

# US Patent & Trademark Office

## Patent Public Search | Text View

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United States Patent Application Publication

20250258370

Kind Code

A1

Publication Date

August 14, 2025

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### **METHODS FOR HIGH INTEGRITY HEAD TRACKING FOR HEAD WORN DISPLAY SYSTEM**

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#### **Abstract**

A system and method for spatial tracking is disclosed. The method may include initializing a tracking of light sources. This initialization may involve determining modulation patterns that are mapped to light sources in a spatial arrangement over a time period, where each of the modulation patterns includes a sequence of planned states. The method may include directing an adjustment of a state of the light sources based on the modulation patterns, receiving images over the time period via optical sensors, identifying features based on the images, and correlating the features to the light sources based on the features and the modulation pattern over the time period. The pose may be determined based on at least the correlation, the feature positions, and the spatial arrangement of the light sources, where the pose includes a direction and a position in three-dimensional space.

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**Family ID:** 1000007741030

**Appl. No.:** 18/441670

**Filed:** February 14, 2024

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#### **Publication Classification**

**Int. Cl.:** G02B27/00 (20060101); B64D43/00 (20060101); G02B27/01 (20060101)

**U.S. Cl.:**

**CPC** G02B27/0093 (20130101); B64D43/00 (20130101); G02B27/0172 (20130101); G02B2027/014 (20130101); G02B2027/0187 (20130101)

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## Background/Summary

### TECHNICAL FIELD

[0001] The present disclosure relates generally to tracking, and, more particularly, to tracking using modulation of optical sources.

### BACKGROUND

[0002] Head worn display (HWD) systems (e.g., helmet mounted displays (HMD)) often render (e.g., as symbology or graphical elements) georeferenced objects. If the rendered georeferenced objects do not conform to their real-world views (e.g., within allowable tolerance), the rendered symbology may constitute hazardously misleading information (HMI). Crucial to ensuring HWD conformality is the alignment of the HWD headtracking system to the aircraft platform. For example, the headtracker determines an accurate position and orientation (e.g., pose) of a head of the pilot or crewmember wearing the HWD, relative to the aircraft reference frame (e.g., body frame, platform frame) in order to ensure that imagery and symbology displayed by the HWD is consistent with what the wearer is currently looking at.

[0003] Therefore, there is a need for a system and method that can address one or more of these issues.

### SUMMARY

[0004] A system for spatial tracking is disclosed in accordance with one or more illustrative embodiments of the present disclosure. In one illustrative embodiment, the system may include light sources in a spatial arrangement relative to an object. In another illustrative embodiment, the system may include optical sensors configured to detect the light sources. In another illustrative embodiment, the system may include a controller communicatively coupled to the light sources and the optical sensors. In another illustrative embodiment, the controller may include one or more processors configured to execute a set of program instructions stored in a memory. In another illustrative embodiment, the set of program instructions may be configured to cause the processors to initialize tracking of the light sources. In another illustrative embodiment, the initialization of tracking may include determining modulation patterns that are mapped to the light sources, directing an adjustment of the state of the light sources based on the modulation patterns, receiving images via the optical sensors, identifying features including feature positions based on the images, correlating the features to the light sources, and determining a pose of the object based on the correlation, feature positions, and spatial arrangement of the light sources, where the pose includes a direction and a position in three-dimensional space.

[0005] In a further aspect, the correlating of the features may be further based on search regions of the images, where the search regions are based on at least one of a previous known pose of the object or previously identified feature locations. In another aspect, a particular search region may be configured to be filtered out based on an expected non-viewability of a particular light source relative to a particular optical sensor. In another aspect, the identification of the features may include identifying a group of adjacent pixels based on a brightness of pixels of an image and identifying a centroid of the group of adjacent pixels. In another aspect, the determination of the pose may be based on a selection of the pose from a set of respective poses determined and associated with a respective image of a respective optical sensor. In another aspect, the determination of the pose may be based on a combination of multiple images from multiple optical sensors at a particular point in time. In another aspect, the controller may be further configured to output an optical-inertial pose, via a hybrid module, based on the pose, inertial data via an inertial sensor of the system, and aircraft navigation data via a navigation system of an aircraft. In another aspect, the system may comprise an aircraft-based head worn display (HWD) system and the object may be coupled to at least one of the light sources or the optical sensors. In another aspect, the

object may comprise an aircraft-based head worn display (HWD) sub-system.

[0006] In another aspect, the controller may be further configured for frame by frame tracking of the features based on the feature positions of the initialization of the tracking, where the frame by frame tracking of the features includes a frame pose determined via the frame by frame tracking is based on predicted search regions of the images, where the predicted search regions are determined based on inertial data via an inertial sensor and one or more previous poses. In another aspect, the controller may be further configured to, based on the modulation patterns, adjust for anomalies associated with at least one of a lack of an expected feature or an unexpected feature. In another aspect, a hamming distance defined as a countable number of different simultaneous states over a particular sequence of planned states of a particular modulation pattern may be at least two compared to another modulation pattern. In another aspect, a total number of ON states may be higher than a total number of OFF states for each sequence of planned states of each modulation pattern. In another aspect, the spatial arrangement of the light sources may comprise a non-planar arrangement such that the light sources are spaced out in two orthogonal directions.

[0007] A method for spatial tracking is disclosed in accordance with one or more illustrative embodiments of the present disclosure. In one illustrative embodiment, the method may include initializing a tracking of light sources. In another illustrative embodiment, the initialization may involve determining modulation patterns that are mapped to light sources in a spatial arrangement relative to an object, including a modulation pattern mapped to each light source over a time period, where each of the modulation patterns includes a sequence of planned states comprising an ON state and an OFF state of a corresponding light source. In another illustrative embodiment, the method may include directing an adjustment of a state of the light sources based on the modulation patterns. In another illustrative embodiment, the method may include receiving images over the time period via optical sensors configured to detect the light sources. In another illustrative embodiment, the method may include identifying features including feature positions based on the images over the time period. In another illustrative embodiment, the method may include correlating the features to the light sources based on at least the features over the time period and the modulation pattern over the time period. In another illustrative embodiment, the method may include determining a pose of the object based on at least the correlation, the feature positions, and the spatial arrangement of the light sources, where the pose includes a direction and a position in three-dimensional space.

