## SUMMARY OF INVENTION

According to a first aspect of the invention, there is provided a method for automated assignment of a staging pad to an unmanned aerial vehicle (UAV), the method comprising:

launching the UAV from a launch location;

tracking a drift of the UAV from the launch location;

determining a subsequent position of the UAV after the launching based upon geofiducial navigation;

calculating an estimated position of the launch location by offsetting the subsequent position by the drift;

attempting to match the estimated position to an available staging pad of a plurality of staging pads; and

assigning the UAV to the available staging pad when the estimated position successfully matches to the available staging pad.

According to a second aspect of the invention, there is provided at least one machine-accessible storage medium that provides instructions that, when executed by an unmanned aerial vehicle (UAV), will cause the UAV to perform operations comprising:

launching the UAV from a launch location;

tracking a drift of the UAV from the launch location;determining a subsequent position of the UAV after the launching based upon geofiducial navigation;

calculating an estimated position of the launch location by offsetting the subsequent position by the drift;

attempting to match the estimated position to an available staging pad of a plurality of staging pads; and

assigning the UAV to the available staging pad when the estimated position successfully matches to the available staging pad.

backend management software is automated removing the human operator from much of the process, thereby saving time, costs, and reducing instances of human error in the laborious data input process of associating UAV identifiers (e.g., tail number) with staging pad identifiers (e.g., pad numbers). As UAVs are more widely adopted, UAV fleets and terminal areas 100 will grow further exasperating this problem accentuating the need for a quick, reliable, automated pad assignment technique as described herein.

**[0015]** Embodiments of the automated pad assignment described herein enable physical placement of UAVs 105 on staging pads 110, but automated execution of fitness test missions. These fitness test missions are assigned from the backend management system to determine each UAVs readiness to fly and enables each UAV to assign itself to an available staging pad 110 within terminal area 100. The fitness test missions may be wirelessly communicated to UAVs 105 over a local area network (e.g., WiFi), cellular network, or otherwise and include a listing of available staging pads within terminal area 100 along with the location (e.g., latitude/longitude) of each available staging pad 110. Since terminal areas 100 are often designated as global positioning system (GPS) denied areas, UAVs 105 may initially launch without true, accurate, or any knowledge of their orientation (e.g., heading) and location (e.g., latitude and longitude). GPS may be denied in terminal area 100 if it is a covered or indoor space, due to close proximity of large buildings or mountains, or other environmental factors, but may also be forcibly denied in software and deemed insufficiently accurate for reliable navigation in and around terminal area 100. Terminal area 100 is a congestion point with the presence of human operators often demanding greater navigation precision than available from civilian/commercial GPS.

**[0016]** A fitness test mission may include an initial test launch where UAV 105 rises straight up to a waypoint above its initial launch location (e.g., 2 m) while tracking drift from its launch location using inertial tracking and/or visual odometry. While rising to the waypoint, or after reaching the waypoint, UAVs105 may use its onboard camera and geofiducial navigation systems to compute a geofiducial navigation solution, from which an actual or accurate heading, latitude, longitude, and altitude (referred to as a navigation solution) is determined. By offsetting the UAV's subsequent position computed based upon geofiducial navigation by the UAV's drift since launch, UAV 105 can calculate an estimated position of its launch

locations by various means including manual placement by an on-site technician/operator or other means of manual, semi-automated, or fully automated deployment. In the example of manual placement by a human operator, the operator need not precisely position and align UAV 105 on a staging pad 110. Rather, the initial placement need only fall within an assignment area 505 (see FIG. 5) encircling a given staging pad 110. In the embodiment illustrated in FIG. 5, assignment areas 505 are circular regions that each fall within a threshold distance (TD) 510 of a center 515 of a corresponding staging pad 110. Furthermore, the human operator need not position UAV 105 with a particular orientation or heading when physically deploying UAV 105.

**[0027]** Once UAV 105 has been physically deployed into terminal area 100, process 300 commences when UAV 105 is powered on to a ready state (process block 302). Upon power cycling, UAV 105 establishes a wireless communication link to backend management system 501 and reports its status (process block 304). Backend management system 501 may be a local command and control system present at terminal area 100, or a cloud-based command and control remotely linked over one or more networks. UAV 105 initially communicates with backend management system 501 to convey its readiness to receive a UAV mission. One such mission is a Fitness Test Mission, which operates as a sort of built-in-self-test where UAV 105 is instructed to cycle through a series of subsystem tests to ensure it is mission ready.

**[0028]** When UAV 105 initially checks in with backend management system 501, backend management system 501 will check its registry to determine whether UAV 105 already has a staging pad reservation/assignment (decision block 306). If a staging pad 110 is already assigned to the given UAV 105, then both a fitness test mission along with the assigned staging pad is communicated to UAV 105 (process block 308). In this scenario, the fitness test mission may also include the location (e.g., latitude and longitude) of the assigned staging pad. A preestablished pad assignment may exist when UAV 105 is always deployed to the same staging pad and the assignment is not cleared at the end of each day. In this scenario, UAV 105 may set the origin coordinates of its navigation coordinate system (e.g., NED coordinates) to the provided latitude and longitude of the previously assigned staging pad (process block 310) and then proceeds to execute the fitness test mission (process block 312). Alternatively, UAV 105 may simply set a waypoint for

tracking to the provided latitude and longitude of the previously assigned staging pad.

