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(54) METHOD AND SYSTEM FOR CONTROLLING SAFE TAKEOFF AND LANDING OF PILOTLESS VERTICAL TAKEOFF AND LANDING (VTOL) AIRCRAFT

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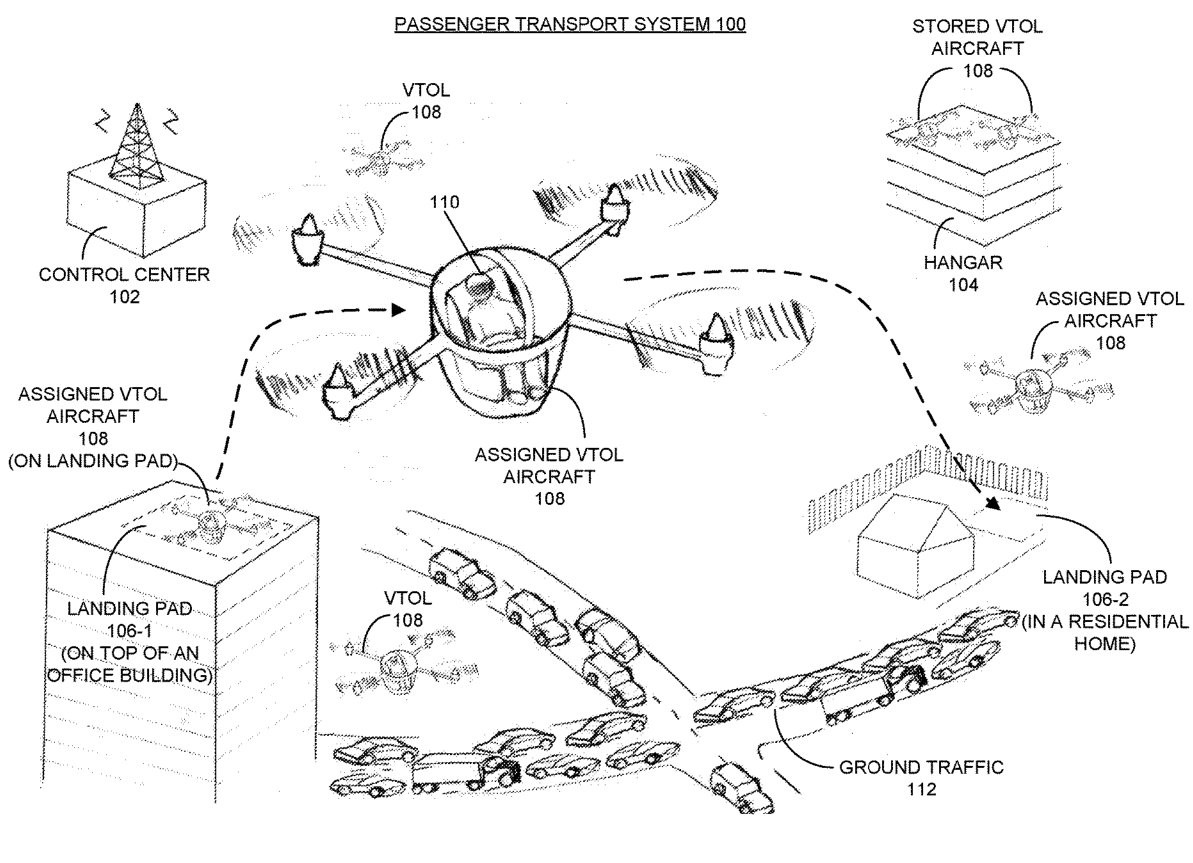
(57) **ABSTRACT**

In one aspect, a system for safely landing a vertical takeoff-and-landing (VTOL) aircraft in the air onto a landing pad on the ground is disclosed. The system can begin by determining an estimated location of the landing pad with a first accuracy. The system then reduces a height of the VTOL aircraft to a first level above the ground while approaching the estimated location of the landing pad. Next, the system determines an updated location of the landing pad with a second accuracy. The system subsequently reduces the height of the VTOL aircraft to a second level above the ground while approaching the updated location of the landing pad. Next, the system aligns a center point of the VTOL aircraft with a center location of the landing pad. Finally, the system lands the VTOL aircraft onto the landing pad by directly lowering the VTOL aircraft onto the landing pad.



