Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 3076342 A1 2020/10/24

(21) 3 076 342

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(22) Date de dépôt/Filing Date: 2020/03/19

(41) Mise à la disp. pub./Open to Public Insp.: 2020/10/24

(30) Priorités/Priorities: 2019/04/24 (US16/393,388); 2019/04/24 (US16/393,376)

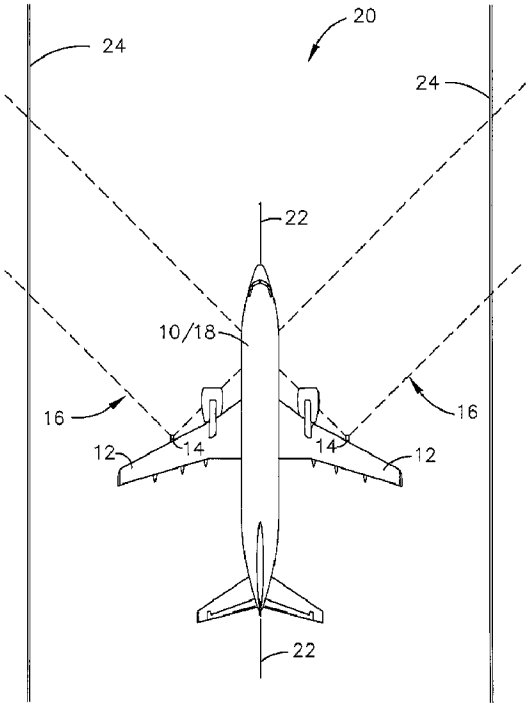
(51) Cl.Int./Int.Cl. *G01B 21/24* (2006.01), *B60S 5/00* (2006.01), *B64D 45/00* (2006.01), *B64F 5/00* (2017.01), *G01S 7/497* (2006.01)

(71) Demandeur/Applicant:
THE BOEING COMPANY, US

(72) Inventeurs/Inventors:
CALLAHAN, KEVIN S., US;
EVANS, NICK S., US;
MUIR, ERIC R., US

(74) Agent: SMART & BIGGAR LLP

(54) Titre : ALIGNEMENT DES CAPTEURS SUR LES VEHICULES AU MOYEN DES SORTIES DES CAPTEURS
(54) Title: ALIGNING SENSORS ON VEHICLES USING SENSOR OUTPUT



(57) Abrégé/Abstract:
Systems and methods of aligning removable sensors mounted on a vehicle based upon sensor output of such sensors are described. Sensor output is collected from a removable sensor (e.g., a digital camera), and a representation of such sensor output

(21) 3 076 342

(13) A1

(57) Abrégé(suite)/Abstract(continued):
is generated (e.g., a digital image). The representation of the sensor output is compared against a spatial template (e.g., a digital mask overlaid on the representation) to determine whether external references in the representation align with corresponding reference indicators in the spatial template. When alignment is required, the removable sensor is aligned by one or both of the following until the external references in a representation of sensor data at an updated current location align with the corresponding reference indicators in the spatial template: (i) adjusting the position of the removable sensor on the vehicle or (ii) adjusting the representation of the sensor output to simulate such repositioning.

ABSTRACT

Systems and methods of aligning removable sensors mounted on a vehicle based upon sensor output of such sensors are described. Sensor output is collected from a removable sensor (*e.g.*, a digital camera), and a representation of such sensor output is generated (*e.g.*, a digital image). The representation of the sensor output is compared against a spatial template (*e.g.*, a digital mask overlaid on the representation) to determine whether external references in the representation align with corresponding reference indicators in the spatial template. When alignment is required, the removable sensor is aligned by one or both of the following until the external references in a representation of sensor data at an updated current location align with the corresponding reference indicators in the spatial template: (i) adjusting the position of the removable sensor on the vehicle or (ii) adjusting the representation of the sensor output to simulate such repositioning.

ALIGNING SENSORS ON VEHICLES USING SENSOR OUTPUT

BACKGROUND

This disclosure relates to systems and methods for aligning removable sensors on a vehicle. Computer vision systems are employed on vehicles to monitor the surrounding environment of the vehicle using various sensors and, in some instances, to control vehicle operation using the sensor data from digital cameras, Light Detection and Ranging (LIDAR) units, and similar sensors. Although computer vision techniques offer many benefits, they are sensitive to changes in location or orientation of the sensors. In order to utilize computer vision systems fully, the sensor positions during operation must be comparable to the sensor positions used in training (or other previous use) or model generation. Because sensors are occasionally removed or replaced over the operational life of a vehicle, sensor realignment must occur whenever a sensor is installed or reinstalled on the vehicle. Additionally, sensor location should be consistent across similar vehicles in order to facilitate the generation and use of computer vision systems that may be used on multiple similarly configured vehicles.

While sensor position is important to computer vision systems, sensor alignment presents particular difficulties. While initial sensor placement in a general area of a vehicle is easily done, such placement in an approximate area of the vehicle is insufficient to obtain the high degree of accuracy needed for optimal computer vision systems. Thus, further alignment of sensors is needed to ensure data accuracy.

SUMMARY

An example includes a method for aligning a removable sensor mounted on a vehicle, comprising: collecting sensor output from the removable sensor at each of a plurality of times, wherein the sensor output at each of the plurality of times is associated with a current position of the removable sensor on the vehicle; generating, by one or more

CA 3076342 2020-03-19

processors, a representation of the sensor output at each of the plurality of times; and/or adjusting (i) the current position of the removable sensor based upon the representation of the sensor output and a spatial template including one or more reference indicators to position the removable sensor at a desired position on the vehicle, in which desired position one or more external reference features in the representation of the sensor output align with the one or more reference indicators in the spatial template, and/or (ii) the representation of the sensor output at the current position of the removable sensor to simulate the removable sensor being positioned at the desired position on the vehicle based upon the spatial template.

Another example includes a computer system for aligning a removable sensor mounted on a vehicle, including one or more processors communicatively connected to the removable sensor and a program memory communicatively connected to the one or more processors and storing executable instructions that, when executed by the one or more processors, cause the computer system to: collect sensor output from the removable sensor at each of a plurality of times, wherein the sensor output at each of the plurality of times is associated with a current position of the removable sensor on the vehicle; generate a representation of the sensor output at each of the plurality of times; and/or adjust (i) the current position of the removable sensor based upon the representation of the sensor output and a spatial template including one or more reference indicators to position the removable sensor at a desired position on the vehicle, in which desired position one or more external reference features in the representation of the sensor output align with the one or more reference indicators in the spatial template, and/or (ii) the representation of the sensor output at the current position of the removable sensor to simulate the removable sensor being positioned at the desired position on the vehicle based upon the spatial template.

Yet another example includes a tangible, non-transitory computer-readable medium storing executable instructions for aligning a removable sensor mounted on a vehicle, which executable instructions, when executed by one or more processors of a computer system, cause the computer system to: collect sensor output from the removable sensor

at each of a plurality of times, wherein the sensor output at each of the plurality of times is associated with a current position of the removable sensor on the vehicle; generate a representation of the sensor output at each of the plurality of times; and/or determine whether the removable sensor is aligned with a desired position on the vehicle based upon the representation of the sensor output and a spatial template including one or more reference indicators by comparing a portion of the spatial template against a corresponding portion of the representation of the sensor output at a time of the plurality of times, in which desired position one or more external reference features in the representation of the sensor output align with the one or more reference indicators in the spatial template.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments or may be combined in yet other embodiments further details of which can be seen with reference to the following description and drawings.

BRIEF SUMMARY OF THE DRAWINGS

FIG. **1** is a top view of a vehicle having a plurality of removable sensors;

FIG. **2** is a block diagram of computer system for aligning removable sensors;

FIG. **3** is a perspective view of an exemplary removable sensor mounted on a vehicle;

FIG. **4** is a representation of a spatial template overlaid on a representation of sensor output of a removable sensor that is misaligned;

FIG. **5** is a representation of the spatial template overlaid on a representation of sensor output of the removable sensor that is properly aligned; and

FIG. **6** is a flow diagram of an exemplary sensor alignment method.