**[0029]** Returning to decision block 306, if the registry of backend management system 501 indicates that no staging pad has yet been assigned to UAV 105, then process 300 continues to a process block 314 and communicates a fitness test mission along with a list of available staging pads to UAV 105. In process block 316, UAV 105 commences the fitness test mission without a staging pad assignment and without foreknowledge of its launch location. As mentioned above, the fitness test mission is a sort of built-in-self-test whereby UAV 105 executes a number of diagnostic tests to ensure its mission readiness. These diagnostic tests may include sensor checks, rotor pulsing, communication checks, or otherwise (process block 318).

**[0030]** Since backend management system 501 does not yet know where UAV 105 has been placed within terminal area 100, it is unable to inform UAV 105 of its launch location and thus the fitness test mission and initial UAV launch proceed without informing UAV 105 of its launch location. While UAV 105 may include GPS sensors, terminal area 100 is often designated as a GPS denied zone, preventing UAV 105 from navigating based solely on GPS. Due to the density of UAVs and expected presence of obstacles and human operators, commercial/civilian GPS may not be sufficiently accurate to permit UAV 105 to navigate exclusively on GPS in the vicinity of terminal area 100. Similarly, the compass heading from the onboard inertial measurement unit (IMU) may also be deemed insufficiently accurate to extract the UAV's heading. Accordingly, in a process block 320, UAV 105 sets its navigation coordinate system to an initial reference frame with origin coordinates set to default values. For example, UAV 105 may operate using North-East-Down (NED) coordinates. In this example, the origin coordinates, corresponding to its initial launch location, are set to default values (e.g., latitude = 0; longitude = 0; altitude = 0). Similarly, the UAV's heading at launch is also set to a default value (e.g., heading = north). Thus, the navigation coordinate system may be set to an initial reference frame. One example initial reference frame may be thought of as a pseudo-NED coordinate system having the initial launch location being the origin coordinates, which are set to the default values mentioned above.

**[0031]** Prior to launch from staging pad 110, UAV 105 commences motion tracking (process block 322). Motion tracking may be performed using visual

odometry, inertial tracking, or a combination thereof. Visual odometry is the process of determining changes in position and orientation by analyzing camera images. UAV 105 may analyze images acquired by onboard camera 220 to track its drift immediately after launch. Inertial tracking is the process of determining changes in position and orientation by analyzing outputs from the onboard IMU. For example, the IMU may include an accelerometer, gyroscope, and magnetic compass. These sensor signals may also be tracked and integrated to determine changes in position and orientation immediately after launch. In one embodiment, output from visual odometry and/or inertial tracking may be input into an Extended Kalman Filter (EKF), which generates a refined estimation of the UAV's position (latitude, longitude, altitude) and heading to track drift based upon motion tracking. It is noteworthy that changes in the UAV's position and heading are tracked in the UAV's initial reference frame or initial navigation coordinate system having the origin coordinates set to default values. In a process block 324, UAV 105 rises towards a waypoint 425 (e.g., 2 m; see FIG. 4) straight above its launch location while tracking its own drift.

**[0032]** Turning to FIG. 3B (see off page reference 326), as UAV 105 rises towards waypoint 425 (or after reaching the waypoint), onboard camera 220 is used to search for one or more geofiducial markers disposed below UAV 105. The geofiducial marks are used for calculating a geofiducial navigation solution (decision block 328). FIG. 4 illustrates an example staging pad 410 surrounded by geofiducial markers 415 of varying size and offset distances from the center 420 of staging pad 410. Staging pad 410 represents an example implementation of staging pads 110. Geofiducial markers 415 may assume a variety of sizes, form factors, and designs. Geofiducial markers 415 are objects placed in the field of view (FOV) of a machine vision system and used as points of reference for calculating a geofiducial navigation solution (e.g., latitude, longitude, altitude, heading) for UAV 105. In the illustrated embodiment, one example geofiducial marker 415A is illustrated in the form of a two-dimensional barcode or quick response (QR) code. During operation, UAV 105 may store or otherwise access a registry of geofiducial codes corresponding to geofiducial markers 415, which lists the position and heading associated with the corresponding geofiducial codes. The onboard machine vision systems, including onboard camera 220, are then able to calculate the position and heading of UAV 105

CLAIMS

What is claimed is:

1. A method for automated assignment of a staging pad to an unmanned aerial vehicle (UAV), the method comprising:

launching the UAV from a launch location;

tracking a drift of the UAV from the launch location;

determining a subsequent position of the UAV after the launching based upon geofiducial navigation;

calculating an estimated position of the launch location by offsetting the subsequent position by the drift;

attempting to match the estimated position to an available staging pad of a plurality of staging pads; and

assigning the UAV to the available staging pad when the estimated position successfully matches to the available staging pad.