[0008] In a further aspect, the correlating of the features may be further based on search regions of the images, where the search regions are based on at least one of a previous known pose of the object or previously identified feature locations. In another aspect, the method may include filtering out a particular search region based on an expected non-viewability of a particular light source relative to a particular optical sensor. In another aspect, the identification of the features may include identifying a group of adjacent pixels based on a brightness of pixels of an image of the images and identifying a centroid of the group of adjacent pixels. In another aspect, the determination of the pose may be based on a selection of the pose from a set of respective poses determined and associated with a respective image of a respective optical sensor. In another aspect, the determination of the pose may be based on a combination of multiple images from multiple optical sensors at a particular point in time. In another aspect, the method may include outputting an optical-inertial pose, via a hybrid module, based on the pose, inertial data from an inertial sensor, and aircraft navigation data from a navigation system of an aircraft. In another aspect, the method may be performed using an aircraft-based head worn display (HWD) system and where the object is coupled to at least one of the light sources or the optical sensors of the aircraft-based head worn display (HWD) system. In another aspect, the object may comprise an aircraft-based head worn display (HWD) sub-system. In another aspect, the method may include frame by frame tracking of the features based on the feature positions of the initialization of the tracking, where the frame by frame tracking of the features includes a frame pose determined via the frame by frame

tracking is based on predicted search regions of the images, where the predicted search regions are determined based on inertial data from an inertial sensor and one or more previous poses. In another aspect, the method may include adjusting for anomalies associated with at least one of a lack of an expected feature or an unexpected feature based on the modulation patterns. In another aspect, a hamming distance defined as a countable number of different simultaneous states over a particular sequence of planned states of a particular modulation pattern is at least two compared to another modulation pattern. In another aspect, a total number of ON states is higher than a total number of OFF states for each sequence of planned states of each modulation pattern. In another aspect, the spatial arrangement of the light sources is a non-planar arrangement such that the light sources are spaced out in two orthogonal directions.

[0009] This Summary is provided solely as an introduction to subject matter that is fully described in the Detailed Description and Drawings. The Summary should not be considered to describe essential features nor be used to determine the scope of the Claims. Moreover, it is to be understood that both the foregoing Summary and the following Detailed Description are example and explanatory only and are not necessarily restrictive of the subject matter claimed.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The detailed description is described with reference to the accompanying figures. The use of the same reference numbers in different instances in the description and the figures may indicate similar or identical items. Various embodiments or examples (“examples”) of the present disclosure are disclosed in the following detailed description and the accompanying drawings. The drawings are not necessarily to scale. In general, operations of disclosed processes may be performed in an arbitrary order, unless otherwise provided in the claims.

[0011] FIG. 1 is a simplified block diagram of a system for spatial tracking, in accordance with one or more embodiments of the present disclosure.

[0012] FIG. 2 is a three-dimensional diagram of a spatial arrangement of optical sensors and light sources, in accordance with one or more embodiments of the present disclosure.

[0013] FIG. 3 is a block diagram of a system 138 in a head worn display (HWD) configuration for spatial tracking of a pose of an object 302 such as a HWD or object in the cockpit of an aircraft, in accordance with one or more embodiments of the present disclosure.

[0014] FIG. 4A is a three-dimensional diagram of light sources having a colinear dispersion.

[0015] FIG. 4B is a three-dimensional diagram of light sources spaced out along an area, in accordance with one or more embodiments of the present disclosure.

[0016] FIG. 5 is a two-dimensional diagram of search regions for detecting features, in accordance with one or more embodiments of the present disclosure.

[0017] FIG. 6 is a conceptual flow diagram for spatial tracking using a hybrid module, in accordance with one or more embodiments of the present disclosure.

[0018] FIG. 7 is a conceptual flow block diagram for spatial tracking, in accordance with one or more embodiments of the present disclosure.

[0019] FIG. 8 is a diagram of various anomalies of search regions and features, in accordance with one or more embodiments of the present disclosure.

[0020] FIG. 9 is two views including a first angle view of an object without overlapping search regions, and a second angle view with one of the overlapping search regions being ignored because a feature is predicted to be occluded, thereby preventing an anomaly from occurring, in accordance with one or more embodiments of the present disclosure.

[0021] FIG. 10 is a view of a table of hamming distances, in accordance with one or more embodiments of the present disclosure.

[0022] FIG. **11** is two diagrams of modulation patterns for spatial tracking, in accordance with one or more embodiments of the present disclosure.

[0023] FIG. **12** is a flow diagram illustrating steps performed in a method for spatial tracking, in accordance with one or more embodiments of the present disclosure.

#### DETAILED DESCRIPTION

[0024] Before explaining one or more embodiments of the disclosure in detail, it is to be understood that the embodiments are not limited in their application to the details of construction and the arrangement of the components or steps or methodologies set forth in the following description or illustrated in the drawings. In the following detailed description of embodiments, numerous specific details may be set forth in order to provide a more thorough understanding of the disclosure. However, it will be apparent to one of ordinary skill in the art having the benefit of the instant disclosure that the embodiments disclosed herein may be practiced without some of these specific details. In other instances, well-known features may not be described in detail to avoid unnecessarily complicating the instant disclosure.

[0025] Broadly speaking, embodiments of the inventive concepts disclosed herein are directed to a system and method for spatial tracking of an object using blinking (e.g., ON/OFF) lights such as LEDs. Various concepts may be used for benefits related to computational efficiency and integrity of the tracking.

[0026] FIG. **1** illustrates a simplified block diagram of a system **138** for spatial tracking, in accordance with one or more embodiments of the present disclosure.

[0027] Note that the figures herein such as FIG. **1** are nonlimiting examples and the methodology herein may be used for any number of tracking purposes. For example, any object may be tracked. For example, embodiments herein may be applied to any system **138** with known (fixed) spatial arrangement of blinking LEDs **202** (e.g., see FIG. **3**) viewed by cameras **118**, to track the relative distance and rotation between the LEDs **202** and the cameras **118**. For instance, a runway **302** may be tracked using an aircraft, or vice versa, using optical sensors **118** (e.g., external cameras **118** or light sources **202** on outside of aircraft **100**). In another instance, a head worn display (HWD) of FIG. **2** may be tracked.

[0028] The system **138** may include sensors **118** such as optical sensors **118** configured to track light sources **202**. For example, the system **138** may include multi-pixel cameras **118** for capturing images of light emitting diodes (LEDs) on an object **302** such as a HWD sub-system **304**, a cockpit object (e.g., dashboard), a runway **302**, and/or any other object **302**. Processing (e.g., pose estimation) may occur on-board an aircraft **100** using an aircraft controller **102**, at an off-board controller **124** (e.g., cloud ground-based server), and/or one or more of any number of controllers. For example, use of the term ‘controller **102**’ and the like, unless otherwise specified, means one or more of any number of controllers at any location.