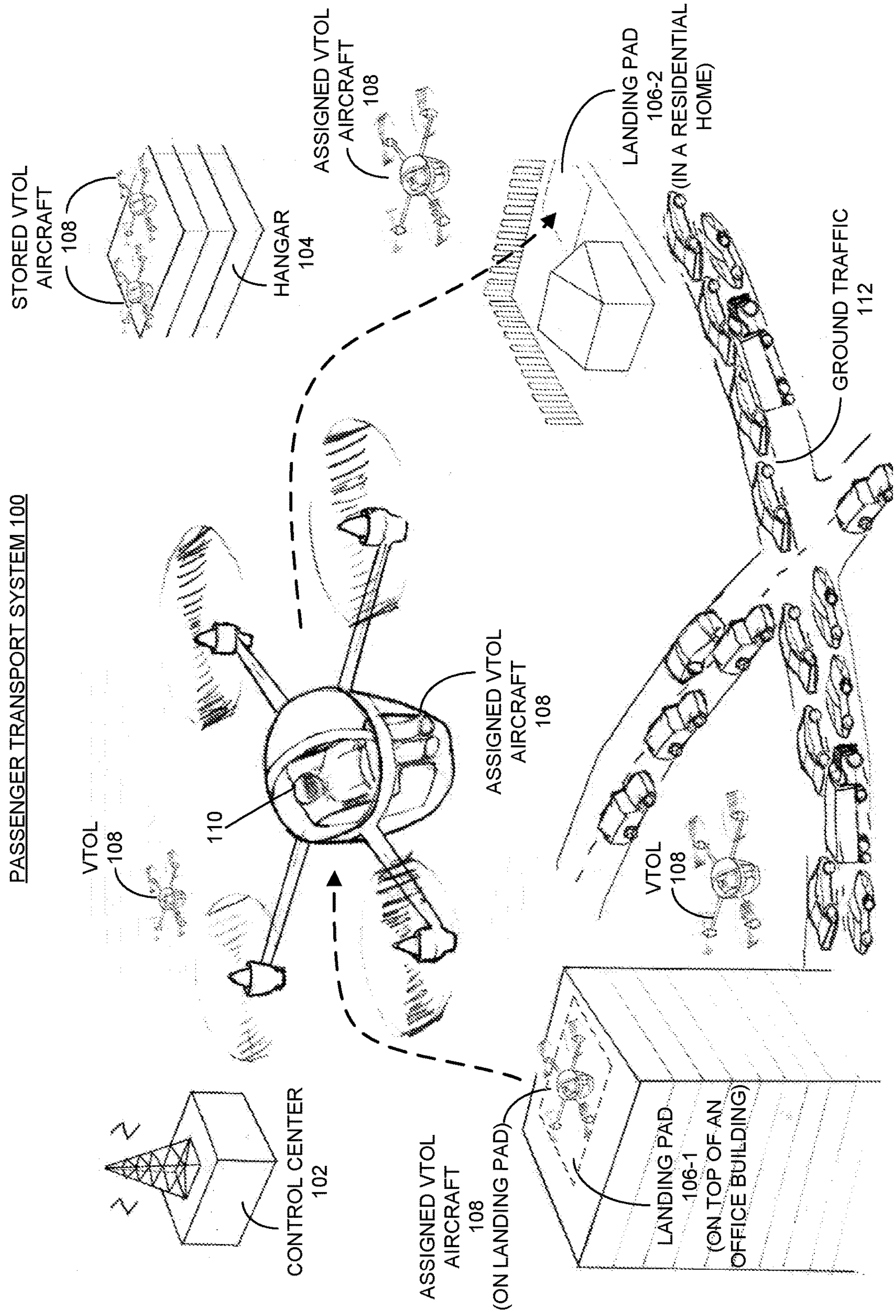

PASSENGER TRANSPORT SYSTEM 100
CONTROL CENTER 102
STORED VTOL AIRCRAFT 108
HANGAR 104
ASSIGNED VTOL AIRCRAFT 108
LANDING PAD 106-2 (IN A RESIDENTIAL HOME)
GROUND TRAFFIC 112
VTOL 108
110
ASSIGNED VTOL AIRCRAFT 108
VTOL 108
ASSIGNED VTOL AIRCRAFT 108 (ON LANDING PAD)
LANDING PAD 106-1 (ON TOP OF AN OFFICE BUILDING)