DESCRIPTION

Disclosed herein are systems, methods, and non-transitory computer-readable media storing instructions for aligning one or more removable sensors on a vehicle, such as digital cameras or LIDAR units on an aircraft. The removable sensors disclosed herein generate sensor output as electronic data regarding the physical local environment around such removable sensors, such as a digital video feed or a three-dimensional spatial map of objects or surfaces in the environment observable by the removable sensors. The following disclosure generally relates to aligning such removable sensors in or on a vehicle using the sensor output to obtain a high degree of accuracy in alignment. The removable sensors may be aligned with previous positions of the same or similar removable sensors, such as when a removable sensor is reinstalled after maintenance or when a new removable sensor is installed to replace a previous removable sensor (*e.g.*, after sensor failure). The removable sensors may likewise be aligned in a corresponding position on multiple vehicles to ensure consistency of sensor position (and thus ensure consistency of sensor data) between multiple vehicles that are similarly configured with removable sensors. Further details regarding such removable sensor alignment are described below.

FIG. **1** illustrates a top view of an example of a vehicle **10** on which removable sensors **14** are mounted. Although the vehicle **10** is illustrated as an aircraft **18** (specifically, as a fixed-wing aircraft), the techniques described herein are applicable to aligning electronic sensors on other types of vehicles (*e.g.*, automobiles, trains, other types of aircraft, ships, trucks, or industrial equipment). The vehicle **10** is illustrated as being positioned on a taxiway **20** for reference. The taxiway **20** has a centerline **22** for use in centering the vehicle **10** while traveling along the taxiway **20**. The taxiway **20** also has edge lines **24** on each side that mark the edge of the usable portion of the taxiway **20**. The vehicle **10** includes wings **12**, which may include a left wing and a right wing. A plurality of removable sensors **14** are mounted on the vehicle **10** to capture sensor data for portions **16** of the taxiway **20** within the respective field of view of each removable sensor **14**.

Each removable sensor **14** is an electronic imaging sensor that generates sensor output as electronic data at each of a plurality of times during sensor operation, from which sensor output a two-dimensional or three-dimensional graphical representation of the corresponding portion **16** of the local environment of the vehicle **10** can be generated. In various embodiments, the removable sensors **14** discussed throughout this document include one or more digital cameras, LIDAR units, radar units, ultrasonic sensor units, or other electronic devices configured to generate electronic images of portions of a local environment. In further embodiments, the removable sensors **14** discussed throughout this document include combinations of two or more of the foregoing types of removable sensors **14**, which combinations improve the robustness of the system by using multiple types of image data. Although illustrated as having two removable sensors **14**, the vehicle **10** may instead have one removable sensor **14** in other configurations, and the vehicle **10** may have more than two removable sensors **14** in still other configurations. As illustrated, some embodiments include one or more removable sensors **14** mounted on each side (*e.g.*, on each wing **12**) of the vehicle **10** to capture sensor data for distinct or partially overlapping portions **16** of the local environment.

FIG. **2** illustrates, as a block diagram, a computer system **200** for use in performing part or all of the sensor alignment method **600** described below. In some exemplary embodiments, the computer system **200** is installed within the vehicle **10**, while the computer system **200** is communicatively connected to the vehicle **10** in other exemplary embodiments. The computer system is configured to receive or collect sensor output from the one or more removable sensors **14** mounted on the vehicle **10** and to generate a representation of the sensor output for use in aligning the one or more removable sensors **14**, as described elsewhere herein. The computer system **200** includes a controller **210**, a database **220**, and a communication unit **230**.

The controller includes one or more of each of the following: a program memory **212**, a processor **214**, and a random access memory (RAM) **216**. Each program memory **212** is a non-transitory, tangible memory device configured to store electronic data, such as executable instructions for implementing processes, routines, and software programs.

Each processor **214** is adapted and configured to execute computer-executable instructions, such as software programs, applications, and routines. Each RAM **216** is configured as a volatile memory for storing electronic data while in use.

Each of the program memory **212**, processor **214**, and RAM **216** is connected to an input/output (I/O) circuit **218**, which I/O circuit **218** also connects the controller **210** to the other components of the computer system **200** (*i.e.*, the database **220**, the communication unit **230**, and any display **240**). The database **220** is configured to store electronic data in a non-transitory, tangible memory device for use by software applications. In some embodiments, the database **220** and the program memory **212** may be combined into a single memory. The communication unit **230** is a component of the computer system **200** configured to manage communication between the controller **210** and external devices that are communicatively connected to the computer system **200**, such as the removable sensors **14** and any motorized mountings **250** associated with the removable sensors **14**.

Although illustrated as connected to the removable sensors **14**, the computer system **200** includes the removable sensors **14** in some embodiments in order to improve control of the electronic data from the removable sensors **14**. In additional or alternative embodiments, the computer system **200** likewise includes one or more motorized mountings **250** configured to adjust the position and/or orientation of removable sensors **14**, as described further below. In further additional or alternative embodiments, the computer system **200** includes a display **240** configured to present visual representations of sensor output from the removable sensors **14** to a user for verification or further use in aligning the removable sensors **14** of the vehicle **10**. Additional or alternative embodiments of the computer system **200** may include fewer, additional, or alternative components, as well as any combination of components illustrated in FIG. **2**.

FIG. **3** is a perspective view of an example of a removable sensor **14** mounted on a vehicle **10** via a motorized mounting **250**. In the illustrated example, the removable sensor **14** is a digital camera mounted to the underside of a wing of an aircraft. In the illustrated example, the motorized mounting **250** is fixedly attached to the vehicle **10** and includes both a motorized translation bed **251** and a motorized gimbal **252**, which are

electrically controlled by the computer system **200**. The motorized translation bed **251** translates the lateral position of the removable sensor **14** relative to the local surface of the vehicle **10** to which the motorized mounting **250** is affixed, thereby enabling the position of the removable sensor **14** to be adjusted relative to the center of the vehicle. The motorized gimbal **252** rotates the removable sensor **14** in three-dimensional space, thereby enabling the orientation of the removable sensor **14** to be adjusted during alignment. Although the illustrated motorized mounting **250** includes both a motorized translation bed **251** and a motorized gimbal **252**, either the motorized translation bed **251** or the motorized gimbal **252** may be installed and used independently (*i.e.*, without the other component) in various embodiments. In further embodiments, the removable sensor **14** may be mounted on the vehicle **10** with a mounting that does not include any motorized components, in which case the removable sensor **14** is adjusted manually.

FIGS. **4** and **5** illustrate the use of spatial templates and representations of sensor output to align a removable sensor **14** mounted on a vehicle **10**. FIG. **4** is a representation of a spatial template overlaid on an unaligned visual representation **400** of sensor output of a removable sensor **14**. FIG. **5** is a representation of the same spatial template overlaid on an aligned visual representation **500** of sensor output of the removable sensor **14** that is properly aligned. Although the illustrated unaligned and aligned visual representations **400** and **500** in FIGS. **4** and **5** are presented graphically as two-dimensional images to aid description, it should be understood that such representations may be two-dimensional or three-dimensional images (*e.g.*, pixel arrays or voxel point clouds) and need not be actually displayed. In some embodiments, representations such as the unaligned and aligned visual representations **400** and **500** may be visually presented to a user via the display **240** to facilitate alignment of a removable sensor **14**. In other embodiments, the computer system **200** may internally process corresponding data representations without visually presenting such representations.

FIG. **4** illustrates the unaligned visual representation **400** of example sensor output of the removable sensor **14**, in which the removable sensor **14** is misaligned. The unaligned visual representation **400** is an image of the local environment of a vehicle **10**,

which in this case is an aircraft **18** with a camera mounted on a wing (not shown) of the aircraft **18**. The local environment of the aircraft **18** in the unaligned visual representation **400** includes portions of the ground and background buildings, as well as a vehicle portion **404**. A horizon **402** may be determined directly in the representation or indirectly from the alignment of buildings or other features. Such features as the horizon **402** and the vehicle portion **404** may be used as external reference features for sensor alignment, as described further elsewhere herein. The spatial template overlays the unaligned visual representation **400** and is visually depicted as a mask having shaded regions representing reference indicators, including a horizon reference indicator **412** and a vehicle reference indicator **414**. As can be seen in FIG. **4**, the horizon reference indicator **412** is misaligned with the horizon **402** (indicating a rotation of the camera from a desired position), and the vehicle reference indicator **414** is misaligned with the vehicle portion **404** (indicating a rotation or translation of the camera from a desired position).