[0029] The system **138** may include (or be) an aircraft-based head worn display (HWD) system **138**. The object **302** may be coupled to at least one of the light sources **202** or the optical sensors **118**. For example, the light sources **202** may be built into (and/or attached to) a housing of a HWD object **302** (e.g., helmet) shown in FIG. **3**. For instance, the object **302** may include (or be) an aircraft-based head worn display (HWD) sub-system **304** with a HWD display **112** screen configured for displaying images (e.g., positioning symbology accurately) based on poses determined herein.

[0030] FIG. **2** illustrates a three-dimensional diagram **200** of a spatial arrangement of optical sensors **118** and light sources **202**, in accordance with one or more embodiments of the present disclosure.

[0031] The spatial arrangement of the light sources **202** may be any arrangement spanning an area. For example, the spatial arrangement of the light sources **202** may be a planar arrangement (e.g., along two axis of a two-dimensional plane on the front of a helmet) such that the light sources **202** are spaced out in two orthogonal directions. In some example, the spatial arrangement of the light

sources **202** may be a non-planar arrangement such that the light sources **202** are spaced out in three orthogonal directions (e.g., around a curved helmet along three axes). ON light sources **202a** include light sources in an ON state (e.g., turned on, activated, and shining out light such as infrared LED light), and OFF light sources **202b** include light sources in an OFF state. The light sources **202** may uniquely blink in a modulation pattern (i.e., turn ON and OFF) for tracking purposes.

[0032] Adjacent light sources **202** may be configured for modulation patterns that are more dissimilar (e.g., a hamming distance **1002** of three or more; see FIG. **10** description for explanation of hamming distance **1002**). Light sources **202c** farther apart (e.g., more than three inches) from each other may be configured for modulation patterns that are more similar (e.g., a hamming distance **1002** of two or less). In this way, closer light sources **202c** may use the more dissimilar blinking modulation patterns so they can be more easily distinguished. This configuration may protect against an erroneous confusion of similar modulation patterns of neighboring light sources **202** caused by positions of search regions **504** being slightly inaccurate.

[0033] The light sources **202** may be any light sources, such as infrared LEDs (IR LEDs) (e.g., non-visible to a human IR LEDs), human-visible LEDs, and/or the like.

[0034] FIG. **3** illustrates a block diagram of a system **138** in a head worn display (HWD) configuration for spatial tracking of a pose of an object **302** such as a HWD or other object in the cockpit of an aircraft **100**, in accordance with one or more embodiments of the present disclosure.

[0035] The system **138** for spatial tracking may include light sources **202** in a spatial arrangement relative to an object **302**.

[0036] The system **138** may also include optical sensors **118** that may be configured to detect/image the light sources **202**.

[0037] A controller **102** (of system **138**) may be communicatively coupled (e.g., wired or wirelessly) to the light sources **202** and the optical sensors **118**.

[0038] The controller **102** may include one or more processors **104** configured to execute a set of program instructions stored in memory **106**. In some embodiments, the controller **102** initializes a tracking of the light sources **202**. This initialization may include determining modulation patterns (e.g., blinking patterns) that are mapped (i.e., unique to a particular light source **202**), over a time period. For example, the time period may be longer than a frame by frame tracking. For instance, the time period may be more than 4 frames, more than 10 milliseconds, more than 100 milliseconds, and/or the like.

[0039] Each of the modulation patterns may include a sequence of planned states (e.g., four or more binary bits of either ON or OFF states) comprising an ON state and an OFF state of a corresponding light source **202**.

[0040] The controller **102** may be configured to direct an adjustment of a state of the light sources **202** based on the modulation patterns (i.e., turn the lights **202** on and off), receive images using the optical sensors **118** over the time period, identify features **502** based on the images, and correlate (e.g., match, compare, pair) the features **502** to the light sources **202** based on at least the features over the time period and the modulation pattern over the time period.

[0041] The controller **102** may also be configured to determine a pose of the object **302** based on at least the correlation, the feature positions, and the spatial arrangement of the light sources **202**. The pose may include a direction (e.g., vector) and a position in three-dimensional space. For instance, the pose may include all six degrees of freedom (e.g., three angles of an orientation, and three coordinates of a position).

[0042] The correlation of the features **502** may be based on search regions **504** of the images. Correlation in this context means knowing which light sources **118** are matched with which features **502** in the images, such as by comparing the modulation patterns. Such a comparison may be done over multiple frames so at least a portion of the modulation patterns is able to be determined. But correlation may also be done frame by frame (e.g., using a single image), to

maintain correlation, once the tracking is initialized. This may make the computation more efficient and more accurate to maintain tracking. The search regions **504** may be based on at least one of a previous known pose of the object **302** (to determine a predicted search region **504**) or previously identified feature locations (e.g., two-dimensional coordinates of the image such as a centroid of each feature **502**) (to determine a static search region **504**).

[0043] FIG. **4A** illustrates a three-dimensional diagram of ON light sources **202** having a colinear dispersion. This may lead to worse performance if the tracking of features **502** are all along the same axis as that may cause limitations in detecting rotations along the same axis. Rather, as noted above, the light sources **118** may be spread over a two-dimensional area to improve tracking.

[0044] FIG. **4B** illustrates a three-dimensional diagram of ON light sources **202** spaced out along an area (e.g., X-axis and Y-axis; any two orthogonal axis; or the like), in accordance with one or more embodiments of the present disclosure.

[0045] FIG. **5** illustrates a two-dimensional diagram **500** of search regions **504** for detecting features **502** of an image, in accordance with one or more embodiments of the present disclosure.

[0046] The identification of the features **502** (e.g., of step **1240** of FIG. **12**) may include identifying a group of adjacent pixels **506** of an image based on a brightness of pixels and identifying a centroid (e.g., midpoint in X and Y direction) of the group of adjacent pixels **506**. This may approximate the center of the light source **202**. For instance, the centroid may be a sub-pixel accuracy measurement (e.g., a centroid of two pixels may be 0.5 between a pixel at location 0 and a pixel at location 1).

[0047] The image may be processed in binary, such that all pixels above a certain brightness threshold are set to 1 (e.g., white) and the other pixels are set to 0 (e.g., black). For example, a threshold cutoff may be used as a filter to produce such a binary image. Then adjacent pixels of value 1 may be grouped in the groups of adjacent pixels **506**. In embodiments, these groups **506** are identified if the groups **506** are located within a search region **504**, or else filtered out (e.g., ignored; logged as an anomaly; and/or the like).

[0048] FIG. **6** illustrates a conceptual flow diagram of a method **600** for spatial tracking using a hybrid module, in accordance with one or more embodiments of the present disclosure.

[0049] The method **600** may include a blink pattern synchronization step **602** (e.g., adjusting the states of the light sources **202** and syncing a global time with the optical sensors **118**.) For example, a common controller **102** may use timestamps (e.g., 2024-01-14T15:30:00.123) to know which images were taken at the same time as when a particular pattern of light sources **202** were in their ON states so proper correlation may be performed.