FIG. 1

AN EXEMPLARY CONFIGURATION OF GROUND FACILITIES 200 OF PASSENGER TRANSPORT SYSTEM 100

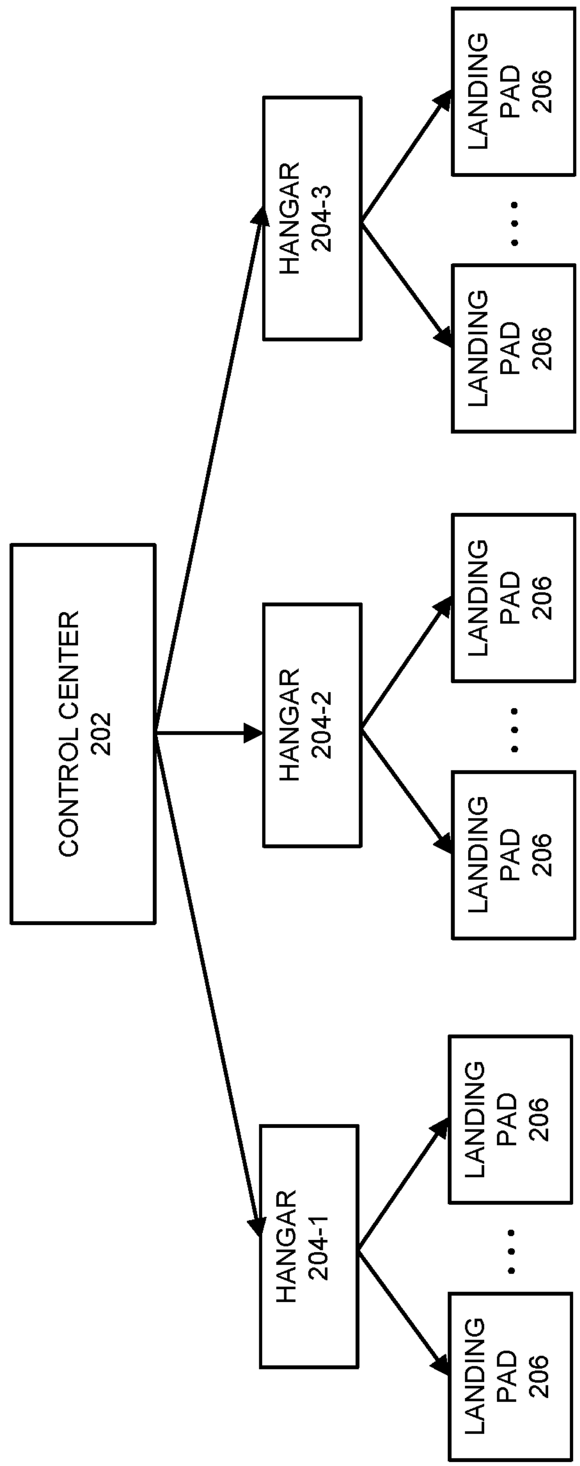


FIG. 2

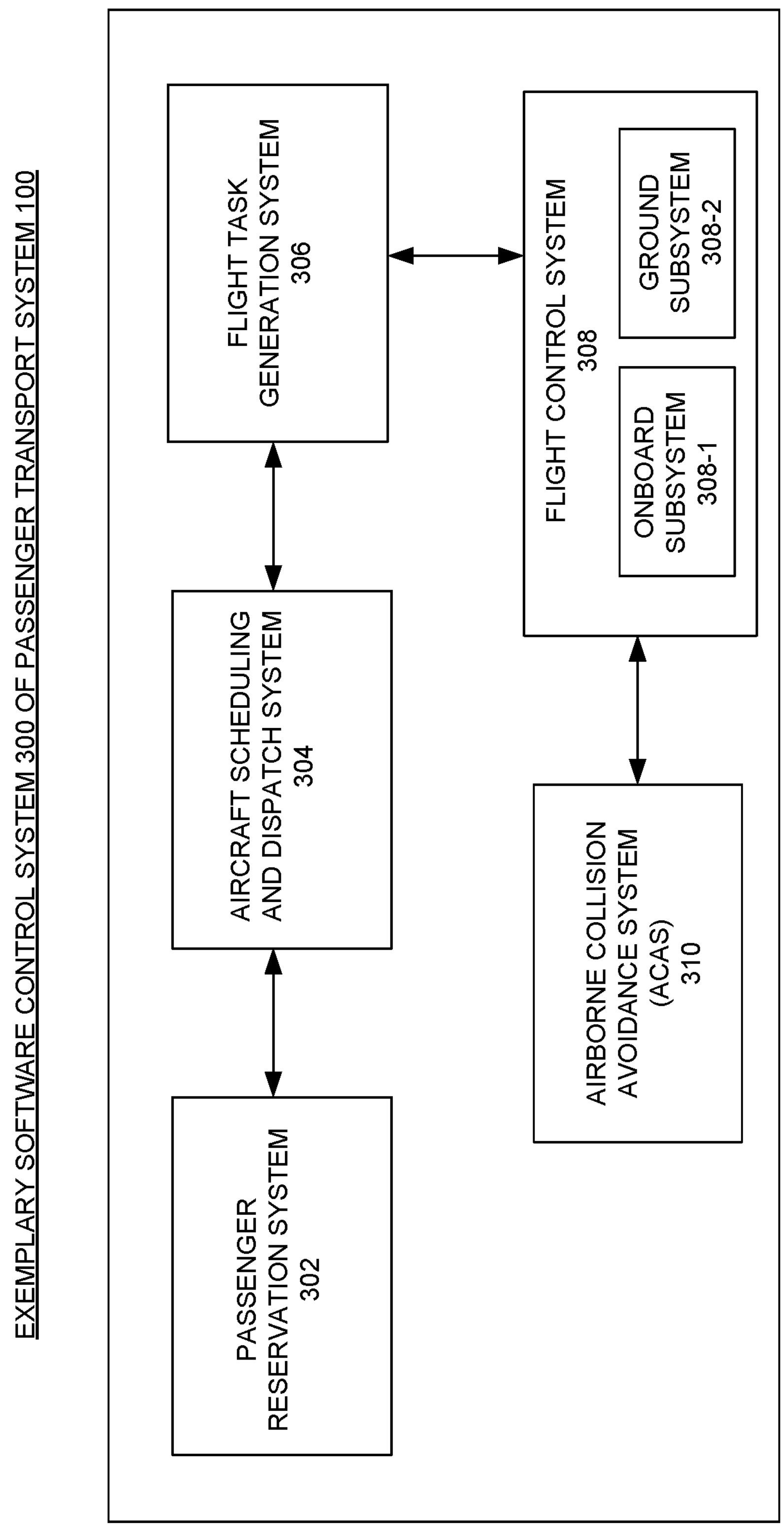
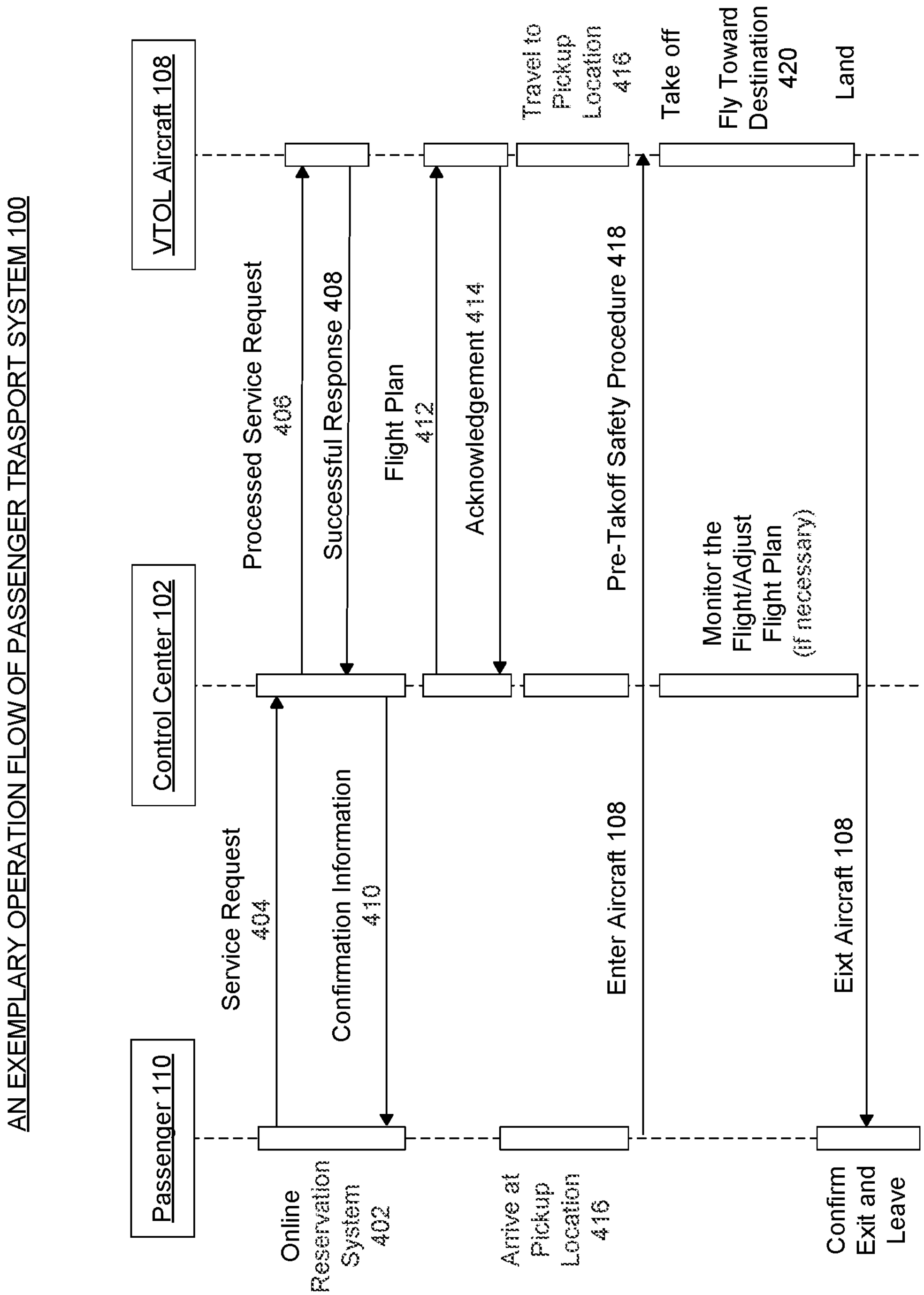

EXEMPLARY SOFTWARE CONTROL SYSTEM 300 OF PASSENGER TRANSPORT SYSTEM 100
PASSENGER RESERVATION SYSTEM 302
AIRCRAFT SCHEDULING AND DISPATCH SYSTEM 304
FLIGHT TASK GENERATION SYSTEM 306
FLIGHT CONTROL SYSTEM 308
GROUND SUBSYSTEM 308-2
ONBOARD SUBSYSTEM 308-1
AIRBORNE COLLISION AVOIDANCE SYSTEM (ACAS) 310

FIG. 3



AN EXEMPLARY OPERATION FLOW OF PASSENGER TRASPORT SYSTEM 100
Passenger 110
Control Center 102
VTOL Aircraft 108
Online Reservation System 402
Service Request 404
Processed Service Request 406
Successful Response 408
Confirmation Information 410
Flight Plan 412
Acknowledgement 414
Arrive at Pickup Location 416
Travel to Pickup Location 416
Enter Aircraft 108
Pre-Takoff Safety Procedure 418
Take off
Monitor the Flight/Adjust Flight Plan (if necessary)
Fly Toward Destination 420
Land
Eixt Aircraft 108
Confirm Exit and Leave