2. The method of claim 1, wherein attempting to match the estimated position to the available staging pad comprises:

determining whether the estimated position falls within a threshold distance to the available staging pad.

3. The method of claim 2, wherein the threshold distance (TD) is defined by:

$$TD = \frac{(D_{MIN} - G)}{2},$$

where $D_{MIN}$ represents a smallest center-to-center distance between any two staging pads in a terminal area for staging the UAV and $G$ represents a pad assignment safety gap.

4. The method of claim 1, wherein launching the UAV comprises launching the UAV without informing the UAV of its launch location within a terminal area for staging UAVs including the UAV.

5. The method of claim 1, wherein tracking the drift of the UAV from the launch location comprises tracking the drift with one or more of inertial tracking or visual odometry.

6. The method of claim 1, further comprising:

setting origin coordinates of a navigation coordinate system used by the UAV for navigation to default values prior to the launching.

7. The method of claim 6, wherein determining the subsequent position of the UAV after the launching based upon the geofiducial navigation comprises:

visually searching for one or more geofiducial markers below the UAV using a camera of the UAV while the UAV rises towards a waypoint height or after the UAV reaches the waypoint height;

calculating a geofiducial navigation solution for the UAV in response to identifying the one or more geofiducial markers; and

latching the navigation coordinate system to a new reference frame based upon calculating the geofiducial navigation solution.

8. The method of claim 7, wherein calculating the estimated position of the launch location by offsetting the subsequent position by the drift comprises:

translating the drift into the new reference frame prior to calculating the estimated position of the launch location.

9. The method of claim 6, further comprising:

resetting a latitude and a longitude of the origin coordinates of the navigation coordinate system to an actual position of the available staging pad in response to the estimated position successfully matching the available staging pad.

10. The method of claim 6, further comprising:

resetting a latitude and a longitude of the origin coordinates of the navigation coordinate system to the estimated position of the launch location in response to the estimated position unsuccessfully matching any available staging pad and calculating a geofiducial navigation solution for the UAV.

11. The method of claim 1, further comprising:

reporting the match to the available staging pad to a backend management system that manages operation of the UAV to reserve the available staging pad.

12. The method of claim 1, further comprising:

navigating back to, and landing at, the launch location when the attempting to match is unsuccessful; and

set a status flag indicating an unsuccessful match has occurred.

13. At least one machine-accessible storage medium that provides instructions that, when executed by an unmanned aerial vehicle (UAV), will cause the UAV to perform operations comprising:

launching the UAV from a launch location;

tracking a drift of the UAV from the launch location;

determining a subsequent position of the UAV after the launching based upon geofiducial navigation;

calculating an estimated position of the launch location by offsetting the subsequent position by the drift;

attempting to match the estimated position to an available staging pad of a plurality of staging pads; and

assigning the UAV to the available staging pad when the estimated position successfully matches to the available staging pad.

14. The at least one machine-accessible storage medium of claim 13, wherein attempting to match the estimated position to the available staging pad comprises:

determining whether the estimated position falls within a threshold distance to the available staging pad.

15. The at least one machine-accessible storage medium of claim 13, wherein launching the UAV comprises launching the UAV without informing the UAV of its launch location within a terminal area for staging UAVs including the UAV.

16. The at least one machine-accessible storage medium of claim 13, wherein tracking the drift of the UAV from the launch location comprises tracking the drift with one or more of inertial tracking or visual odometry.

17. The at least one machine-accessible storage medium of claim 13, further providing instructions that, when executed by the UAV, will cause the UAV to perform further operations, comprising:

setting origin coordinates of a navigation coordinate system used by the UAV for navigation to default values prior to the launching.

18. The at least one machine-accessible storage medium of claim 17, wherein determining the subsequent position of the UAV after the launching based upon the geofiducial navigation comprises:

visually searching for one or more geofiducial markers below the UAV using a camera of the UAV while the UAV rises towards a waypoint height or after the UAV reaches the waypoint height;

calculating a geofiducial navigation solution for the UAV in response to identifying the one or more geofiducial markers; and

latching the navigation coordinate system to a new reference frame based upon calculating the geofiducial navigation solution.

19. The at least one machine-accessible storage medium of claim 18, wherein calculating the estimated position of the launch location by offsetting the subsequent position by the drift comprises:

translating the drift into the new reference frame prior to calculating the estimated position of the launch location.

20. The at least one machine-accessible storage medium of claim 17, further providing instructions that, when executed by the UAV, will cause the UAV to perform further operations, comprising:

resetting a latitude and a longitude of the origin coordinates of the navigation coordinate system to an actual position of the available staging pad in response to the estimated position successfully matching the available staging pad.

21. The at least one machine-accessible storage medium of claim 17, further providing instructions that, when executed by the UAV, will cause the UAV to perform further operations, comprising:

resetting a latitude and a longitude of the origin coordinates of the navigation coordinate system to the estimated position of the launch location in response to the estimated position unsuccessfully matching any available staging pad and calculating a geofiducial navigation solution for the UAV.