[0050] Alternatively, in some embodiments, a blink pattern synchronization (using an initial syncing of global timestamps or the like between images and light sources **202**) is not necessarily used. For example, it may not be known which light sources **202** are in an ON state during which image frame. For example, the method **600** may include an alternate syncing using the modulation pattern without necessarily knowing (or relying on) a timestamp at which an image was taken. For instance, the blinking patterns of the features **502** may be compared to the known modulation patterns to determine which images correspond/match to which timing of the sequences of the known modulation patterns. Multiple images over multiple frames may be used to determine a portion of a blinking pattern for a portion of the features **502**. Then the portion of the blinking patterns (i.e., modulation patterns) for the portion of the features **502** may be compared to a sliding window of each possible range of times and corresponding states at those ranges that could be a match. If the modulation patterns are unique enough over time with respect to other modulation patterns (e.g., if a particular modulation pattern is not merely a time-shifted copy of other modulation patterns), then a single global timing may be determined-solving for the timing of the received images in relation to the modulation patterns. An advantage may include not necessarily sending or receiving a common time reference between the image detectors **118** and the light sources **202** and allowing for receiving images at any time. However, in some embodiments, this

configuration may use relatively longer modulation patterns, and longer initializations of tracking to avoid using time-shifted versions of the same modulation patterns.

[0051] The method **600** may include an image processing step **604**, such as processing the image using controller **102**. For example, one or more steps to identify the features **502** may be used such as, but not necessarily limited to or requiring, applying binary filters to the image (e.g., so pixels are either 0 or 1); grouping adjacent pixels **506** with value of 1 (e.g., bright pixels); and measuring and calculating a centroid of each group **506**.

[0052] The method **600** may include calculating a pose step **608** (e.g., optical head pose based on optical/camera images). For example, knowledge of the spatial arrangement **612** (i.e., 3D constellation data **612**) of the light sources **202** and any analysis/data from step **604** may be used to determine the pose. For instance, the feature positions of the features **502** (after being correlated to their corresponding light sources **202**) may be used to deterministically calculate the orientation and position of the headset, as having enough light sources **202** dispersed in enough directions allows for a single mathematical solution of pose. For instance, the light sources **202** may be calibrated such that a feature position defines a position or set of positions that limits where each light source **202** could be in space. For example, each pixel of a calibrated optical detector **118** may correspond to a virtual vector extending from the optical detector **118** in three-dimensional space. For instance, at least in theory using perfect measurements, two light sources **202** with a known distance between each other and known to be constrained to two non-parallel virtual vectors already can be used to solve for five of the six degrees of freedom using a single image if the image is perfectly calibrated for and a high enough resolution. In practice, additional light sources **202** may be used for increased accuracy and for solving for all degrees of freedom. For instance, the system **138** may include three or more light sources **202**.

[0053] The method **600** may include a hybrid module **606** (e.g., set of program instructions such as computer code such as C++, Python, etc.; hardware implemented functions such as field programmable gate arrays (FPGAs); and/or the like) to determine an optical-inertia pose relative to an inertial reference frame. For example, the controller **102** may be configured to output an optical-inertial pose, via a hybrid module **606**, based on the pose (i.e., optical pose), inertial data (e.g., accelerometer data) via an inertial sensor **140** of the system **138**, and aircraft navigation data **614** (e.g., aircraft position data, aircraft inertia data) via a navigation system **120** of an aircraft **100**. The inertia data of a, for example, (HWD) sub-system **304** may be used to increase the accuracy of a subsequent (e.g., final) pose estimation. For instance, the optical-inertia pose may be estimated using the inertial data of the inertial sensor **140** for a point in time after the last image was captured (e.g., a current point in time, a point in time slightly in the future, and/or the like). For example, the optical pose may be determined at discrete instances of time (for every image) and the optical-inertia pose may be determined at one or more discrete instances of time between each optical pose. The optical-inertia pose may be based on inertial data such as estimated velocity (e.g., translational velocity in 3D space, and rotational velocity around each axis). For instance, an optical-inertia position may be determined by a calculation based on a simplified equation such as  $\text{current\_position} * \text{translational\_velocity} * \text{time}$ . Such a configuration may provide a higher rate of update of the pose than just an optical pose. Such a configuration may provide robustness as well, such as allowing a fallback determination of a pose even after one or more failed/lost images, by relying on the inertia data. This may increase integrity of the system **138**.

[0054] The HWD may receive coordinates and information related to world-referenced symbology data **616** (e.g., known positions of real-world external objects/features in a global coordinate system). The alignment/position of symbols in a HWD may need to adjust for changes to an aircraft's **100** own movement/orientation, if the system **138** is to properly use real-world external objects. A symbology alignment (to real-world features) module **618** may be configured to align (e.g., render in a certain position of a display **112**) earth-fixed symbology (e.g., text/symbols rendered to float above an external real-world feature). For example, the symbology alignment



module **618** may determine an alignment of a symbol based on the pose (e.g., optical-inertial pose) and world-referenced symbology data **616**.

[0055] FIG. 7 illustrates a conceptual flow block diagram of a method **700** for spatial tracking, in accordance with one or more embodiments of the present disclosure.

[0056] The method **700** may include an updating of (light source **202**) feature states **702** (step). For example, an adjustment of the state of the light sources **202** may be made based on the modulation pattern, which may include step **1220** of FIG. 12.

[0057] The method **700** may include capturing images **704** (step), such as receiving images using the optical sensors **118**.

[0058] The method **700** may include extracting two-dimensional features **706** (step), which may include step **604** of FIG. 6 and/or step **1240** of FIG. 12. For example, features **502** may be identified by grouping white pixels together.

[0059] The method **700** may then apply a determination of initialization in step **708**. For example, the system **138** may use an if-then statement to decide which type of search region **504** (e.g., predicted or static) to use to correlate the features **502** based on whether the tracking of the light sources **202** has happened (e.g., whether steps **1202** of FIG. 12 are complete).

[0060] If the determination is positive (e.g., tracking initialization affirmed), then a step **710** that is based on pose-based predicted search regions **504** may be used, based on a previous pose already known. For example, the locations of the features **502** may be able to be predicted based on the pose of the last frame. For instance, an optical-inertia pose may be used to predict where the search regions **504** will move to between image frames. This may allow for more advanced anomaly mitigation, such as being able to know which features **502** are supposed to be ON or OFF or overlapping ahead of time. For instance, an anticipation of a rotation of a HWD helmet around a Y-axis (vertical axis) based on inertia data applied to a previous pose, may allow a prediction that in the next image frame, two features **502** will overlap and/or some of the features **502** will shift to the left a couple of pixels. This prediction may include calculating a change in position of each feature **502** based on a manipulation/movement of a 3D model of the spatial arrangement of the light sources **202** as viewed from an optical sensor **118**.