FIG. 4

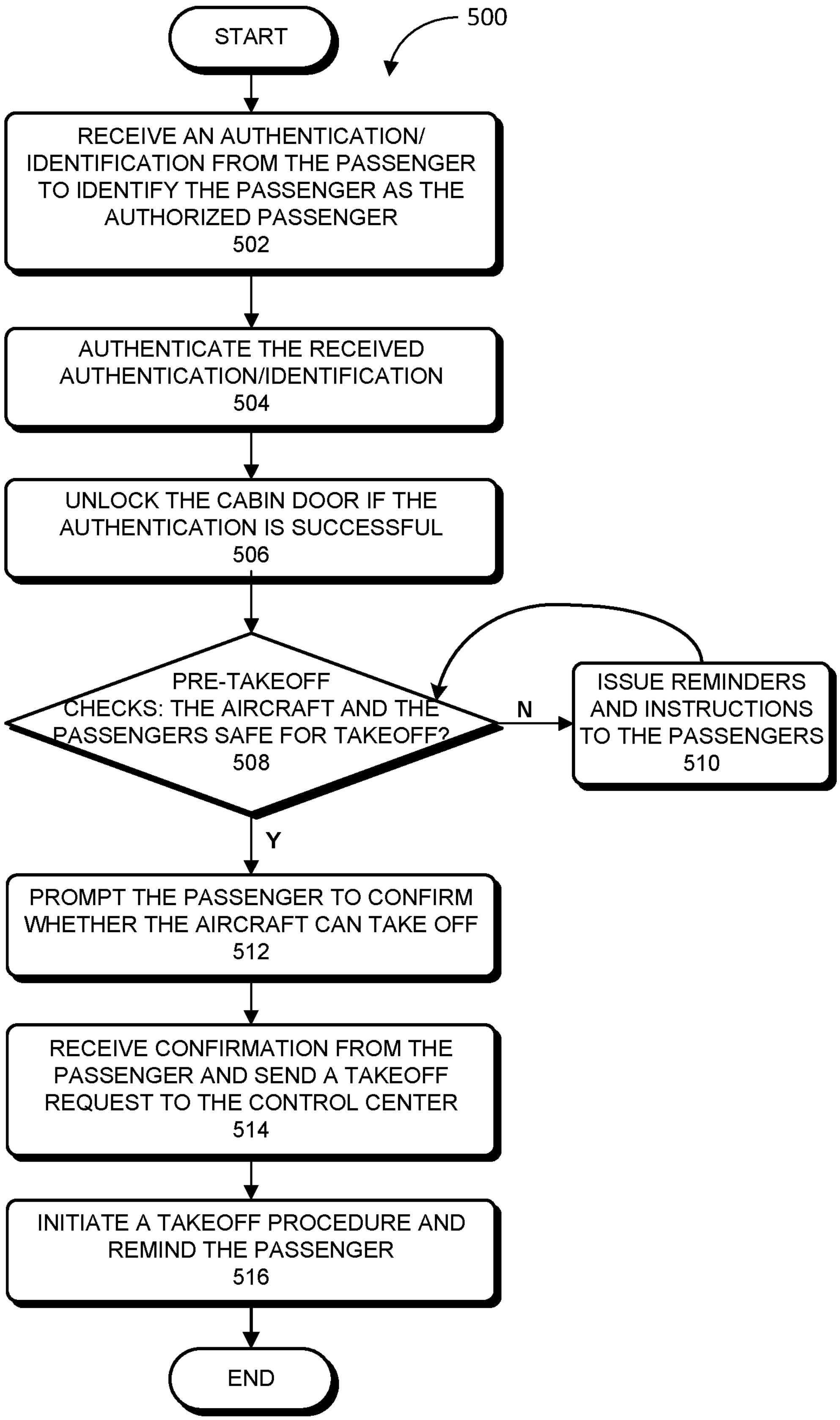

500
START
RECEIVE AN AUTHENTICATION/ IDENTIFICATION FROM THE PASSENGER TO IDENTIFY THE PASSENGER AS THE AUTHORIZED PASSENGER
502
AUTHENTICATE THE RECEIVED AUTHENTICATION/IDENTIFICATION
504
UNLOCK THE CABIN DOOR IF THE AUTHENTICATION IS SUCCESSFUL
506
PRE-TAKEOFF CHECKS: THE AIRCRAFT AND THE PASSENGERS SAFE FOR TAKEOFF?
508
N
ISSUE REMINDERS AND INSTRUCTIONS TO THE PASSENGERS
510
Y
PROMPT THE PASSENGER TO CONFIRM WHETHER THE AIRCRAFT CAN TAKE OFF
512
RECEIVE CONFIRMATION FROM THE PASSENGER AND SEND A TAKEOFF REQUEST TO THE CONTROL CENTER
514
INITIATE A TAKEOFF PROCEDURE AND REMIND THE PASSENGER
516
END

