or taxiways return the light **204** with greater intensity than unpaved surfaces such as grass or dirt. Additionally, paved surfaces such as runways or taxiways will generally have a distinctive three-dimensional shape when compared to other surfaces.

[0044] It should be noted that the terms runway and taxiway are used somewhat interchangeably herein. However, the term runway generally refers to a long and straight section of a (e.g., paved) surface that is used for takeoff and/or landing. The term taxiway generally refers to a paved surface used by a taxiing aircraft to get from a hangar to a runway and vice versa.

[0045] The light sensor **104** generates the data **206** representing the light **204**. The data **206** maps intensities of the light **204** to respective positions on the surface **202**. For example, the data **206** includes a table that maps intensity values of the light **204** to respective sets of three-dimensional Cartesian or spherical coordinates.

[0046] FIG. **5**A is a schematic diagram of the data **206** corresponding to the surface **202**. The navigation system **100** identifies within the data **206** a subset **210** of the data **206** that corresponds to a border **212**. The border **212** generally separates a second region **260** of paved surface on a first side of the border **212** from a first region **262** of unpaved surface on a second side of the border **212**. In FIG. **5**A, the border **212** is a line, but a border can be a curved border that corresponds to an intersection or to a curved section of a runway or a taxiway as well. The border **212** can take on any shape and generally is any boundary that separates a runway or a taxiway from an unpaved surface. The subset **210** of the data **206** can be identified using statistical techniques as described below.

[0047] In other examples, a runway surface could be dirt or gravel and the non-runway surface could be grass. In yet other examples, runway surfaces can be distinguished from non-runway surfaces by their differing (e.g., painted) colors and resulting return intensity of the light **204**. In yet further examples, the non-runway surface can be paved as well. Generally, a runway surface can be distinguished from a non-runway surface because the light **204** returning from the runway surface will be different in intensity from the light **204** returning from the non-runway surface.

[0048] The navigation system **100** (e.g., randomly) selects an arbitrary data point **244** and an arbitrary data point **246** of the data **206** and determines parameters of a curve **248** (e.g., a line) that includes the arbitrary data point **244** and arbitrary data point **246**. The parameters could take the form of a, b, and c in the equation z=ax+by+c, for example. In other examples, the curve **248** could be an arc of a circle, an arc of an ellipse, a parabola, a hyperbola, etc. Next, the navigation system **100** determines that less than a threshold amount of data points of the data **206** conform to the curve **248** within a margin of error. For example, the navigation system **100** could determine that less than ten data points of the data **206** conform to the curve **248** because less than ten residuals of the data **206** with respect to the curve **248** are less than a threshold amount. This process of searching for a curve fit for much of the data **206** can repeat until the navigation system **100** does find a curve that fits at least the threshold amount of data points of the data **206**.

[0049] For example, the navigation system **100** (e.g, randomly) selects an arbitrary data point **236** and an arbitrary data point **238** of the data **206** and determines parameters of a curve (e.g., the border **212**) that includes the arbitrary data point **236** and the arbitrary data point **238**. Next, the navigation system **100** determines that each data point of the subset **210** of the data **206** conforms to the curve (e.g., the border **212**) within a margin of error and that the subset **210** of the data **206** includes at least a threshold amount of data points. That is, the navigation system **100** could determine that the subset **210** includes at least ten data points of the data **206**, for example.

[0050] To additionally confirm a good fit to the curve, the navigation system **100** can determine that the subset **210** of the data **206** includes at least a threshold amount of data points per unit distance along the curve (e.g., the border **212**). The threshold amount of data points here could be ten data points per meter along the border **212**, for example.

[0051] To add additional confidence that the border **212** is, in fact, a border, the navigation system **100** can determine that the subset **210** of the data **206** has an average intensity of the light **204** that is greater than a threshold intensity that typically corresponds to a paved surface.