[0061] If the determination is negative (e.g., tracking initialization not yet completed), then a step **712** that is based on a static search region **504** may be used. For example, the static search region **504** may be based on a centroid of the features **502**. For instance, feature locations from a previous frame may be used as a center of a search region to maintain consistency of tracking each feature **502** separately. In this way, for example, a feature may be tracked over multiple frames to determine the blinking/modulation pattern over time, for correlation. As a new centroid is calculated, then a new static search region **504** location is updated for the next frame. This method does not necessarily require knowing which features **502** are correlated to which light sources **202** and may be used in initialization.

[0062] The method **700** may then find feature correspondence **714** (e.g., correlating the features **502** in step **1250** of FIG. 12).

[0063] The method **700** may then calculate head pose **716** (e.g., determine the pose in step **1260** of FIG. 12).

[0064] FIG. 8 illustrates a diagram **800** of various anomalies **802**, **804**, **806** of search regions **504** and features **502**, in accordance with one or more embodiments of the present disclosure.

[0065] The controller **102** may be further configured to, based on the modulation patterns, adjust for anomalies **802**, **804**, **806** associated with at least one of a lack of an expected feature **502** or an unexpected feature **502**. For example, an anomaly **804** of an unexpected feature **502** in an OFF region **508** (e.g., where the light source **202** should be in an OFF state based on the modulation pattern) may be filtered out (e.g., ignored and not included in the features). An anomaly **802** of an additional feature **502** in the same search region **504** may be ignored (e.g., one or all of such features **502** may be filtered out). A missing anomaly **806** of an expected (but missing) feature (not

labeled) in a search region **504** may be adjusted for by allowing a certain number of missed features **502** (e.g., more than 30% of features **502** missing) before an initialization of tracking is restarted.

[0066] FIG. **9** is two views including a first angle view **900** of an object **302** without overlapping search regions **504**, and a second angle view **902** with an overlapping search region **504** being ignored because a feature **502** is predicted to be occluded (e.g., occluded by HWD plastic housing), thereby preventing an anomaly from occurring, in accordance with one or more embodiments of the present disclosure.

[0067] A particular search region **504** may be configured to be filtered out based on an expected non-viewability of a particular light source **202** relative to a particular optical sensor **118**.

[0068] For example, the system **138** may calculate known occlusions that will be likely or nearly likely to occur based on a position of a light source **202** and an optical sensor **118** on the opposite side of something (e.g., an object **302**). For instance, the optical sensor **118** may be on the opposing side of a plastic housing of the HWD, and therefore unable to be seen by the optical sensor **118**.

[0069] FIG. **10** illustrates a table **1000** of hamming distances **1002** (e.g., quantifiable difference between two patterns of bits, in accordance with one or more embodiments of the present disclosure. For example, 1001 and 0111 have a hamming distance of three because the first three bits are different.

[0070] The modulation patterns may be based on (and/or characterized by) a hamming distance **1002**. For example, for purposes of the present disclosure, a hamming distance **1002** is defined as a countable number of different simultaneous states (e.g., ON state vs. OFF state at the same time) over a particular sequence of planned states of particular modulation patterns. For instance, the determining modulation patterns of step **1210** may be based on a hamming distance **1002** of at least two. For instance, the determining modulation patterns of step **1210** may be based on a hamming distance **1002** of at least four. For example, each modulation pattern may include some number of bits (e.g., 12 bits) and at least two of those bits may be different at a particular point in time compared to all other modulation patterns of the other light sources **118**. This may allow for (and/or aid in) unique identification of each light source **118** during the correlation of the features **502**.

[0071] FIG. **11** illustrates diagrams **1100**, **1102** of modulation patterns for spatial tracking, in accordance with one or more embodiments of the present disclosure.

[0072] The features **502a** in an ON state that are imaged, may outnumber features **502b** in an OFF state that are not identified because they are OFF. For example, a total number of ON states may be higher than a total number of OFF states for each sequence of planned states of each modulation pattern. In this way, the system **138** may bias to increase identification of each light source **118** by having the light sources **118** in an ON state most of the time.

[0073] FIG. **12** illustrates a flow diagram illustrating steps performed in a method **1200** for spatial tracking, in accordance with one or more embodiments of the present disclosure.

[0074] At step **1202**, the tracking of the light sources **202** may be initialized (e.g., started). For instance, the system **138** may be configured to initiate a tracking based on a tracking of the features **502** being lost (such as losing tracking due to a large occlusion) and/or when the system **138** is turned on.

[0075] At step **1210** (e.g., sub-step **1210**), modulation patterns that are mapped to light sources **202** in a spatial arrangement relative to an object **302** may be determined.

[0076] At step **1220**, an adjustment of a state of the light sources **202** may be directed based on the modulation patterns.

[0077] At step **1230**, features **502** and feature locations (e.g., centroid or the like) may be identified based on the images.

[0078] At step **1240**, images over the time period may be received via optical sensors **118** that may be configured to detect the light sources **202**.

[0079] At step **1250**, the features **502** may be correlated to the light sources **202**. For example, the

states of the features **502** may be matched/compared to the states of the modulation patterns that control the light sources **202**, which may be stored/determined using the controller **102**. The correlation may take longer during step **1202** of initializing if a previous pose is not yet known. [0080] At step **1260**, a pose of an object **302** based on at least the correlation of step **1250** (e.g., where each feature **502** is now known as matched to a particular optical sensor **118** based on the modulation patterns), the feature positions (e.g., pixel positions of the centroids of each feature **502**), and a spatial arrangement of the light sources **202** (e.g., a known distance in space between fixed locations of each of the light sources **202**). For example, the spatial arrangement may be based on a computer design (e.g., 3D model) of the light sources **202**, manually measured distances, triangulated distances during a calibration mode, and/or the like. The spatial arrangement of the light sources **202** may be mapped to the feature locations based on the correlation of step **1250** and the pose then known relative to the optical sensors **118**. For example, the optical sensors **118** may be calibrated to triangulate two dimensional locations in images of at least three optical sensors **118** to real-world three-dimensional coordinates of a pose.

[0081] At an optional step, a frame by frame tracking of the features **502** is performed based on the feature positions of the initialization of the tracking. For example, once step **1202** is performed, the controller **102** may enter a separate mode where tracking of the features **502** to generate a pose is performed for each frame, rather than over multiple frames. The frame by frame tracking of the features **502** may include a frame pose determined via the frame by frame tracking based on predicted search regions **504** of the images. The predicted search regions **504** may be determined based on inertial data via an inertial sensor **140** and may be based on one or more previous poses (e.g., previous frame by frame poses, or the last (and/or only) pose determine in step **1202**).