FIG. **5** illustrates the aligned visual representation **500** of example sensor output of the removable sensor **14**, in which the removable sensor **14** is properly aligned. The local environment of the vehicle **10** illustrated in FIG. **5** is substantially similar to that of the local environment illustrated in FIG. **4**, but the removable sensor **14** has been properly aligned. Thus, the horizon reference indicator **512** aligns with the horizon **502**, and the vehicle reference indicator **514** aligns with the vehicle portion **504**.

FIG. **6** is a flow diagram of a sensor alignment method **600** for aligning one or more removable sensors **14** mounted on a vehicle **10**. In some embodiments, the processor **214** of the computer system **200** executes computer-executable instruction stored in the program memory **212** to implement part or all of the sensor alignment method **600**. The sensor alignment method **600** is implemented to align one or more removable sensors **14** using sensor output from the one or more removable sensors **14**. In some embodiments, the sensor alignment method **600** may be implemented separately for each of a plurality of removable sensors **14** of one or more vehicles **10**. Additional, alternative, or fewer aspect may be included in alternative similar methods. Although the sensor alignment method **600** is described herein by reference to the computer system **200** for clarity, other

similar computing systems may be used, as will be readily apparent to those of ordinary skill in the art.

At block **602**, in some embodiments, one or more removable sensors **14** are mounted on a vehicle **10**. For example, the removable sensor **14** mounted on a vehicle **10** via a motorized mounting **250** or via a non-motorized mounting. Such removable sensors **14** will not generally be properly aligned when first mounted, so the sensor alignment method **600** aligns the removable sensors **14** to a desired position and orientation to generate useful sensor output.

At block **604**, the computer system **200** collects sensor output from the one or more removable sensors **14** mounted on the vehicle **10**. For each removable sensor **14**, the computer system **200** collects sensor output generated by the removable sensor **14** at one or more times. The sensor output is generated by the removable sensor **14** as electronic data and transmitted via wired or wireless communication to the computer system **200** through the communication unit **230**. The sensor output indicates sensed data regarding a portion of the environment of the vehicle **10**, as observed from the current position of the removable sensor **14**. In some embodiments, the removable sensor **14** is configured to generate sensor output on an ongoing basis (*e.g.*, periodically at constant intervals), in which case either sensor output at a single time or sensor output at a plurality of times may be collected by the computer system **200**. For example, the sensor output may be a video feed including a plurality of electronic data representing still images at a plurality of times. Because the sensor output is associated with the current position of the removable sensor **14**, the sensor output likewise changes as the position (*e.g.*, location and/or orientation) of the removable sensor **14** is adjusted.

At block **606**, the computer system **200** generates one or more representations of the sensor output collected from the one or more removable sensors **14** to facilitate sensor alignment. Each representation of the sensor output represents a portion of the current local environment of the vehicle **10** as observed from the current position of a removable sensor **14** at a particular time. Such representation may comprise computer-readable data in the program memory **212** (a representation that is not displayed to a

user) or may alternatively comprise a visual representation of the sensor data presented to a user via the display **240**. In some embodiments, the representation of the sensor output is generated as a digital image including a portion of the vehicle **10** and a portion of the environment of the vehicle **10** in order to provide external reference features from which to align the removable sensor **14** using a corresponding digital mask, as discussed below. For example, representations such as the unaligned visual representation **400** and the aligned visual representation **500** discussed above may be generated by the computer system **200** from the sensor output. In some embodiments, the computer system **200** generates a representation of the sensor output for each removable sensor **14** at each time in order to facilitate sensor alignment in real-time as the removable sensor **14** is adjusted.

At block **608**, the computer system **200** compares at least one of the representations of the sensor output against one or more spatial templates. The one or more spatial templates are configured to overlay the representations of the sensor output in order to indicate whether the one or more removable sensors **14** are properly aligned in a desired position. Each spatial template includes at least one reference indicator to be aligned with an external reference feature in the representation of the sensor output relating to the observed environment of the vehicle **10**. Each such reference indicator represents an expected position of an external reference feature in the representation of the sensor output when the removable sensor **14** is in a desired position (*i.e.*, when the removable sensor **14** is properly aligned). Such external reference features may be parts of physical objects in the local physical environment of the vehicle **10** (including portions of the vehicle **10** itself or temporary static alignment objects placed within the environment of the vehicle **10**) or may be observable aspects of the local physical environment of the vehicle **10** derivable from the sensor output (such as orienting surfaces or lines). In some embodiments, the one or more reference indicators of the one or more spatial templates include expected spatial positions corresponding to one or more of the following external reference features: one or more portions of the vehicle **10**, one or more alignment markings on the surface of the vehicle **10**, one or more temporary static alignment objects placed within an environment of the vehicle **10**, or a horizon as observed from the position

of the removable sensor **14**. Use of such external references enables robust performance of the sensor alignment method **600** in many environments. In some embodiments, the spatial template comprises a digital mask including the one or more reference indicators as one or more shapes within digital mask. Such digital mask may include reference indicators relating to portions of the vehicle **10** or other observable aspects of local environment of the vehicle **10**, such as the horizon reference indicators **412**, **512** and the vehicle reference indicators **414**, **514** described above with respect to FIGS. **4** and **5**. In additional or alternative embodiments, the digital mask may include one or more reference indicators relating to temporary static alignment objects placed within the local of the vehicle **10** for sensor alignment. For example, temporary static alignment objects (*e.g.*, traffic cones, signs, or targets) may be placed temporarily at specific positions relative to the vehicle **10** (*e.g.*, at a predetermined distance from the vehicle **10** along a centerline **22** of a taxiway **20**) to facilitate alignment of one or more removable sensors **14**. Such digital masks may simplify comparison by either the computer system **200** or a user via the display **240**. Additional or alternative two-dimensional digital masks or three-dimensional digital masks may be used in various embodiments.

As with the one or more representations of the sensor output, the one or more spatial templates may comprise computer-readable data in the program memory **212** (such as a data template that is not displayed to a user) or may alternatively comprise a visual spatial template (such as a visual mask that is displayed to a user). Thus, comparing a representation of the sensor output against a spatial template may be performed automatically by the controller **210** of the computer system **200** or may be performed manually by a user of the computer system **200**. To compare a representation of the sensor output against a spatial template, the controller **210** may perform a pixel-wise or bit-wise comparison of one or more portions of the spatial template corresponding to the reference indicators against the corresponding one or more portions of the representation of the sensor output. Alternatively, the controller **210** may perform object determination to extract relevant features (*e.g.*, portions of the vehicle **10**, markings, other objects, or a horizon) from the representation of the sensor output and compare the one or more portions of the spatial template corresponding to the reference indicators against such

extracted relevant features. To compare a representation of the sensor output against a spatial template, the user of the computer system **200** may review the spatial template as an overlay on the representation of the sensor output displayed at the display **240** to identify areas of overlap between the reference indicators in the spatial template and external features in the representation of the sensor output. The user may likewise identify areas without overlap for which overlap is desired, indicating sensor misalignment.

Because the sensor alignment method **600** may be performed for unaligned sensors in order to align such unaligned sensors and for aligned sensors in order to confirm proper alignment, comparing the one or more spatial templates against the one or more representations of the sensor output may occur prior to performing sensor alignment (*i.e.*, adjusting a current position of a removable sensor **14** or adjusting a representation of the sensor output) or after performing sensor alignment, as described further below. As can be seen by reference to FIG. **6**, comparing the one or more spatial templates against the one or more representations of the sensor output may in some instances occur both prior to performing sensor alignment and after performing such sensor alignment over multiple iterations of such comparisons until the one or more removable sensors **14** are sufficiently aligned. Thus, the sensor alignment method **600** is made more flexible and more broadly applicable to sensor alignment under various conditions.

At block **610**, a difference level between the at least one representation of the sensor output and the corresponding one or more spatial templates is determined. In some instances, there may be no difference between the representation of the sensor output and the spatial template against which the representation is compared, in which cases the difference level will be determined as zero difference. The difference level represents a level of divergence between one or more portions of the spatial template corresponding to reference indicators and the corresponding one or more portions of the representation of the sensor output corresponding to external references in the environment of the vehicle **10**. Although described herein as being evaluated based upon a difference level, the comparison of representations of sensor output and spatial templates may instead by

evaluated using a correspondence level, matching level, or other metrics of either differences or matches between a representation of sensor output and a spatial template in alternative embodiments.