[0052] In some examples, the navigation system **100** determines parameters of a line that corresponds to the border **212** and determines that the region **262** of the surface **202** on one side of the line has an average intensity that is less than a first threshold intensity. Additionally, the navigation system **100** determines that the region **260** of the surface **202** on another side of the line has an average intensity that is greater than a second threshold intensity. In this way, the navigation system **100** can confirm that the border **212** in fact separates a paved region from an unpaved region, or more generally a runway region from a non-runway region.

[0053] In some examples, the navigation system **100** also identifies a subset **278** of the data **206** that does not correspond to a border and deletes, filters, or ignores the subset **278** of the data **206** so that it is not further processed.

[0054] Additionally, the navigation system **100** causes navigation of the aircraft **10** (e.g., during taxiing) based on a position of the border **212** indicated by the subset **210** of the data **206**. For example, the navigation system **100** adjusts the control surfaces **182** and/or the landing gear **184** based on the position of the border **212** indicated by the subset **210** of the data **206**. In one example, the aircraft **10** is controlled to maintain a minimum distance from the border **212**. Navigation can also be aided by the data **192** collected by the inertial navigation system **190** of the aircraft **10**.

[0055] The navigation system **100** can also identify a subset **216** of the data **206** that corresponds to a border **218**. In such examples, the navigation system **100** can cause navigation of the aircraft **10** additionally based on a position of the border **218** indicated by the subset **216** of the data **206**. For example, the aircraft **10** could be controlled to stay substantially centered between the border **212** and the border **218**. As shown in FIG. **5**A, the border **218** is substantially parallel to the border **212**. Additionally, the border **212** could be on a first side of the aircraft **10** and the border **218** could be on a second side of the aircraft **10** that is opposite the first side.

[0056] FIG. **5**B is a schematic diagram of a portion of the data **206** corresponding to the surface **202**, with a more forward-looking perspective than FIG. **5**A. FIG. **5**B also includes a pictorial representation of an example runway, for the purpose of clarity.

[0057] FIG. **6** is a schematic diagram of the data **206** shown corresponding to the surface **202**. In this example, a border **224** intersects both the border **212** and the border **218** to form a dead end. As such, the navigation system **100** identifies a subset **222** of the data **206** that corresponds to the border **224** that intersects the border **212** and the border **218**. In this context, the navigation system **100** causes navigation of the aircraft **10** additionally based on a position of the border **224** indicated by the subset **222** of the data **206**. For example, upon encountering the dead end, the aircraft **10** is controlled to turn around or stop.

[0058] FIG. **7**A is a schematic diagram of the data **206** shown mapped onto the surface **202**. In this example, the border **212** intersects the border **218** to form a 90 degree corner at an intersection. Other examples include the border **212** forming a rounded corner with the border **218**.

[0059] As such, the navigation system **100** determines an angle **230** at which the border **212** intersects the border **218** and a position of the angle **230**. In this context, the navigation system **100** can cause navigation of the aircraft **10** additionally based on the angle (e.g., the value of the angle) and the position of the angle. That is, the aircraft **10** could make a 90 degree right turn after passing the border **218**. In another example, the angle **230** could be 45 degrees and the aircraft **10** could make a 45 degree right turn at the angle **230**.

[0060] FIG. **7**B is a schematic diagram of the data **206** in an example in which runway surfaces form a four-way intersection. The navigation system **100** additionally determines that a subset **210**B of the data **206** represents a border **212**B, determines that a subset **216**B of the data **206** represents a border **218**B, and determines an angle **230**B at which the border **212**B intersects the border **218**B and a position of the angle **230**B. The navigation system **100** additionally determines that a subset **210**C of the data **206** represents a border **212**C, determines that a subset **216**C of the data **206** represents a border **218**C, and determines an angle **230**C at which the border **212**C intersects the border **218**C and a position of the angle **230**C. The navigation system **100** additionally determines that a subset **210**D of the data **206** represents a border **212**D, determines that a subset **216**D of the data **206** represents a border **218**D, and determines an angle **230**D at which the border **212**D intersects the border **218**D and a position of the angle **230**D.