FIG. 5

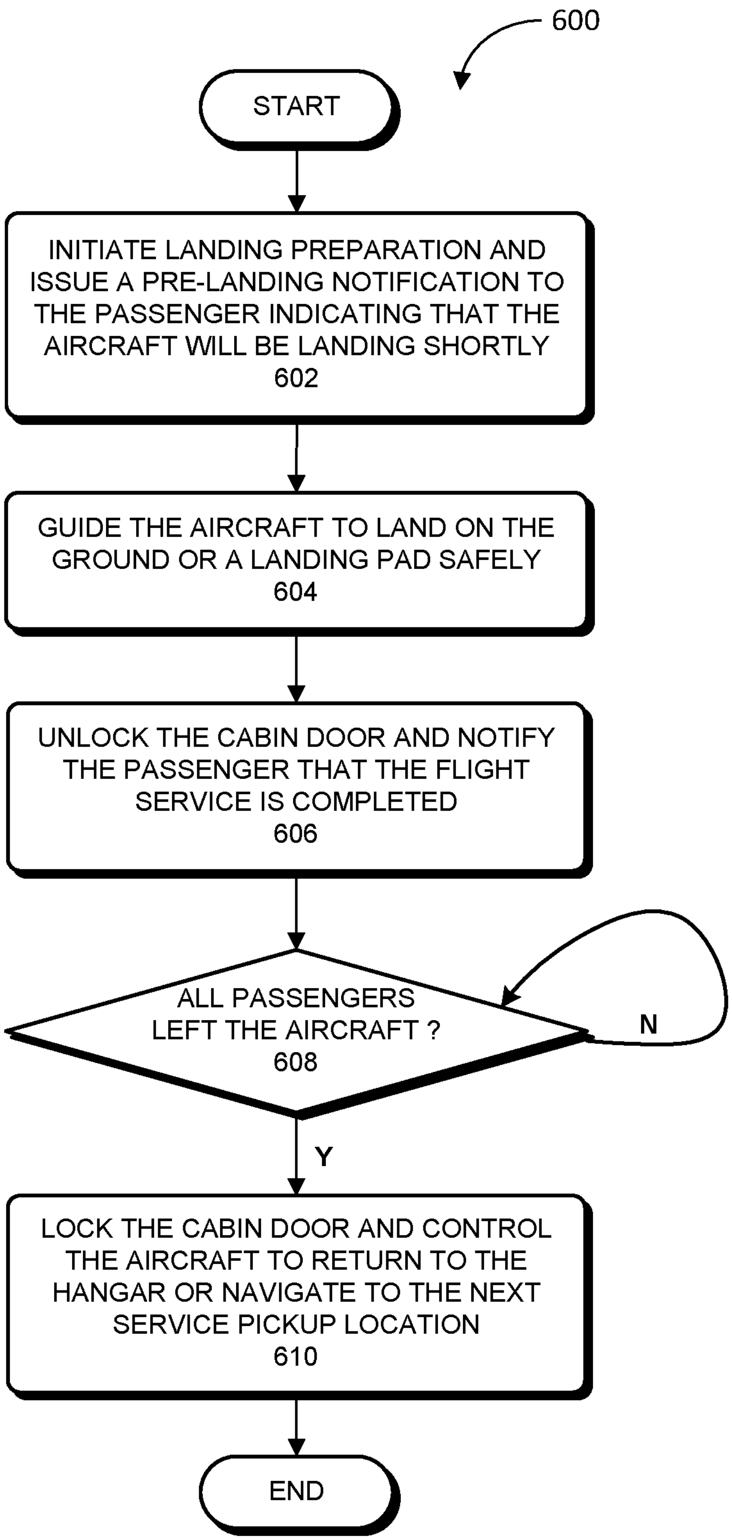

600
START
INITIATE LANDING PREPARATION AND ISSUE A PRE-LANDING NOTIFICATION TO THE PASSENGER INDICATING THAT THE AIRCRAFT WILL BE LANDING SHORTLY
602
GUIDE THE AIRCRAFT TO LAND ON THE GROUND OR A LANDING PAD SAFELY
604
UNLOCK THE CABIN DOOR AND NOTIFY THE PASSENGER THAT THE FLIGHT SERVICE IS COMPLETED
606
ALL PASSENGERS LEFT THE AIRCRAFT ?
608
N
Y
LOCK THE CABIN DOOR AND CONTROL THE AIRCRAFT TO RETURN TO THE HANGAR OR NAVIGATE TO THE NEXT SERVICE PICKUP LOCATION
610
END

FIG. 6

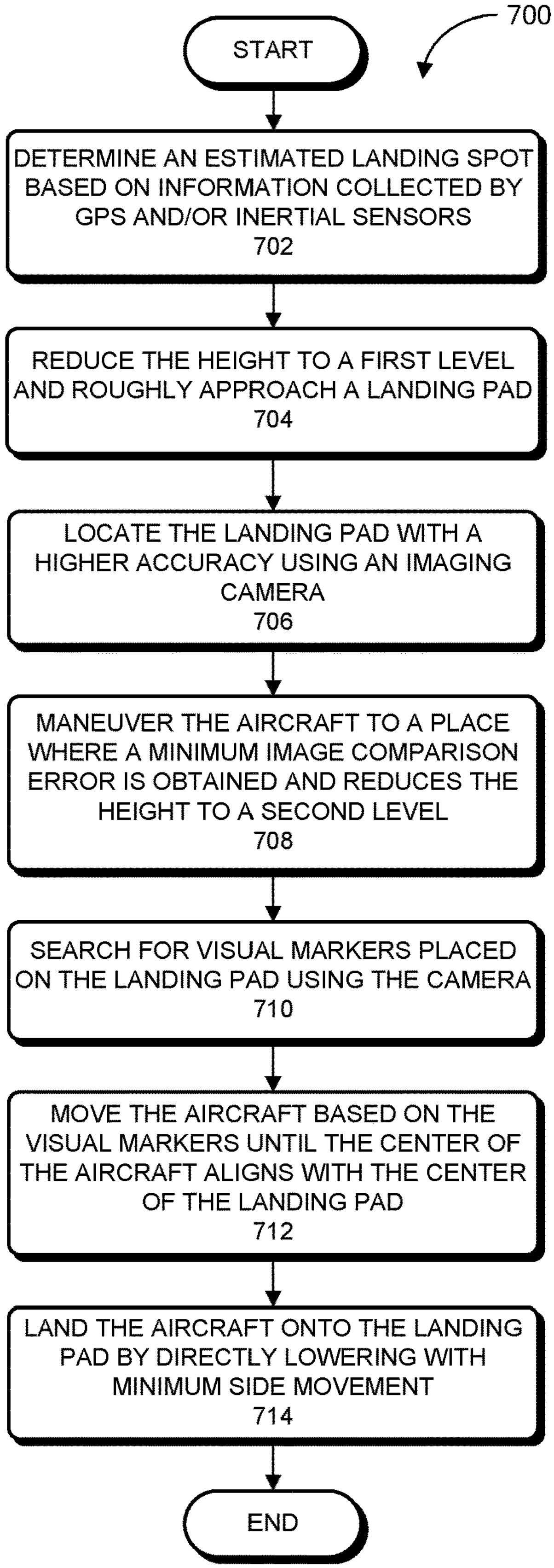

700
START
DETERMINE AN ESTIMATED LANDING SPOT BASED ON INFORMATION COLLECTED BY GPS AND/OR INERTIAL SENSORS
702
REDUCE THE HEIGHT TO A FIRST LEVEL AND ROUGHLY APPROACH A LANDING PAD
704
LOCATE THE LANDING PAD WITH A HIGHER ACCURACY USING AN IMAGING CAMERA
706
MANEUVER THE AIRCRAFT TO A PLACE WHERE A MINIMUM IMAGE COMPARISON ERROR IS OBTAINED AND REDUCES THE HEIGHT TO A SECOND LEVEL
708
SEARCH FOR VISUAL MARKERS PLACED ON THE LANDING PAD USING THE CAMERA
710
MOVE THE AIRCRAFT BASED ON THE VISUAL MARKERS UNTIL THE CENTER OF THE AIRCRAFT ALIGNS WITH THE CENTER OF THE LANDING PAD
712
LAND THE AIRCRAFT ONTO THE LANDING PAD BY DIRECTLY LOWERING WITH MINIMUM SIDE MOVEMENT
714
END