As above with respect to block **608**, the difference level may be determined automatically by the controller **210** of the computer system **200** or may be determined manually by a user of the computer system **200**. When determined automatically, the controller **210** may aggregate the differences between the representation of the sensor output and the spatial template across a plurality of bits or pixels. When determined manually, the user may estimate the degree of overlap or match between the representation of the sensor output and the spatial template.

At block **612**, the computer system **200** or a user of the computer system **200** determines whether the one or more removable sensors **14** are properly aligned based upon the difference level determined from the comparison of the at least one representation of sensor output against the one or more spatial templates. In some embodiments, the computer system **200** is configured to determine the one or more removable sensors **14** are sufficiently properly aligned by determining the difference level determined at block **610** does not exceed a tolerance threshold (indicating that the removable sensor **14** is at a current position that is properly aligned to a desired position) and/or is configured to determine the one or more removable sensors **14** are not sufficiently properly aligned by determining the difference level determined at block **610** does exceed the tolerance threshold (indicating that the removable sensor **14** is at a current position that is not properly aligned to a desired position). In further embodiments, the user of the computer system **200** determines whether the one or more removable sensors **14** are sufficiently properly aligned by evaluation of the difference level determined at block **610**. As indicated by FIG. **6**, the sensor alignment method **600** may perform multiple iterations at a plurality of times, including a time prior to sensor alignment (*i.e.*, when the difference level exceeds the tolerance threshold) and a time after sensor alignment (*i.e.*, when the difference level does not exceed the tolerance threshold). When the one or more removable sensors **14** are determined to be properly aligned, the sensor

alignment method **600** continues to block **620** or terminates. When the one or more removable sensors **14** are determined not to be properly aligned, the sensor alignment method **600** continues to block **614** or to one of blocks **616** or **618**.

At block **614**, in some embodiments, the computer system **200** presents an indication of misalignment of at least one removable sensor **14** to a user via the display **240**. Such indication of misalignment may include an indication of the difference level to indicate the degree of misalignment. In some embodiments, the indication of misalignment may include corrective instructions to the user, such as instructions to translate or rotate the position of one or more removable sensors **14**. In further embodiments, the indication of misalignment may include a plurality of options presented to the user via the display **240**, such as options to automatically align a removable sensor **14** or to manually align such removable sensor **14**. In some such embodiments, the options may include an option to adjust a current position of the removable sensor or to adjust the representation of the sensor output to perform the alignment. A use selection of one of such options may determine whether the sensor alignment method **600** proceeds to block **616** or block **618**, or whether the sensor alignment method **600** proceeds to manual or automatic alignment. In embodiments in which the sensor alignment method **600** operates on a plurality of removable sensors **14** simultaneously, the indication of misalignment may indicate one or more of the removable sensors **14** requiring alignment in order to assist the user in performing such alignment.

The sensor alignment method **600** may implement either an adjustment to a current position of a removable sensor **14** (block **616**) on a vehicle **10** or an adjustment to the representation of the sensor output (block **618**). In some instances, the sensor alignment method **600** may repeatedly make such adjustments until the removable sensor **14** is properly aligned over a plurality of iterations, and the same type of adjustment need not occur at each iteration. For example, the sensor alignment method **600** may first adjust the current position of the removable sensor **14** during a first iteration, then adjust the representation of the sensor output from the removable sensor **14** during a second iteration at the adjusted current position.

At block **616**, one or more current positions of the one or more removable sensors **14** mounted on the vehicle **10** are adjusted to improve the alignment of the one or more removable sensors **14**. Adjusting the current position of a removable sensor **14** may include either or both adjusting a location of the removable sensor **14** on the vehicle **10** or adjusting an orientation of the removable sensor **14** (*e.g.*, by rotation of the removable sensor **14**). The current position of each removable sensor **14** is adjusted to position the removable sensor **14** at a desired position on the vehicle **10** based upon the representation of the sensor output and the spatial template, such that one or more external reference features in the representation of the sensor output of the removable sensor **14** at the adjusted current position align with the one or more reference indicators in the spatial template. In some embodiments, adjusting the current position of a removable sensor **14** includes adjusting an orientation of the removable sensor **14** to align one or more external reference features in a digital image with one or more shapes within a digital mask used as the spatial template.

Adjusting the current positions of the one or more removable sensors **14** may be performed manually or automatically. When performed manually, a user may physically adjust the position of each removable sensor **14** needing adjustment, or the user may control a motorized mounting **250** to adjust the position of the removable sensor **14**. When performed automatically, the controller **210** of the computer system **200** controls the motorized mounting **250** to adjust the position of each removable sensor **14** needing adjustment. Controlling the motorized mounting **250** includes generating and communicating from the computer system **200** to the motorized mounting **250** an electrical signal to actuate at least one of the motorized translation bed **251** or the motorized gimbal **252** of the motorized mounting **250** to adjust the current position of the one or more removable sensors **14**. Such motorized mounting **250** may be used for convenience of the user, for increased efficiency or accuracy, or to facilitate automatic alignment of the removable sensors **14**.

At block **618**, the computer system **200** adjusts the representation of the sensor output of the one or more removable sensors **14** to simulate the removable sensor **14**

being positioned at the desired position. Thus, in some embodiments, the representation of the sensor output is aligned without requiring physically adjusting the position of the removable sensor **14**, thereby reducing error and cost. Such alignment may include any of the following, separately or in any combination: rotating the representation of the sensor output, translating the representation of the sensor output, or scaling the representation of the sensor output. In some embodiments, adjusting the representation of the sensor output at the current position of the removable sensor **14** includes applying one or more of a translation or a rotation of the representation of the sensor output to align one or more external reference features in a digital image with one or more shapes within a digital mask used as the spatial template. In various embodiments, adjustments to the representation of the sensor output of the one or more removable sensors **14** may be determined automatically by the controller **210** of the computer system (by identifying the best match between the adjusted representation of the sensor output and the spatial template) or manually by a user (by user input of adjustment instructions to the computer system **200** to obtain alignment between the adjusted representation of the sensor output and the spatial template).

Following alignment of the one or more removable sensors **14** by adjustment of current positions of such removable sensors **14** or adjustment of representations of sensor output of such removable sensor **14**, the sensor alignment method **600** returns to collecting sensor output from the one or more removable sensors **14** at block **604**. The sensor alignment method **600** then performs further analysis at block **606-612**, as described above. Further adjustments to align the one or more removable sensor **14** may be required, or the removable sensors **14** may be determined to be sufficiently properly aligned at block **612**.

When the computer system **200** determines that the one or more removable sensors **14** are properly aligned at block **612**, the sensor alignment proceeds, in some embodiments, to block **620**. At block **620**, in some embodiments, the computer system **200** presents an indication of alignment of at least one removable sensor **14** to a user via the display **240** to notify the user that the one or more removable sensors **14** are properly

aligned. For example, the computer system **200** may determine a removable sensor **14** has been properly aligned and present the indication of alignment to the user as confirmation of such alignment. In some such embodiments, a record of sensor alignment may be stored in the database **220** for future verification. The sensor alignment method **600** then terminates.

While various embodiments have been described above, this disclosure is not intended to be limited thereto. Variations can be made to the disclosed embodiments that are still within the scope of the appended claims.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for aligning a removable sensor mounted on a vehicle, comprising:

collecting sensor output from the removable sensor at each of a plurality of times, wherein the sensor output at each of the plurality of times is associated with a current position of the removable sensor on the vehicle;

generating, by one or more processors, a representation of the sensor output at each of the plurality of times; and

adjusting either (i) the current position of the removable sensor based upon the representation of the sensor output and a spatial template including one or more reference indicators to position the removable sensor at a desired position on the vehicle, in which desired position one or more external reference features in the representation of the sensor output align with the one or more reference indicators in the spatial template, or (ii) the representation of the sensor output at the current position of the removable sensor to simulate the removable sensor being positioned at the desired position on the vehicle based upon the spatial template.

2. The method of claim 1, wherein:

generating the representation of the sensor output at each of the plurality of times includes generating a digital image including a portion of an environment of the vehicle; and

the spatial template comprises a digital mask including the one or more reference indicators as one or more shapes within the digital mask.