[0061] In this context, the navigation system **100** can cause navigation of the aircraft **10** additionally based on the angles **230**, **230**B, **230**C, and/or **230**D (e.g., the value of the angles) and the position of the angles **230**, **230**B, **230**C, and/or **230**D. That is, the aircraft **10** could make a 90 degree right turn after passing the border **218**, upon recognizing the four-way intersection.

[0062] In some embodiments, the navigation system **100** could look for a particular shape of intersection before executing a turn. For example, the aircraft **10** could be instructed to ignore a 45 degree turn that is encountered first and make a 90 degree right turn at the angle **230** thereafter in response to recognizing the 90 degree intersection of the border **212** and the border **218**.

[0063] FIGS. **8-13** are block diagrams of methods **300**, **310**, **314**, **318**, **322**, and **326** for operating a navigation system of an aircraft. The methods **300**, **310**, **314**, **318**, **322**, and **326** present examples of methods that could be used with the navigation system **100** as shown in FIGS. **1-7**. As shown in FIGS. **8-13**, the methods **300**, **310**, **314**, **318**, **322**, and **326** include one or more operations, functions, or actions as illustrated by blocks **302**, **304**, **306**, **308**, **312**, **316**, **320**, **324**, **328**, and **330**. Although the blocks are illustrated in a sequential order, these blocks may also be performed in parallel, and/or in a different order than those described herein. Also, the various blocks may be combined into fewer blocks, divided into additional blocks, and/or removed based upon the desired implementation.

[0064] FIG. **8** is a block diagram of the method **300**.

[0065] At block **302**, the method **300** includes illuminating the surface **202** to cause the light **204** to be reflected from the surface **202**. For example, the light source **102** is used to illuminate the surface **202** with a light **203** (e.g., a laser light) to cause the light **204** to be reflected from the surface **202**. This functionality is described in more detail with reference to FIG. **4** above.

[0066] At block **304**, the method **300** includes detecting the light **204** and generating the data **206** representing the light **204**. The data **206** maps intensities of the light **204** to respective positions

208 on the surface **202**. For example, the light sensor **104** detects the light **204** that reflects from the surface **202** and generates the data **206** representing the light **204**. The data **206** maps intensities of the light **204** to respective positions on the surface **202**. For example, the data **206** includes a table that maps intensity values of the light **204** to respective sets of three-dimensional Cartesian or spherical coordinates. This functionality is described in more detail with reference to FIG. **4**, FIG. **5**A, and FIG. **5**B above.

[0067] At block **306**, the method **300** includes identifying within the data **206** the subset **210** of the data **206** that corresponds to the border **212**. For example, the navigation system **100** identifies within the data **206** the subset **210** of the data **206**. This functionality is described in more detail with reference to FIG. **5**A and FIG. **5**B above.

[0068] At block **308**, the method **300** includes causing navigation of the aircraft **10** based on a position of the border **212** indicated by the subset **210** of the data **206**. For example, the navigation system **100** causes navigation of the aircraft **10** based on the position of the border **212**. This functionality is described in more detail with reference to FIGS. **5-7** above. FIG. **9** is a block diagram of the method **310**.

[0069] At block **312**, the method **310** includes identifying the second subset **216** of the data **206** that corresponds to the second border **218**. For example, the navigation system **100** identifies the second subset **216**. This functionality is described in more detail with reference to FIG. **5**A and FIG. **5**B above.

[0070] FIG. **10** is a block diagram of the method **314**.

[0071] At block **316**, the method **314** includes identifying the third subset **222** of the data **206** that corresponds to the third border **224** that intersects the first border **212** and the second border **218**. For example, the navigation system **100** identifies the third subset **222**. This functionality is described in more detail with reference to FIG. **6** above.

[0072] FIG. **11** is a block diagram of the method **318**.

[0073] At block **320**, the method **318** includes determining the angle **230** at which the first border **212** intersects the second border **218** and a position of the angle **230**. For example, the navigation system **100** determines the angle **230** and the position of the angle **230**. This functionality is described in more detail with reference to FIG. **7**A and FIG. **7**B above.