FIG. 7

EXEMPLARY FLIGHT SAFETY SYSTEM 800 OF PASSENGER TRANSPORT SYSTEM 100

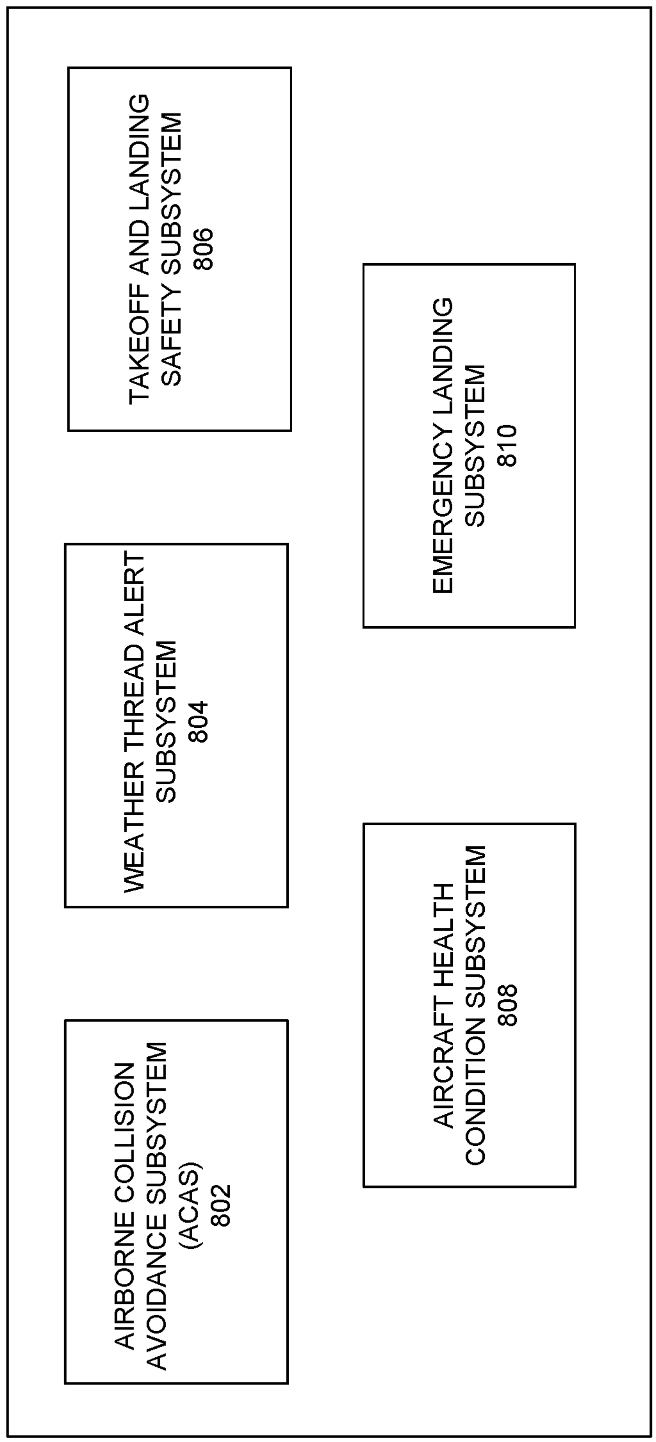


FIG. 8

METHOD AND SYSTEM FOR CONTROLLING SAFE TAKEOFF AND LANDING OF PILOTLESS VERTICAL TAKEOFF AND LANDING (VTOL) AIRCRAFT

PRIORITY CLAIM AND RELATED PATENT APPLICATIONS

[0001] The present application is a continuation of, and claims priority to, U.S. patent application Ser. No. 15/256,755, entitled "METHOD AND SYSTEM FOR TRANSPORTING PASSENGERS USING PILOTLESS VERTICAL TAKEOFF AND LANDING (VTOL) AIRCRAFT," by inventor Tao Ma, which was filed on 6 Sep. 2016 (Atty. Docket No. MT001.US02), and which is herein incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] This patent document generally relates to personal transportation systems. More specifically, this patent document relates to systems, devices, and processes for transporting passengers on-demand using a fleet of pilotless vertical takeoff and landing (VTOL) aircraft traveling in three-dimensional spaces.

BACKGROUND

[0003] This patent document provides systems and techniques for solving traffic congestion problems in urban and metropolitan areas. Conventional modes of ground transportation such as roads, rails, and ferries provide limited resources for people to commute in densely populated areas. The ever-increasing population in big cities imposes heavy burdens to these ground transport systems. An important reason that causes traffic congestion is that the ground transport vehicles travel in two-dimensional spaces. This greatly limits the amount of vehicles that can be accommodated in a particular area. An ideal route from one place to another is a straight line. Unfortunately, passengers usually have to take a longer route because there is not always a straight road between two places. This two-dimensional nature of ground transportation increases travel time, decreases energy efficiency, and can cause the aforementioned traffic congestion in high population areas. In contrast, aircraft traveling in three-dimensional spaces can be more energy efficient and are not limited by the two-dimensional routes. Moreover, aircraft traveling in three-dimensional spaces can have much higher transportation capacity because three-dimensional spaces can accommodate a much greater number of vehicles.

SUMMARY

[0004] Techniques, systems, and devices are disclosed for safely transporting passengers from pickup locations to destination locations on demand using automated/pilotless vertical takeoff and landing (VTOL) aircraft traveling in three-dimensional (3D) spaces. In one implementation, an on-demand passenger transport system is disclosed. This on-demand passenger transport system can include one or more VTOL aircraft which operate without human pilots, and each of the one or more VTOL aircraft operates under the control of an associated onboard computer. The disclosed passenger transport system further includes a ground control system located within an urban area and communicatively coupled to the one or more VTOL aircraft. The ground control system is configured to: receive a service request from a passenger for a transport service of the one or more VTOL aircraft; assign one of the one or more VTOL aircraft to the requesting passenger; process the service request to generate a flight task; transmit the flight task to the assigned VTOL aircraft, wherein the flight task is programmed onto the onboard computer of the assigned VTOL aircraft. The onboard computer of the assigned VTOL aircraft is configured to control a flight of the assigned VTOL aircraft to safely transport the passenger from a pickup location to a destination location by air based on the received flight task.

[0005] In some embodiments, a disclosed pilotless VTOL aircraft, which provides services on demand, is able to carry one or more passengers and does not need runways to take off and land. For example, the pilotless VTOL aircraft can take off and land from designated landing pads which are located in both urban business locations and suburban residential locations.

[0006] In one aspect, a process for ensuring safe takeoff of a pilotless VTOL aircraft dispatched by a ground control system to a scheduled pickup location to serve a passenger request is disclosed. The process starts by authenticating a passenger attempting to enter the VTOL aircraft at the scheduled pickup location. If the passenger authentication is successful, the process allows the passenger to enter the VTOL aircraft. The process next performs pre-takeoff safety checks on the VTOL aircraft and the passenger inside the VTOL aircraft. If the pre-takeoff safety checks are successful, the process subsequently obtains a takeoff confirmation.

[0007] In some embodiments, the process authenticates the passenger attempting to enter the VTOL aircraft by receiving authentication information from the passenger. This authentication information can include one or more of: entering reservation codes or a password; tapping an radio frequency identification (RFID) or a near field communication (NFC) card/key-fob; scanning a barcode displayed on a mobile device of the passenger; and providing a biometric-based authentication of the passenger. In some embodiments, the biometric-based authentication includes one or more of fingerprints, facial recognition, and an eye scan.

[0008] In some embodiments, the process authenticates the passenger attempting to enter the VTOL aircraft by receiving the authentication information from the passenger and comparing the authentication information with pre-stored information of the passenger.