[0082] The feature locations and/or pose may be determined, in some embodiments, using a monocular image (e.g., image from a single optical sensor **118**). In some embodiments, the feature locations and/or pose may be determined using multiple images (for more accuracy, such as using triangulation).

[0083] The determination of the pose may be based on a selection of the pose from a set of respective poses determined and associated with a respective image of a respective optical sensor **118**. For example, each optical sensor **118** may be used independently to determine a pose, and then a particular pose from a set of poses from multiple cameras **118** may be selected as the most accurate. For instance, any method may be used such as choosing the pose determined using an image having the least number of anomalies; using the pose that is the median of all of the poses to avoid outliers; and/or the like.

[0084] The determination of the pose may, alternatively and/or in addition, be based on a combination of multiple images from multiple optical sensors **118** at a particular point in time. For example, the pose may be based on an average of poses from multiple optical sensors **118**, or the features **502** may individually be triangulated (e.g., using three optical sensors **118**) across multiple images in three-dimensional space.

[0085] Referring now to FIG. **1**, the aircraft **100** may include an aircraft controller **102** (e.g., on-board/run-time controller). The aircraft controller **102** may include one or more processors **104**, memory **106** configured to store one or more program instructions **108**, and/or one or more communication interfaces **110**.

[0086] The aircraft **100** may include an avionics environment such as, but not limited to, a cockpit. The aircraft controller **102** may be coupled (e.g., physically, electrically, and/or communicatively) to one or more display devices **112**. The one or more display devices **112** may be configured to display three-dimensional images and/or two-dimensional images.

[0087] The aircraft controller **102** may be coupled (e.g., physically, electrically, and/or communicatively) to one or more user input devices **114**. The one or more display devices **112** may be coupled to the one or more user input devices **114**. For example, the one or more display devices **112** may be coupled to the one or more user input devices **114** by a transmission medium that may

include wireline and/or wireless portions. The one or more display devices **112** may include and/or be configured to interact with one or more user input devices **114**.

[0088] The one or more display devices **112** and the one or more user input devices **114** may be standalone components within the aircraft **100**. It is noted herein, however, that the one or more display devices **112** and the one or more user input devices **114** may be integrated within one or more common user interfaces **116**.

[0089] Where the one or more display devices **112** and the one or more user input devices **114** are housed within the one or more common user interfaces **116**, the aircraft controller **102**, one or more offboard controllers **124**, and/or the one or more common user interfaces **116** may be standalone components. It is noted herein, however, that the aircraft controller **102**, the one or more offboard controllers **124**, and/or the one or more common user interfaces **116** may be integrated within one or more common housings or chassis.

[0090] The aircraft controller **102** may be coupled (e.g., physically, electrically, and/or communicatively) to and configured to receive data from one or more aircraft sensors **118**. The one or more aircraft sensors **118** may be configured to sense a particular condition(s) external or internal to the aircraft **100** and/or within the aircraft **100**. The one or more aircraft sensors **118** may be configured to output data associated with particular sensed condition(s) to one or more components/systems onboard the aircraft **100**. Generally, the one or more aircraft sensors **118** may include, but are not limited to, one or more airspeed sensors, one or more radio altimeters, one or more flight dynamic sensors (e.g., sensors configured to sense pitch, bank, roll, heading, and/or yaw), one or more weather radars, one or more air temperature sensors, one or more surveillance sensors, one or more air pressure sensors, one or more engine sensors, and/or one or more optical sensors (e.g., one or more cameras configured to acquire images in an electromagnetic spectrum range including, but not limited to, the visible light spectrum range, the infrared spectrum range, the ultraviolet spectrum range, or any other spectrum range known in the art).

[0091] The aircraft controller **102** may be coupled (e.g., physically, electrically, and/or communicatively) to and configured to receive data from one or more navigational systems **120**. The one or more navigational systems **120** may be coupled (e.g., physically, electrically, and/or communicatively) to and in communication with one or more GPS satellites **122**, which may provide vehicular location data (e.g., aircraft location data) to one or more components/systems of the aircraft **100**. For example, the one or more navigational systems **120** may be implemented as a global navigation satellite system (GNSS) device, and the one or more GPS satellites **122** may be implemented as GNSS satellites. The one or more navigational systems **120** may include a GPS receiver and a processor. For example, the one or more navigational systems **120** may receive or calculate location data from a sufficient number (e.g., at least four) of GPS satellites **122** in view of the aircraft **100** such that a GPS solution may be calculated.

[0092] It is noted herein the one or more aircraft sensors **118** may operate as a navigation device **120**, being configured to sense any of various flight conditions or aircraft conditions typically used by aircraft and output navigation data (e.g., aircraft location data, aircraft orientation data, aircraft direction data, aircraft speed data, and/or aircraft acceleration data). For example, the various flight conditions or aircraft conditions may include altitude, aircraft location (e.g., relative to the earth), aircraft orientation (e.g., relative to the earth), aircraft speed, aircraft acceleration, aircraft trajectory, aircraft pitch, aircraft bank, aircraft roll, aircraft yaw, aircraft heading, air temperature, and/or air pressure. By way of another example, the one or more aircraft sensors **118** may provide aircraft location data and aircraft orientation data, respectively, to the one or more processors **104**, **126**.

[0093] The aircraft controller **102** of the aircraft **100** may be coupled (e.g., physically, electrically, and/or communicatively) to one or more offboard controllers **124**.

[0094] The one or more offboard controllers **124** may include one or more processors **126**, memory **128** configured to store one or more programs instructions **130** and/or one or more communication

interfaces **132**.

[0095] The aircraft controller **102** and/or the one or more offboard controllers **124** may be coupled (e.g., physically, electrically, and/or communicatively) to one or more satellites **134**. For example, the aircraft controller **102** and/or the one or more offboard controllers **124** may be coupled (e.g., physically, electrically, and/or communicatively) to one another via the one or more satellites **134**. For instance, at least one component of the aircraft controller **102** may be configured to transmit data to and/or receive data from at least one component of the one or more offboard controllers **124**, and vice versa. By way of another example, at least one component of the aircraft controller **102** may be configured to record event logs and may transmit the event logs to at least one component of the one or more offboard controllers **124**, and vice versa. By way of another example, at least one component of the aircraft controller **102** may be configured to receive information and/or commands from the at least one component of the one or more offboard controllers **124**, either in response to (or independent of) the transmitted event logs, and vice versa.