[0074] FIG. **12** is a block diagram of the method **322**.

[0075] At block **324**, the method **322** includes determining that the first border **212** forms a particular shape with the second border **218**. For example, the navigation system **100** determines that the border **212** forms the particular shape with the second runway border **218**. This functionality is described in more detail with reference to FIG. **7**A and FIG. **7**B above.

[0076] FIG. **13** is a block diagram of the method **326**.

[0077] At block **328**, the method **326** includes identifying the subset **278** of the data **206** that does not correspond to a border. For example, the navigation system **100** identifies the subset **278**. This functionality is described in more detail with reference to FIG. **5**A and FIG. **5**B above.

[0078] At block **330**, the method **326** includes deleting the subset **278** of the data **206**. For example, the navigation system **100** deletes the subset **278**. This functionality is described in more detail with reference to FIG. **5**A and FIG. **5**B above.

[0079] Examples of the present disclosure can thus relate to one of the enumerated clauses (ECs) listed below.

[0080] EC 1 is a navigation system for an aircraft comprising: a light source; a light sensor; one or more processors; and a computer readable medium storing instructions that, when executed by the one or more processors, cause the navigation system to perform functions comprising: illuminating a surface using the light source to cause light to be reflected from the surface; detecting the light and generating data representing the light using the light sensor, wherein the data maps intensities of the light to respective positions on the surface; identifying within the data a subset of the data that corresponds to a border; and causing navigation of the aircraft based on a position of the

border indicated by the subset of the data.
[0081] EC 2 is the navigation system of EC 1, wherein the border is a first border, the functions further comprising: identifying a second subset of the data that corresponds to a second border, wherein causing navigation of the aircraft comprises causing navigation of the aircraft additionally based on a second position of the second border indicated by the second subset of the data.
[0082] EC 3 is the navigation system of EC 2, wherein the second border is substantially parallel to the first border.
[0083] EC 4 is the navigation system of EC 3, the functions further comprising: identifying a third subset of the data that corresponds to a third border that intersects the first border and the second border, wherein causing navigation of the aircraft comprises causing navigation of the aircraft additionally based on a third position of the third border indicated by the third subset of the data.
[0084] EC 5 is the navigation system of any of ECs 2-4, wherein the first border is on a first side of the aircraft and the second border is on a second side of the aircraft that is opposite the first side.
[0085] EC 6 is the navigation system of any of ECs 2-5, wherein the first border intersects the second border.
[0086] EC 7 is the navigation system of EC 6, the functions further comprising: determining an angle at which the first border intersects the second border and a position of the angle, wherein causing navigation of the aircraft comprises causing navigation of the aircraft additionally based on the position and the angle.
[0087] EC 8 is the navigation system of any of ECs 2-7, the functions further comprising: determining that the first border forms a particular shape with the second border, wherein causing navigation of the aircraft comprises causing navigation of the aircraft additionally based on determining that the first border forms the particular shape with the second border.
[0088] EC 9 is the navigation system of any of ECs 1-8, wherein causing navigation of the aircraft comprises causing navigation of the aircraft on the surface.
[0089] EC 10 is the navigation system of any of ECs 1-9, wherein identifying the subset of the data comprises: selecting two arbitrary data points of the data; determining parameters of a shape that includes the two arbitrary data points; and determining that each data point of the subset of the data conforms to the shape within a margin of error and that the subset of the data includes at least a threshold amount of data points.
[0090] EC 11 is the navigation system of EC 10, wherein identifying the subset of the data further comprises: selecting a second two arbitrary data points of the data; determining parameters of a second curve that includes the second two arbitrary data points; and determining that less than the threshold amount of data points of the data conform to the second curve within the margin of error.
[0091] EC 12 is the navigation system of any of ECs 10-11, wherein identifying the subset of the data further comprises determining that the subset of the data includes at least a second threshold amount of data points per unit distance.
[0092] EC 13 is the navigation system of any of ECs 10-12, wherein identifying the subset of the data further comprises determining that the subset of the data has an average intensity that is greater than a threshold intensity.
[0093] EC 14 is the navigation system of any of ECs 1-13, wherein causing navigation of the aircraft comprises causing navigation of the aircraft additionally based on data collected by an inertial navigation system of the aircraft.
[0094] EC 15 is the navigation system of any of ECs 1-14, wherein identifying the subset of the data comprises: determining parameters of a line that corresponds to the border; determining that a first region of the surface on a first side of the line has a first average intensity that is less than a first threshold intensity; and determining that a second region of the surface on a second side of the line has a second average intensity that is greater than a second threshold intensity.
[0095] EC 16 is the navigation system of any of ECs 1-15, wherein causing navigation of the aircraft comprises adjusting a control surface or landing gear of the aircraft based on the position of