3. The method of claim **2**, comprising adjusting the current position of the removable sensor, wherein adjusting the current position of the removable sensor based upon the representation of the sensor output and the spatial template includes adjusting an orientation of the removable sensor to align the one or more external reference features in the digital image with the one or more shapes within the digital mask.

4. The method of claim **2**, comprising adjusting the representation of the sensor output at the current position of the removable sensor, wherein adjusting the representation of the sensor output at the current position of the removable sensor includes applying one or more of a translation or a rotation of the representation of the sensor output to align the one or more external reference features in the digital image with the one or more shapes within the digital mask.

5. The method of claim **1**, wherein the one or more external reference features include a horizon.

6. The method of claim **1**, wherein the one or more external reference features include one or more of: a portion of the vehicle or alignment markings on a surface of the vehicle.

7. The method of claim **1**, wherein the one or more external reference features include one or more temporary static alignment objects placed within an environment of the vehicle.

8. The method of claim **1**, further comprising:

comparing, by the one or more processors, a portion of the spatial template against a corresponding portion of the representation of the sensor output at a time of the plurality of times, wherein the time occurs prior to adjusting the

current position of the removable sensor or the representation of the sensor output;

determining, by the one or more processors, a difference level between the portion of the spatial template and the corresponding portion of the representation of the sensor output; and

determining, by the one or more processors, the difference level exceeds a tolerance threshold.

9. The method of claim **1**, further comprising:

comparing, by the one or more processors, a portion of the spatial template against a corresponding portion of the representation of the sensor output at a time of the plurality of times, wherein the time occurs after adjusting the current position of the removable sensor or the representation of the sensor output;

determining, by the one or more processors, a difference level between the portion of the spatial template and the corresponding portion of the representation of the sensor output; and

determining, by the one or more processors, the difference level does not exceed a tolerance threshold.

10. The method of claim **1**, wherein adjusting the position of the removable sensor includes controlling a motorized gimbal to adjust the position of the removable sensor.

11. A computer system for aligning a removable sensor mounted on a vehicle, comprising:

one or more processors communicatively connected to the removable sensor; and

a program memory communicatively connected to the one or more processors and storing executable instructions that, when executed by the one or more processors, cause the computer system to:

collect sensor output from the removable sensor at each of a plurality of times, wherein the sensor output at each of the plurality of times is associated with a current position of the removable sensor on the vehicle;

generate a representation of the sensor output at each of the plurality of times; and

adjust either (i) the current position of the removable sensor based upon the representation of the sensor output and a spatial template including one or more reference indicators to position the removable sensor at a desired position on the vehicle, in which desired position one or more external reference features in the representation of the sensor output align with the one or more reference indicators in the spatial template, or (ii) the representation of the sensor output at the current position of the removable sensor to simulate the removable sensor being positioned at the desired position on the vehicle based upon the spatial template.

12. The computer system of claim **11**, wherein:

the executable instructions that cause the computer system to generate the representation of the sensor output at each of the plurality of times cause the computer system to generate a digital image including a portion of the vehicle and a portion of an environment of the vehicle; and

the spatial template comprises a digital mask including the one or more reference indicators as one or more shapes within the digital mask.

13. The computer system of claim **12**, wherein the executable instructions cause the computer system to adjust the current position of the removable sensor by adjusting an orientation of the removable sensor to align the one or more external reference features in the digital image with the one or more shapes within the digital mask.

14. The computer system of claim **12**, the executable instructions cause the computer system to adjust the representation of the sensor output at the current position of the removable sensor by applying one or more of a translation or a rotation of the representation of the sensor output to align the one or more external reference features in the digital image with the one or more shapes within the digital mask.

15. The computer system of claim **11**, further comprising one or more of a motorized gimbal or a motorized translation bed, wherein the executable instructions that cause the computer system to adjust the current position of the removable sensor cause at least one of the motorized gimbal or the motorized translation bed to adjust the current position of the removable sensor.

16. The computer system of claim **11**, wherein the vehicle is an aircraft.

17. A tangible, non-transitory computer-readable medium storing executable instructions for aligning a removable sensor mounted on a vehicle that, when executed by one or more processors of a computer system, cause the computer system to:

collect sensor output from the removable sensor at each of a plurality of times, wherein the sensor output at each of the plurality of times is associated with a current position of the removable sensor on the vehicle;

generate a representation of the sensor output at each of the plurality of times; and

determine whether the removable sensor is aligned with a desired position on the vehicle based upon the representation of the sensor output and a spatial template including one or more reference indicators by comparing a portion of the spatial template against a corresponding portion of the representation of the sensor output at a time of the plurality of times, in which desired position one or more external reference features in the representation of the sensor output align with the one or more reference indicators in the spatial template.

18. The tangible, non-transitory computer-readable medium of claim **17**, wherein the executable instructions that cause the computer system to determine whether the removable sensor is aligned with the desired position on the vehicle further cause the computer system to:

determine a difference level between the portion of the spatial template and the corresponding portion of the representation of the sensor output; and

determine whether the difference level exceeds a tolerance threshold.

19. The tangible, non-transitory computer-readable medium of claim **18**, wherein the executable instructions further cause the computer system to, when the difference level exceeds the tolerance threshold:

adjust the current position of the removable sensor to position the removable sensor at the desired position by adjusting an orientation of the removable sensor to align the one or more external reference features in the representation of the sensor output with the one or more reference indicators in the spatial template.

20. The tangible, non-transitory computer-readable medium of claim **18**, wherein the executable instructions further cause the computer system to, when the difference level exceeds the tolerance threshold:

adjust the representation of the sensor output at the current position of the removable sensor to simulate the removable sensor being positioned at the desired position on the vehicle based upon the spatial template by applying one or more of a translation or a rotation of the representation of the sensor output to align the one or more external reference features in the representation of the sensor output with the one or more reference indicators in the spatial template.

21. The tangible, non-transitory computer-readable medium of claim **18**, wherein the executable instructions further cause the computer system to, when the difference level does not exceed the tolerance threshold:

present an indication of alignment to a user of the computer system via a display.