[0009] In some embodiments, the passenger authentication is performed either at the VTOL aircraft or at the ground control system which is configured to communicate and monitor the operation of the VTOL aircraft.

[0010] In some embodiments, the process allows the passenger to enter the VTOL aircraft by unlocking the cabin door of the VTOL aircraft.

[0011] In some embodiments, the process performs the pre-takeoff safety checks on the VTOL aircraft and the passenger by checking whether the cabin door of the VTOL aircraft is securely locked.

[0012] In some embodiments, the process performs the pre-takeoff safety checks on the VTOL aircraft and the passenger by checking whether the passenger's seatbelt is securely fastened.

[0013] In some embodiments, if the pre-takeoff safety checks are not successful, the process includes issuing

reminders and/or instructions to the passenger in form of voice, signal light, or displayed text messages.

[0014] In some embodiments, the process obtains the takeoff confirmation from the passenger inside the VTOL aircraft by: prompting the passenger to confirm whether the VTOL aircraft can take off; and receiving a response from the passenger to confirm a takeoff readiness by way of a voice command, pressing a button, or touching a touch-screen in the cabin.

[0015] In some embodiments, the process obtains the takeoff confirmation from the ground control system.

[0016] In some embodiments, after obtaining the takeoff confirmation, the process allows the VTOL aircraft to initiate a takeoff procedure.

[0017] In another aspect, a process for ensuring safe landing at a destination location and completing an assigned passenger service of a pilotless VTOL aircraft is disclosed. This VTOL aircraft is communicatively coupled to and monitored by a ground control system. More specifically, the process includes notifying passengers inside the VTOL aircraft that the VTOL aircraft is about to land at the destination location. After landing the VTOL aircraft, the process notifies the passengers that the landing is completed and issues instructions on how to safely exiting the VTOL aircraft. The process then performs post-landing safety checks on the VTOL aircraft. If the post-landing safety checks are successful, the process allows the VTOL aircraft to return to a hangar or depart for another pickup location to execute a next assigned passenger service.

[0018] In some embodiments, the post-landing safety checks includes checking one or more of the following conditions: whether the passengers have left the cabin of the VTOL aircraft; whether the cabin doors of the VTOL aircraft are closed; and any other conditions that can affect the safety of the next flight of the VTOL aircraft.

[0019] In some embodiments, if any of the post-landing safety checks fails, the process further includes keeping the VTOL aircraft grounded and repeating the post-landing safety checks until the failed post-landing safety check becomes successful.

[0020] In yet another aspect, a process for detecting obstacles to ensure safe landing of a pilotless VTOL aircraft using an obstacle detection system installed on the VTOL aircraft is disclosed. This VTOL aircraft is communicatively coupled to and monitored by a ground control system. The process includes controlling the VTOL aircraft to approach a designated landing pad; detecting, using the obstacle detection system, if there is any obstacle along a landing path of the VTOL aircraft to prevent a safe landing the VTOL aircraft; if an obstacle is detected in the landing path, guiding the aircraft to maneuver away from the obstacle; and if the obstacle detection system determines that the obstacle cannot be avoid, aborting the landing procedure.

[0021] In some embodiments, the obstacle detection system detects an obstacle along the landing path by using obstacle detection sensors having three-dimensional (3D) sensing capability installed on the VTOL aircraft. For example, the obstacle detection sensors can include one or more of radars, LIDARs, and stereo cameras.

[0022] In some embodiments, the field of view of the obstacle detection sensors is configured to be at least greater than a projected area of the VTOL aircraft on the ground.

[0023] In some embodiments, the obstacle detection sensors are installed on the bottom of the VTOL aircraft for detecting if there is any obstacle below the VTOL aircraft.

[0024] In some embodiments, if the obstacle detection system determines that the VTOL aircraft cannot land onto the designated landing pad because of the detected obstacles, the process includes notifying the ground control system of the failed landing attempt. In some embodiments, after receiving the notification of the failed landing attempt from the VTOL aircraft, the ground control system assigns an alternative landing pad which is close to the designated landing pad.

[0025] In some embodiments, the landing pad includes a set of landing assistant equipments, such as visual markers, to guide the VTOL aircraft to land onto the designated landing pad with high accuracy.

[0026] In some embodiments, the process includes performing a landing pad localization maneuver by using GPS and/or inertial sensors to localize the VTOL aircraft onto the designated land pad.

[0027] In still another aspect, a process for detecting obstacles to ensure safe takeoff of a pilotless VTOL aircraft using an obstacle detection system installed on the VTOL aircraft is disclosed. This VTOL aircraft is communicatively coupled to and monitored by a ground control system. This process includes: during a takeoff procedure, detecting, using the obstacle detection system, if there is any obstacle along a takeoff path of the VTOL aircraft to prevent a safe takeoff the VTOL aircraft; if an obstacle is detected in the takeoff path, guiding the VTOL aircraft to maneuver away from the obstacle; and if the obstacle detection system determines that the obstacle cannot be avoid, returning to the ground and sending notification to the ground control system.

[0028] In some embodiments, the process detects an obstacle along the takeoff path by using obstacle detection sensors having 3D sensing capability installed on top of the VTOL aircraft to detect if there is any obstacle above the VTOL aircraft.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] The structure and operation of the present disclosure will be understood from a review of the following detailed description and the accompanying drawings in which like reference numerals refer to like parts and in which:

[0030] FIG. **1** shows a conceptual schematic of an exemplary passenger transport system in accordance with one embodiment described herein.

[0031] FIG. **2** presents a block diagram illustrating an exemplary configuration of ground facilities of the disclosed passenger transport system in accordance with one embodiment described herein.

[0032] FIG. **3** illustrates various modules of an exemplary software control system of the disclosed passenger transport system in accordance with one embodiment described herein.

[0033] FIG. **4** presents a flow diagram illustrating an exemplary operation of the disclosed passenger transport system in accordance with one embodiment described herein.

[0034] FIG. **5** presents a flowchart illustrating an exemplary process of performing a pre-takeoff passenger safety procedure in accordance with one embodiment described herein.

[0035] FIG. **6** presents a flowchart illustrating an exemplary process of performing a landing passenger safety procedure in accordance with one embodiment described herein.

[0036] FIG. **7** presents a flowchart illustrating a VTOL aircraft landing process based on a three-step landing pad localization procedure in accordance with one embodiment described herein.

[0037] FIG. **8** illustrates an exemplary flight safety system implemented in the disclosed passenger transport system in accordance with one embodiment described herein.

DETAILED DESCRIPTION

[0038] The rapid development of driverless car brings the hope to release human driving burden and boost driving safety. However, a driverless car needs to deal with very complex situations on the roadways, such as traffic lights, different signs, pedestrians, other vehicles, road constructions, accidents and emergencies, among others. Many random situations can arise during driving. Thus, sophisticated sensors and software systems are needed for accurately detecting and predicting such situations. This leads to the fact that driverless cars are still in its early stage of commercialization in spite of decades of research and development efforts. In contrast, situations in the air can be much simpler than the roadways because there are generally no fixed routes and obstacles in the air.