the border indicated by the subset of the data.
[0096] EC 17 is the navigation system of any of ECs 1-16, wherein the subset is a first subset, the functions further comprising: identifying a second subset of the data that does not correspond to a border; and deleting the second subset of the data.
[0097] EC 18 is a non-transitory computer readable medium storing instructions that, when executed by a navigation system of an aircraft, cause the navigation system to perform functions comprising: illuminating a surface to cause light to be reflected from the surface; detecting the light and generating data representing the light, wherein the data maps intensities of the light to respective positions on the surface; identifying within the data a subset of the data that corresponds to a border; and causing navigation of the aircraft based on a position of the border indicated by the subset of the data.
[0098] EC 19 is a method of operating a navigation system of an aircraft, the method comprising: illuminating a surface to cause light to be reflected from the surface; detecting the light and generating data representing the light, wherein the data maps intensities of the light to respective positions on the surface; identifying within the data a subset of the data that corresponds to a border; and causing navigation of the aircraft based on a position of the border indicated by the subset of the data.
[0099] EC 20 is the method of EC 19, wherein identifying the subset of the data comprises: selecting two arbitrary data points of the data; determining parameters of a curve that includes the two arbitrary data points; and determining that each data point of the subset of the data conforms to the curve within a margin of error and that the subset of the data includes at least a threshold amount of data points. The description of the different advantageous arrangements has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the examples in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different advantageous examples may describe different advantages as compared to other advantageous examples. The example or examples selected are chosen and described in order to explain the principles of the examples, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various examples with various modifications as are suited to the particular use contemplated.

Claims

1. A navigation system for a vehicle, comprising: memory; and one or more processors, coupled to the memory, configured to cause the navigation system to: illuminate a surface to cause light to be reflected from the surface; detect the light reflected from the surface; generate data representing the light, wherein the data maps intensities of the light to respective positions on the surface; identify, within the data, a subset of the data that corresponds to a border based on the subset of the data having an average intensity that is greater than a threshold intensity; and cause navigation of the vehicle based on a position of the border indicated by the subset of the data.
2. The navigation system of claim 1, wherein: the border is a first border, the subset of the data is a first subset of the data, the one or more processors are further configured to cause the navigation system to identify a second subset of the data that corresponds to a second border, and the navigation of the vehicle is further based on a second position of the second border indicated by the second subset of the data.
3. The navigation system of claim 2, wherein the second border is substantially parallel to the first border.
4. The navigation system of claim 3, wherein the one or more processors are further configured to cause the navigation system to: identify a third subset of the data that corresponds to a third border that intersects the first border and the second border, wherein the navigation of the vehicle is further based on a third position of the third border indicated by the third subset of the data.