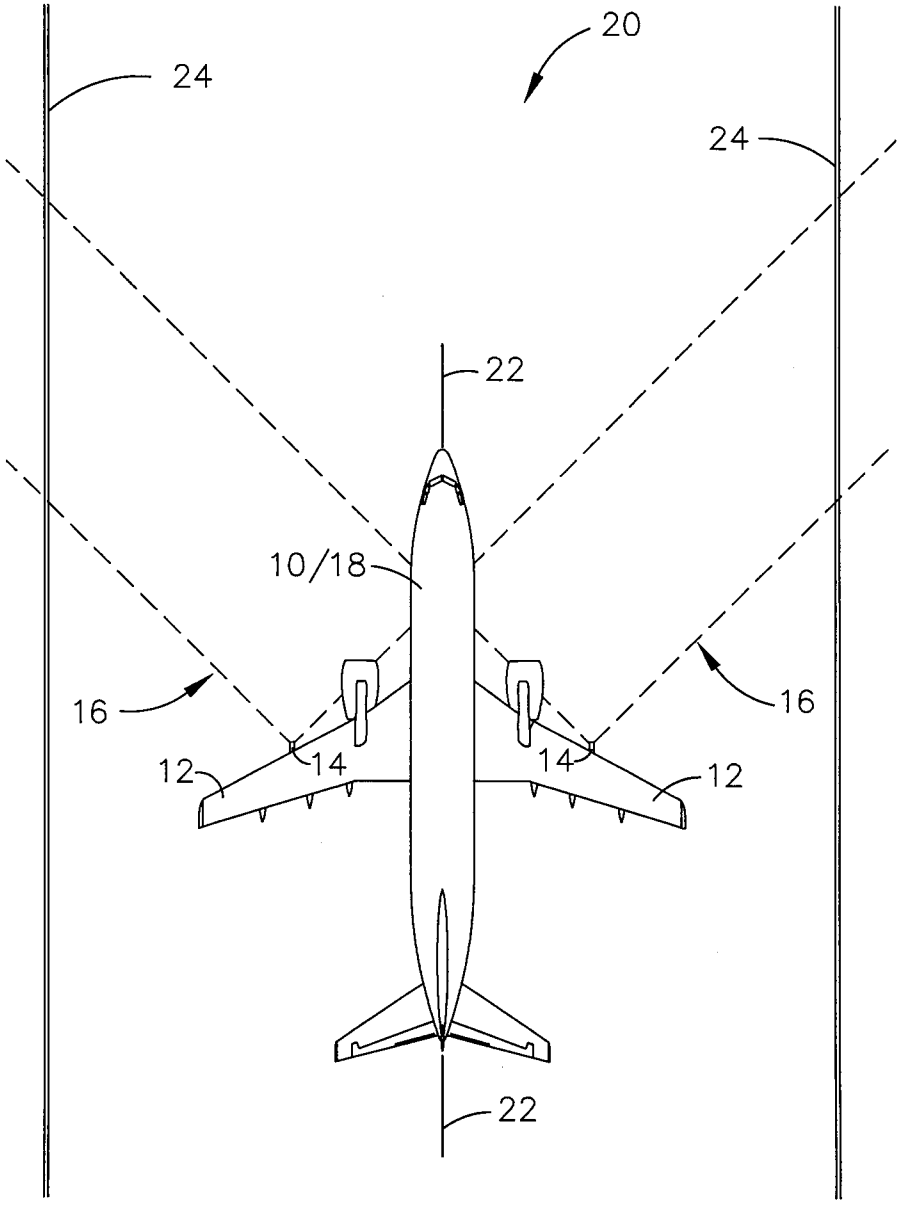


FIG. 1

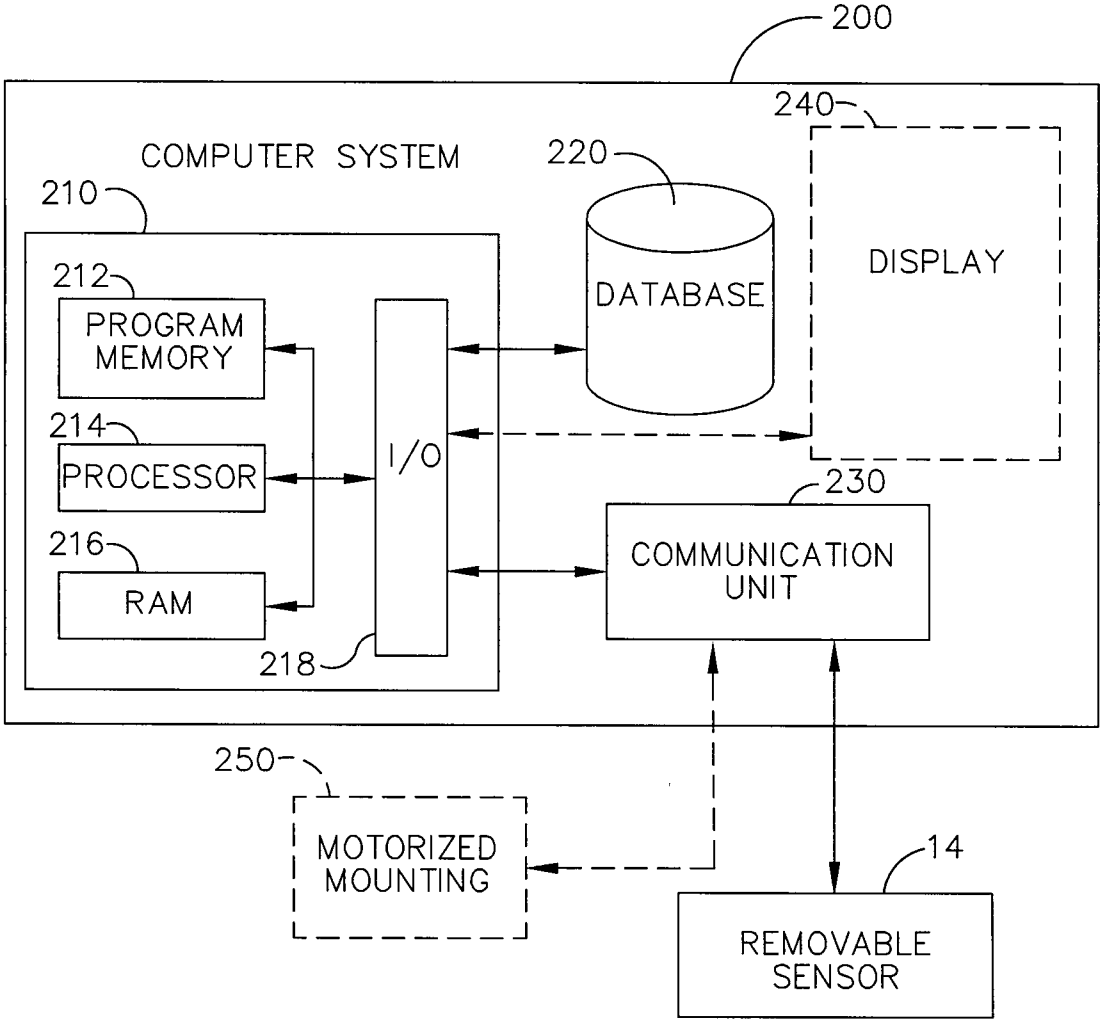

200
240
COMPUTER SYSTEM
220
210
DISPLAY
212
PROGRAM MEMORY
DATABASE
214
PROCESSOR
I/O
230
216
COMMUNICATION UNIT
RAM
218
250
MOTORIZED MOUNTING
14
REMOVABLE SENSOR