[0096] It is noted herein that the aircraft **100** and the components onboard the aircraft **100**, the one or more offboard controllers **124**, the one or more GPS satellites **122**, and/or the one or more satellites **134** may be considered components of a system **138**, for purposes of the present disclosure.

[0097] The one or more processors **104**, **126** may include any one or more processing elements, micro-controllers, circuitry, field programmable gate array (FPGA) or other processing systems, and resident or external memory for storing data, executable code, and other information accessed or generated by the aircraft controller **102** and/or the one or more offboard controllers **124**. In this sense, the one or more processors **104**, **126** may include any microprocessor device configured to execute algorithms and/or program instructions. It is noted herein, however, that the one or more processors **104**, **126** are not limited by the materials from which it is formed or the processing mechanisms employed therein and, as such, may be implemented via semiconductor(s) and/or transistors (e.g., using electronic integrated circuit (IC) components), and so forth. In general, the term “processor” may be broadly defined to encompass any device having one or more processing elements, which execute a set of program instructions from a non-transitory memory medium (e.g., the memory), where the set of program instructions is configured to cause the one or more processors to carry out any of one or more process steps.

[0098] The memory **106**, **128** may include any storage medium known in the art suitable for storing the set of program instructions executable by the associated one or more processors. For example, the memory **106**, **128** may include a non-transitory memory medium. For instance, the memory **106**, **128** may include, but is not limited to, a read-only memory (ROM), a random access memory (RAM), a magnetic or optical memory device (e.g., disk), a magnetic tape, a solid state drive, flash memory (e.g., a secure digital (SD) memory card, a mini-SD memory card, and/or a micro-SD memory card), universal serial bus (USB) memory devices, and the like. The memory **106**, **128** may be configured to provide display information to the display device (e.g., the one or more display devices **112**). In addition, the memory **106**, **128** may be configured to store user input information from a user input device of a user interface. The memory **106**, **128** may be housed in a common controller housing with the one or more processors. The memory **106**, **128** may, alternatively or in addition, be located remotely with respect to the spatial location of the processors and/or a controller. For instance, the one or more processors and/or the controller may access a remote memory (e.g., server), accessible through a network (e.g., internet, intranet, and the like).

[0099] The aircraft controller **102** and/or the one or more offboard controllers **124** may be configured to perform one or more process steps, as defined by the one or more sets of program instructions **108**, **130**. The one or more process steps may be performed iteratively, concurrently, and/or sequentially. The one or more sets of program instructions **108**, **130** may be configured to operate via a control algorithm, a neural network (e.g., with states represented as nodes and hidden

nodes and transitioning between them until an output is reached via branch metrics), a kernel-based classification method, a Support Vector Machine (SVM) approach, canonical-correlation analysis (CCA), factor analysis, flexible discriminant analysis (FDA), principal component analysis (PCA), multidimensional scaling (MDS), principal component regression (PCR), projection pursuit, data mining, prediction-making, exploratory data analysis, supervised learning analysis, Boolean logic (e.g., resulting in an output of a complete truth or complete false value), fuzzy logic (e.g., resulting in an output of one or more partial truth values instead of a complete truth or complete false value), or the like. For example, in the case of a control algorithm, the one or more sets of program instructions **108, 130** may be configured to operate via proportional control, feedback control, feedforward control, integral control, proportional-derivative (PD) control, proportional-integral (PI) control, proportional-integral-derivative (PID) control, or the like.

[0100] The one or more communication interfaces **110, 132** may be operatively configured to communicate with one or more components of the aircraft controller **102** and/or the one or more offboard controllers **124**. For example, the one or more communication interfaces **110, 132** may also be coupled (e.g., physically, electrically, and/or communicatively) with the one or more processors **104, 126** to facilitate data transfer between components of the one or more components of the aircraft controller **102** and/or the one or more offboard controllers **124** and the one or more processors **104, 126**. For instance, the one or more communication interfaces **110, 132** may be configured to retrieve data from the one or more processors **104, 126**, or other devices, transmit data for storage in the memory **106, 128**, retrieve data from storage in the memory **106, 128**, or the like. By way of another example, the aircraft controller **102** and/or the one or more offboard controllers **124** may be configured to receive and/or acquire data or information from other systems or tools by a transmission medium that may include wireline and/or wireless portions. By way of another example, the aircraft controller **102** and/or the one or more offboard controllers **124** may be configured to transmit data or information (e.g., the output of one or more procedures of the inventive concepts disclosed herein) to one or more systems or tools by a transmission medium that may include wireline and/or wireless portions (e.g., a transmitter, receiver, transceiver, physical connection interface, or any combination). In this regard, the transmission medium may serve as a data link between the aircraft controller **102** and/or the one or more offboard controllers **124** and the other subsystems (e.g., of the aircraft **100** and/or the system **138**). In addition, the aircraft controller **102** and/or the one or more offboard controllers **124** may be configured to send data to external systems via a transmission medium (e.g., network connection).

[0101] The one or more display devices **112** may include any display device known in the art. For example, the display devices **112** may include, but are not limited to, one or more head-down displays (HDDs), one or more HUDs, one or more multi-function displays (MFDs), or the like. For instance, the display devices **112** may include, but are not limited to, a liquid crystal display (LCD), a light-emitting diode (LED) based display, an organic light-emitting diode (OLED) based display, an electroluminescent display (ELD), an electronic paper (E-ink) display, a plasma display panel (PDP), a display light processing (DLP) display, or the like. Those skilled in the art should recognize that a variety of display devices may be suitable for implementation in the present invention and the particular choice of display device may depend on a variety of factors, including, but not limited to, form factor, cost, and the like. In a general sense, any display device capable of integration with the user input device (e.g., touchscreen, bezel mounted interface, keyboard, mouse, trackpad, and the like) is suitable for implementation in the present invention.

[0102] The one or more user input devices **114** may include any user input device known in the art. For example, the user input device **114** may include, but is not limited to, a keyboard, a keypad, a touchscreen, a lever, a knob, a scroll wheel, a track ball, a switch, a dial, a sliding bar, a scroll bar, a slide, a handle, a touch pad, a paddle, a steering wheel, a joystick, a bezel input device, or the like. In the case of a touchscreen interface, those skilled in the art should recognize that a large number of touchscreen interfaces may be suitable for implementation in the present invention. For instance,

the display device may be integrated with a touchscreen interface, such as, but not limited to, a capacitive touchscreen, a resistive touchscreen, a surface acoustic based touchscreen, an infrared based touchscreen, or the like. In a general sense, any touchscreen interface capable of integration with the display portion of a display device is suitable for implementation in the present invention. In another embodiment, the user input device may include, but is not limited to, a bezel mounted interface.