5. The navigation system of claim 2, wherein the first border intersects the second border.
6. The navigation system of claim 5, wherein the one or more processors are further configured to cause the navigation system to: determine an angle at which the first border intersects the second border and a position of the angle, wherein the navigation of the vehicle is further based on the position and the angle.
7. The navigation system of claim 2, wherein the one or more processors are further configured to cause the navigation system to: determine that the first border forms a particular shape with the second border, wherein the navigation of the vehicle is further based on determining that the first border forms the particular shape with the second border.
8. The navigation system of claim 1, wherein, to identify the subset of the data, the one or more processors are configured to cause the navigation system to: select two arbitrary data points of the data; determine parameters of a curve that includes the two arbitrary data points; and determine that each data point of the subset of the data conforms to the curve within a margin of error and that the subset of the data includes at least a threshold amount of data points.
9. The navigation system of claim 8, wherein, to identify the subset of the data, the one or more processors are configured to cause the navigation system to: select a second two arbitrary data points of the data; determine parameters of a second curve that includes the second two arbitrary data points; and determine that less than the threshold amount of data points of the data conform to the second curve within the margin of error.
10. The navigation system of claim 8, wherein, to identify the subset of the data, the one or more processors are configured to cause the navigation system to: determine that the subset of the data includes at least a second threshold amount of data points per unit distance.
11. The navigation system of claim 1, wherein the navigation of the vehicle is further based on data collected by an inertial navigation system of the vehicle.
12. The navigation system of claim 1, wherein the average intensity is a first average intensity and the threshold intensity is a first threshold intensity, and wherein, to identify the subset of the data, the one or more processors are configured to cause the navigation system to: determine parameters of a line that corresponds to the border; determine that a first region of the surface on a first side of the line has the first average intensity that is greater than the first threshold intensity; and determine that a second region of the surface on a second side of the line has a second average intensity that is less than a second threshold intensity.
13. The navigation system of claim 1, wherein the vehicle is an aircraft, and wherein, to cause navigation of the vehicle, the one or more processors are configured to cause the navigation system to: adjust a control surface or propel the aircraft via motorized landing gear of the aircraft based on the position of the border indicated by the subset of the data.
14. The navigation system of claim 1, wherein the vehicle is a fixed wing aircraft, a helicopter, a rotorcraft, an unmanned aerial vehicle, a drone, a satellite, or a spacecraft.
15. The navigation system of claim 1, wherein the subset of the data is a first subset of the data, and wherein the one or more processors are further configured to cause the navigation system to: identify a second subset of the data that does not correspond to a border; and delete the second subset of the data.
16. The navigation system of claim 1, further comprising: a light source configured to illuminate the surface; and a light sensor configured to detect the light reflected from the surface.
17. A method of operating a navigation system of a vehicle, the method comprising: illuminating a surface to cause light to be reflected from the surface; detecting the light reflected from the surface; generating data representing the light, wherein the data maps intensities of the light to respective positions on the surface; identifying, within the data, a subset of the data that corresponds to a border based on the subset of the data having an average intensity that is greater than a threshold intensity; and causing navigation of the vehicle based on a position of the border indicated by the subset of the data.

18. The method of claim 17, wherein the average intensity is a first average intensity and the threshold intensity is a first threshold intensity, and wherein identifying the subset of the data comprises: determining parameters of a line that corresponds to the border; determining that a first region of the surface on a first side of the line has the first average intensity that is greater than the first threshold intensity; and determining that a second region of the surface on a second side of the line has a second average intensity that is less than a second threshold intensity.

19. A non-transitory computer readable medium storing instructions that, when executed by a navigation system of vehicle, cause the navigation system to perform functions comprising: illuminating a surface to cause light to be reflected from the surface; detecting the light reflected from the surface; generating data representing the light, wherein the data maps intensities of the light to respective positions on the surface; identifying, within the data, a subset of the data that corresponds to a border based on the subset of the data having an average intensity that is greater than a threshold intensity; and causing navigation of the vehicle based on a position of the border indicated by the subset of the data.

20. The non-transitory computer readable medium of claim 19, wherein the average intensity is a first average intensity and the threshold intensity is a first threshold intensity, and wherein identifying the subset of the data comprises: determining parameters of a line that corresponds to the border; determining that a first region of the surface on a first side of the line has the first average intensity that is greater than the first threshold intensity; and determining that a second region of the surface on a second side of the line has a second average intensity that is less than a second threshold intensity.