FIG. 2

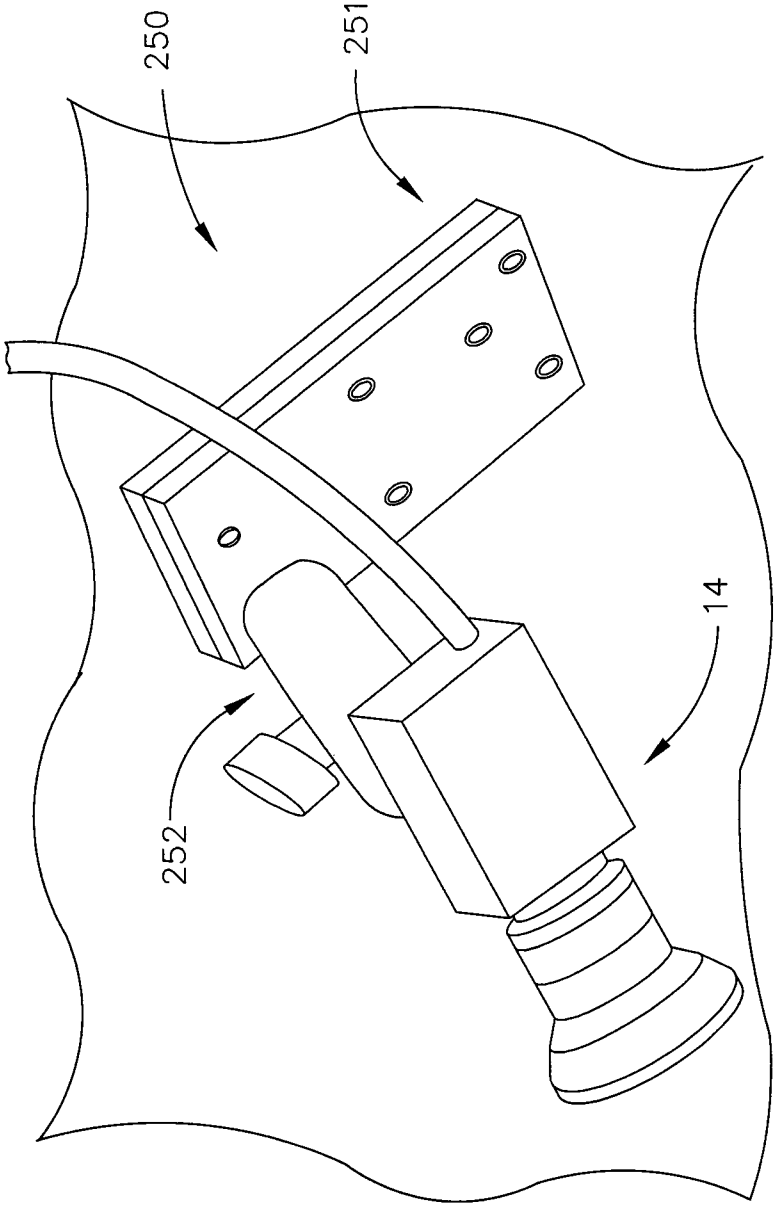


FIG. 3

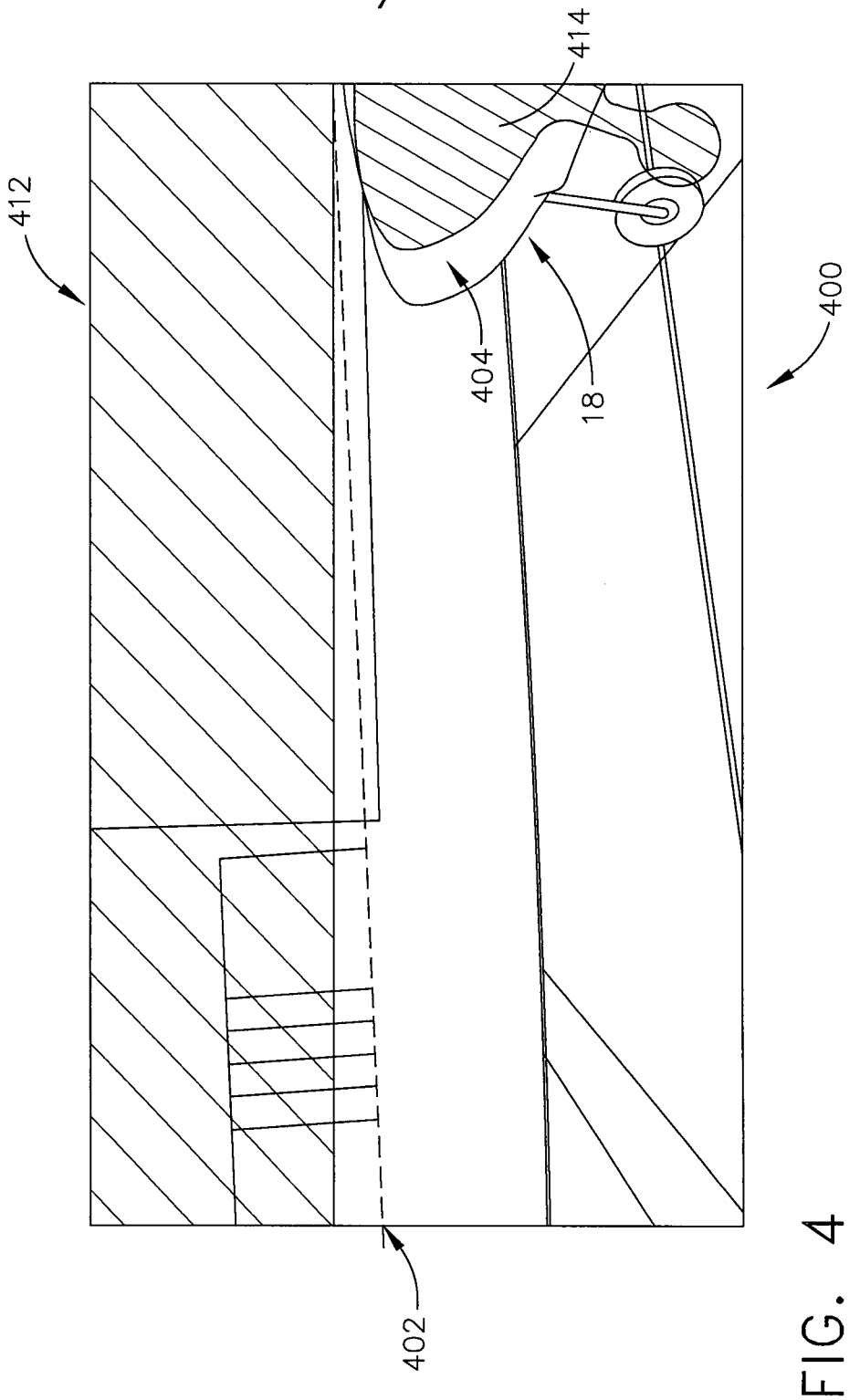


FIG. 4

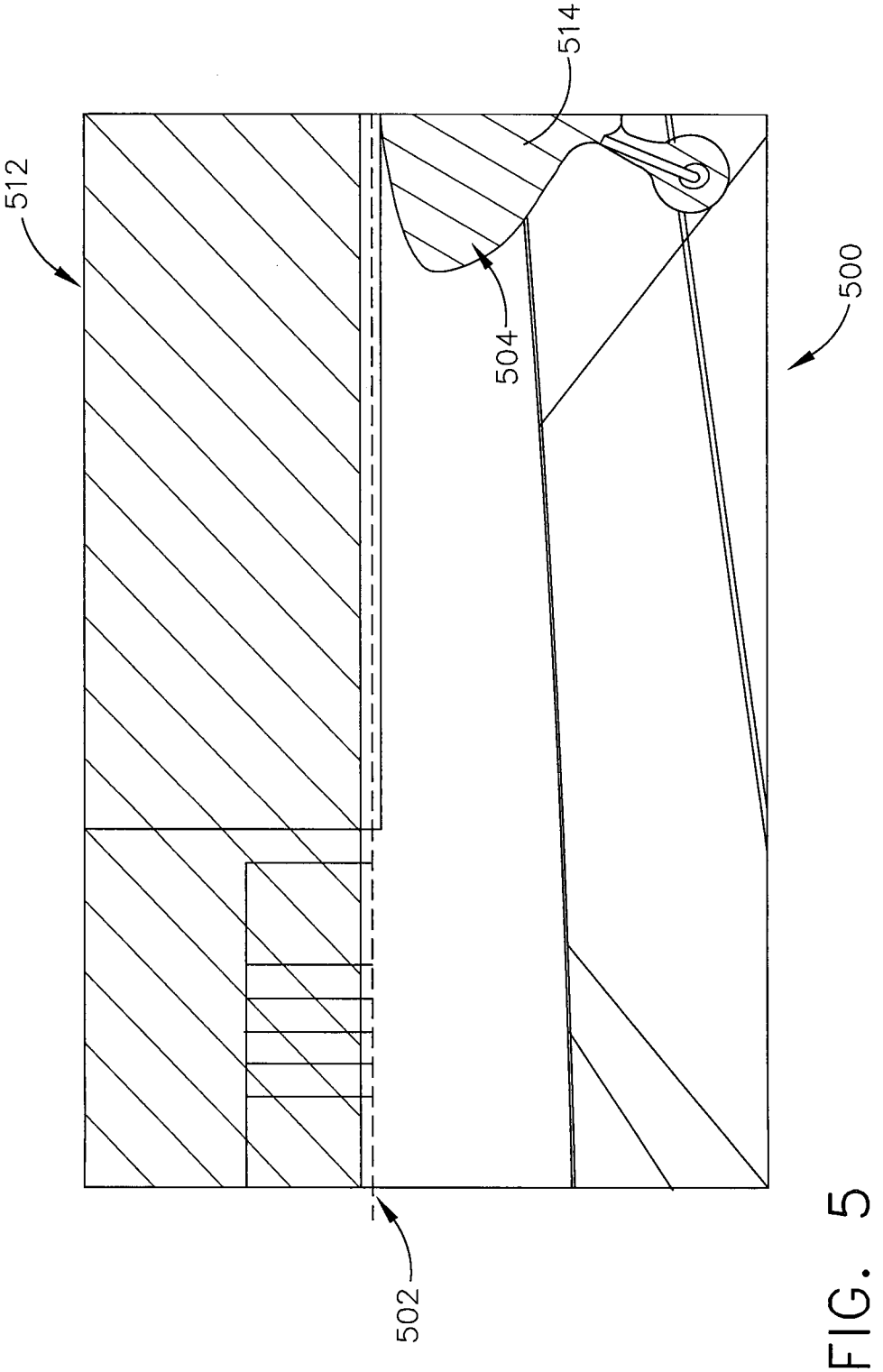


FIG. 5

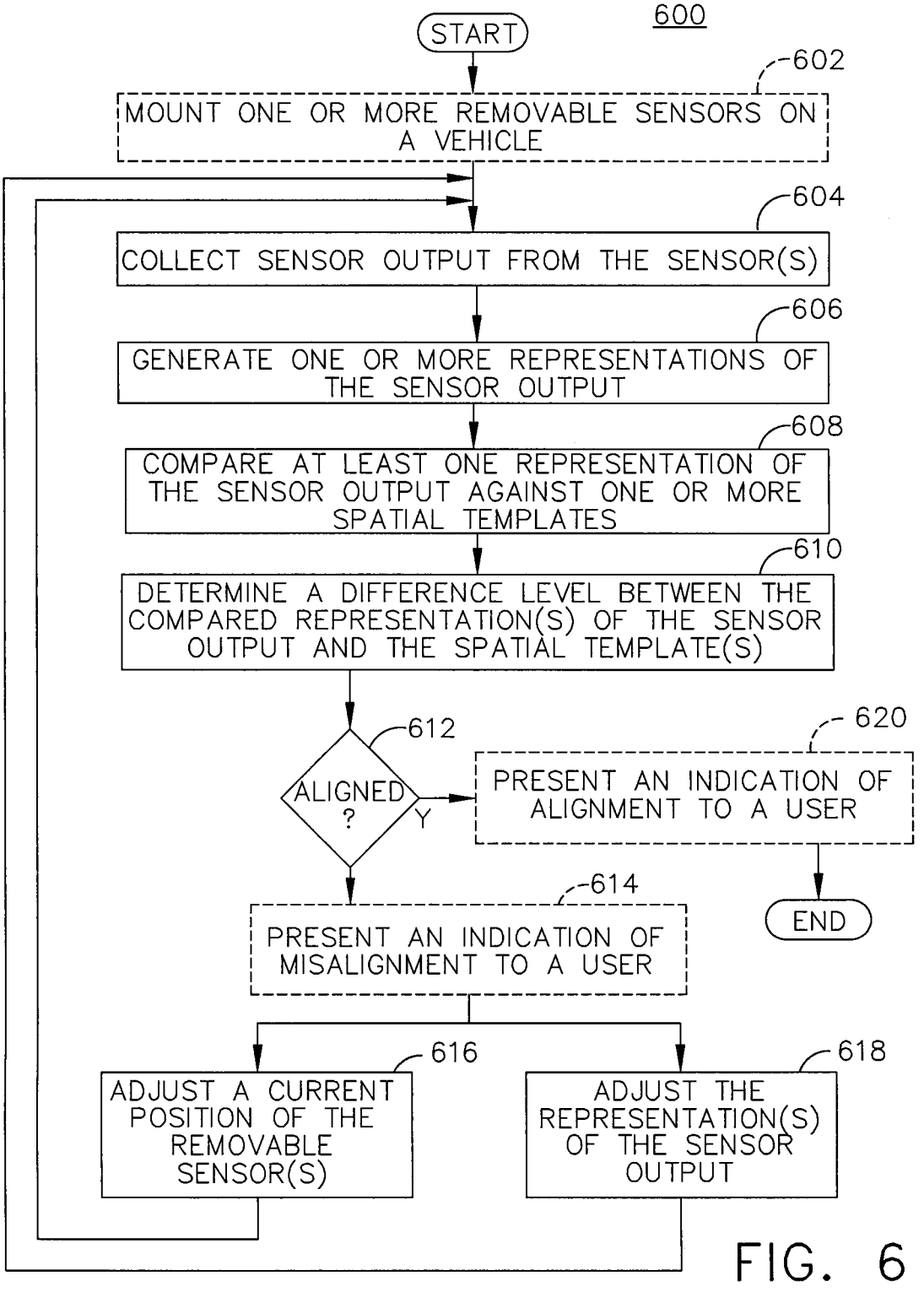
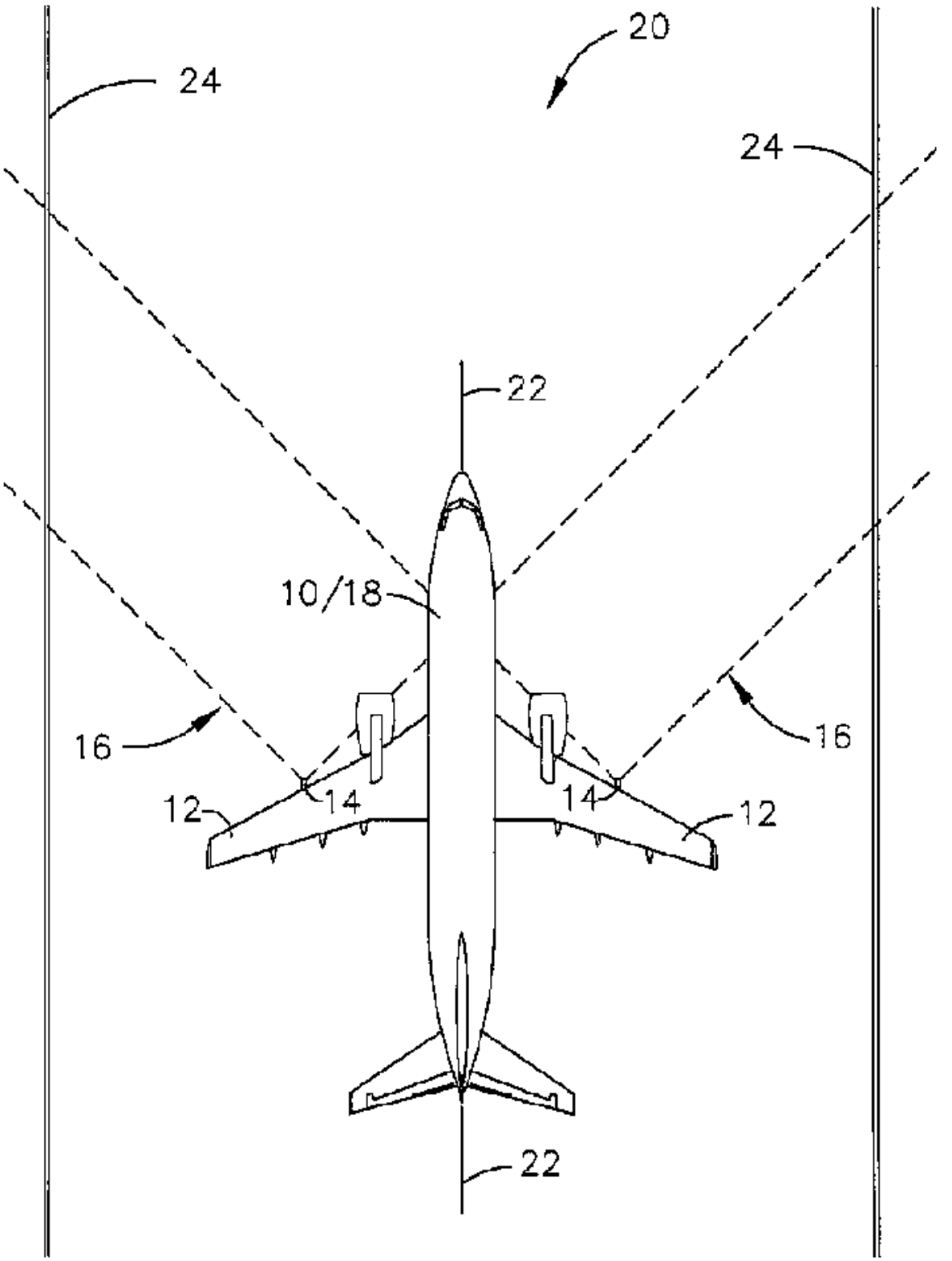

600
START
602
MOUNT ONE OR MORE REMOVABLE SENSORS ON A VEHICLE
604
COLLECT SENSOR OUTPUT FROM THE SENSOR(S)
606
GENERATE ONE OR MORE REPRESENTATIONS OF THE SENSOR OUTPUT
608
COMPARE AT LEAST ONE REPRESENTATION OF THE SENSOR OUTPUT AGAINST ONE OR MORE SPATIAL TEMPLATES
610
DETERMINE A DIFFERENCE LEVEL BETWEEN THE COMPARED REPRESENTATION(S) OF THE SENSOR OUTPUT AND THE SPATIAL TEMPLATE(S)
612
ALIGNED ?
Y
620
PRESENT AN INDICATION OF ALIGNMENT TO A USER
END
614
PRESENT AN INDICATION OF MISALIGNMENT TO A USER
616
ADJUST A CURRENT POSITION OF THE REMOVABLE SENSOR(S)
618
ADJUST THE REPRESENTATION(S) OF THE SENSOR OUTPUT

FIG. 6


20
24
24
22
10/18
16
16
12
14
14
12
22