[0103] As used herein a letter following a reference numeral is intended to reference an embodiment of the feature or element that may be similar, but not necessarily identical, to a previously described element or feature bearing the same reference numeral (e.g., 1, 1a, 1b). Such shorthand notations are used for purposes of convenience only and should not be construed to limit the disclosure in any way unless expressly stated to the contrary.

[0104] Further, unless expressly stated to the contrary, “or” refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0105] In addition, use of “a” or “an” may be employed to describe elements and components of embodiments disclosed herein. This is done merely for convenience and “a” and “an” are intended to include “one” or “at least one,” and the singular also includes the plural unless it is obvious that it is meant otherwise.

[0106] Finally, as used herein any reference to “in embodiments”, “one embodiment” or “some embodiments” means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment disclosed herein. The appearances of the phrase “in some embodiments” in various places in the specification are not necessarily all referring to the same embodiment, and embodiments may include one or more of the features expressly described or inherently present herein, or any combination or sub-combination of two or more such features, along with any other features which may not necessarily be expressly described or inherently present in the instant disclosure.

[0107] It is to be understood that embodiments of the methods disclosed herein may include one or more of the steps described herein. Further, such steps may be carried out in any desired order and two or more of the steps may be carried out simultaneously with one another. Two or more of the steps disclosed herein may be combined in a single step, and in some embodiments, one or more of the steps may be carried out as two or more sub-steps. Further, other steps or sub-steps may be carried in addition to, or as substitutes to one or more of the steps disclosed herein.

[0108] Although inventive concepts have been described with reference to the embodiments illustrated in the attached drawing figures, equivalents may be employed and substitutions made herein without departing from the scope of the claims. Components illustrated and described herein are merely examples of a system/device and components that may be used to implement embodiments of the inventive concepts and may be replaced with other devices and components without departing from the scope of the claims. Furthermore, any dimensions, degrees, and/or numerical ranges provided herein are to be understood as non-limiting examples unless otherwise specified in the claims.

## Claims

1. A system for spatial tracking, the system comprising: light sources in a spatial arrangement relative to an object; optical sensors configured to detect the light sources; and a controller communicatively coupled to the light sources and the optical sensors, wherein the controller comprises one or more processors configured to execute a set of program instructions stored in a memory, the set of program instructions configured to cause the one or more processors to: initialize a tracking of the light sources comprising: determining modulation patterns that are

mapped to the light sources, including a modulation pattern mapped to each light source over a time period, wherein each of the modulation patterns comprises a sequence of planned states comprising an ON state and an OFF state of a corresponding light source; directing an adjustment of a state of the light sources based on the modulation patterns; receiving images via the optical sensors over the time period; identifying features including feature positions of the features based on the images over the time period; correlating the features to the light sources based on at least the features over the time period and the modulation pattern over the time period; and determine a pose of the object based on at least the correlation, the feature positions, and the spatial arrangement of the light sources, wherein the pose comprises a direction and a position in three-dimensional space.

2. The system of claim 1, wherein the correlating of the features is further based on search regions of the images, wherein the search regions are based on at least one of a previous known pose of the object or previously identified feature locations.
3. The system of claim 2, wherein a particular search region is configured to be filtered out based on an expected non-viewability of a particular light source relative to a particular optical sensor.
4. The system of claim 1, wherein the identification of the features comprises: identifying a group of adjacent pixels based on a brightness of pixels of an image of the images; and identifying a centroid of the group of adjacent pixels.
5. The system of claim 1, wherein the determination of the pose is based on a selection of the pose from a set of respective poses determined and associated with a respective image of a respective optical sensor.
6. The system of claim 1, wherein the determination of the pose is based on a combination of multiple images from multiple optical sensors at a particular point in time.
7. The system of claim 1, wherein the controller is further configured to output an optical-inertial pose, via a hybrid module, based on the pose, inertial data via an inertial sensor of the system, and aircraft navigation data via a navigation system of an aircraft.
8. The system of claim 1, wherein the system comprises an aircraft-based head worn display (HWD) system and wherein the object is coupled to at least one of the light sources or the optical sensors.
9. The system of claim 1, wherein the object comprises an aircraft-based head worn display (HWD) sub-system.
10. The system of claim 1, wherein the controller is further configured for a frame by frame tracking of the features based on the feature positions of the initialization of the tracking, wherein the frame by frame tracking of the features includes a frame pose determined via the frame by frame tracking is based on predicted search regions of the images, wherein the predicted search regions are determined based on inertial data via an inertial sensor and one or more previous poses.
11. The system of claim 1, wherein the controller is further configured to, based on the modulation patterns, adjust for anomalies associated with at least one of a lack of an expected feature or an unexpected feature.
12. The system of claim 1, wherein a hamming distance, defined as a countable number of different simultaneous states over a particular sequence of planned states, of a particular modulation pattern is at least two compared to another modulation pattern.
13. The system of claim 1, wherein a total number of ON states is higher than a total number of OFF states for each sequence of planned states of each modulation pattern.
14. The system of claim 1, wherein the spatial arrangement of the light sources comprises a non-planar arrangement such that the light sources are spaced out in two orthogonal directions.
15. A method for spatial tracking, the method comprising: initializing a tracking of light sources comprising: determining modulation patterns that are mapped to light sources in a spatial arrangement relative to an object, including a modulation pattern mapped to each light source over a time period, wherein each of the modulation patterns comprises a sequence of planned states comprising an ON state and an OFF state of a corresponding light source; directing an adjustment



of a state of the light sources based on the modulation patterns; receiving images over the time period via optical sensors configured to detect the light sources; identifying features including feature positions of the features based on the images over the time period; correlating the features to the light sources based on at least the features over the time period and the modulation pattern over the time period; and determining a pose of the object based on at least the correlation, the feature positions, and the spatial arrangement of the light sources, wherein the pose comprises a direction and a position in three-dimensional space.

**16.** The method of claim 15, wherein the correlating the features is further based on search regions of the images, wherein the search regions are based on at least one of a previous known pose of the object or previously identified feature locations.

**17.** The method of claim 15, further comprising outputting an optical-inertial pose, via a hybrid module, based on the pose, inertial data from an inertial sensor, and aircraft navigation data from a navigation system of an aircraft.

**18.** The method of claim 15, wherein the method is performed using an aircraft-based head worn display (HWD) system and wherein the object is coupled to at least one of the light sources or the optical sensors of the aircraft-based head worn display (HWD) system.

**19.** The method of claim 15, wherein the object comprises a head worn display (HWD) sub-system.

**20.** The method of claim 15, wherein a total number of ON states is higher than a total number of OFF states for each sequence of planned states of each modulation pattern.

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