[0039] In this patent document, a vertical takeoff and landing (VTOL) aircraft is proposed as a type of vehicle to transport passengers in the air, i.e., a three-dimensional (3D) space between two locations. A VTOL aircraft does not need runways to take off and land, and typically navigates at a lower altitude and speed compared with other commercial or military aircraft, which can be ideal for personal short-range transportation in urban areas.

[0040] Recently, unmanned aerial vehicles (UAV), or drones, in the form of multicopters, experience fast development due to their mechanical simplicity and versatility. Such multicopters provide an ideal prototype for the proposed VTOL aircraft to carry passengers. For example, E-volo disclosed a manned electric-powered 18-rotor multicopter VC200 which can carry two people with more than one hour flight time [http://www.e-volo.com/ongoing-development/vc-200]. However, hiring a pilot is expensive. A pilot onboard also reduces the load capacity, which increases the cost and reduces the efficiency. This patent document proposes using self-piloting or "pilotless" VTOL aircraft that do not rely on human pilots. The proposed VTOL aircraft is able to carry one or more passengers and navigate in urban areas on demand. In some embodiments, the proposed pilotless VTOL aircraft will be operating fully automated under the control of an onboard computer and with the assistant from a ground control center. The proposed pilotless VTOL aircraft are also referred to as "automated" VTOL aircraft below.

[0041] For the safety consideration, airborne collision avoidance system (ACAS) for civil aviation and air force has become very mature and therefore can be applied to the proposed VTOL aircraft. Moreover, the probability that a man-made aircraft hits an airborne animal (e.g., a bird or a bat) is very low. Furthermore, bird strikes should have less effect on the proposed VTOL aircraft due to the low navigation speed compared with other high speed commercial or military aircraft.

[0042] Hence, various examples of a passenger transport system based on using a fleet of pilotless VTOL aircraft to transport passengers from departure locations to arrival locations are disclosed. In some implementations, upon receiving a passenger's service request, an available pilotless VTOL aircraft is dispatched to pick up the requesting passenger at a departure location on a scheduled time and drop off the passenger at a corresponding arrival location. The flight of the VTOL aircraft can be fully automated, i.e., no human pilot is needed at any time during the execution of the flight task.

[0043] In some implementations, passengers reserve VTOL aircraft services on reservation websites using computers or portable devices. Next, a control center of the disclosed passenger transport system processes each request and assigns and dispatches multiple VTOL aircraft to carry out the services. Once flight instructions are programmed into an assigned VTOL aircraft's onboard computer, the VTOL aircraft takes off and travels to the pickup location. The onboard computer of the dispatched VTOL aircraft controls the flight at all time. Multiple sensors on the VTOL aircraft provide real time flight status for the onboard computer. The control center monitors the flight status of the airborne aircraft and feeds new instructions into the traveling aircraft if necessary. A collision avoidance system, such as an ACAS is used to ensure that the aircraft travel in "safe zones." The disclosed passenger transport system provides a novel way of fast, short to medium range commute as well as a solution to urban traffic congestion. This passenger transport system also has broad applications in sightseeing tours, emergency rescue missions, air ambulance services, and so on.

[0044] FIG. **1** shows a conceptual schematic of an exemplary passenger transport system **100** in accordance with one embodiment described herein. As can be seen in FIG. **1**, the disclosed passenger transport system **100** includes a control center **102**, one or more hangars **104**, multiple landing pads **106**, and a fleet of automated VTOL aircraft **108**. In various embodiments, control center **102**, hangars **104** and landing pads **106** are fixed-location structures constructed at various physical locations. For example, control center **102** can be located inside a building. However, control center **102** can also be a mobile structure, for example, when control center **102** is located inside a vehicle. In some embodiments, control center **102**, hangars **104** and landing pads **106** are collectively referred to as the "ground facilities" of passenger transport system **100**. For example, the ground facilities of a proposed passenger transport system in an urban area can include one control center, several hangars, and numerous landing pads.

[0045] FIG. **1** also shows an automated VTOL aircraft **108** picks up a passenger **110** at a departure location in form of a first landing pad **106-1** on top of an office building (e.g., the workplace of passenger **110**) located in an urban area where traffic is heavy during the service time (as illustrated by ground traffic **112**), and then travels by air above the ground traffic **112** to an arrival location in form of a second landing pad **106-2** located at a residential home. In the embodiment shown, the second landing pad **106-2** is located in the backyard of the residential home. However, the second landing pad **106-2** may be located in the front yard of the residential home or it can also be a shared landing pad near the residential home shared by multiple residential homes.

[0046] In an alternative scenario, a VTOL aircraft **108** can pick up passenger **110** from the residential home, i.e., the departure location, at the second landing pad **106-2**, and then travels by air to an arrival location at the first landing pad **106-1** on top of the office building. As can be seen in FIG. **1**, the proposed passenger transport system **100** completely avoids the heavy ground traffic and provides passenger **110** with a direct line-of-sight commute route.

Automated VTOL Aircraft

[0047] In some embodiments, unlike some existing VTOL aircraft which are operated by human pilots, the disclosed automated VTOL aircraft **108** using by passenger transport system **100** do not have human pilot. In some embodiments, each of the disclosed VTOL aircraft **108** operates under the controls of both control center **102** and an onboard computer of VTOL aircraft **108**. In some implementations, the disclosed VTOL aircraft **108** can have geometrical shapes or mechanical architectures of multicopter drones. However, the disclosed VTOL aircraft **108** can have other possible geometrical shapes and architectures. VTOL aircraft **108** can be electrically-powered and can have multiple electric motors and propellers. For example, the number of propellers can be 2, 3, 4, or more. Redundant power components can be included in each VTOL aircraft **108** to increase safety and reliability. In such designs, if one motor stops working, other motors can still provide sufficient lift force to keep the aircraft flying or to land the aircraft at a safe place.

[0048] In some implementations, VTOL aircraft **108** are not owned by individuals. Rather, passengers who need the transportation services can "rent" VTOL aircraft **108** for a specific amount of time, e.g., by one or more hours, in a way similar to other conventional vehicle rental services. The service requests can be placed on an online reservation website using a computer or a portable device. The service requests from the passengers are then received by control center **102**, which assigns VTOL aircraft **108** and creates flight plans based on the service requests.

[0049] In some implementations, each assigned VTOL aircraft **108** receives a flight plan/task in the form of a sequence of instructions from control center **102** through radio communication channels. The flight plan can include times, locations, routes, speeds, and other information necessary to perform a flight service. The onboard computer of each VTOL aircraft **108** controls the aircraft to perform the flight plan based on these instructions. Multiple types of sensors, such as GPS, gyroscopes, light detection and ranging (LIDARs), piton tubes, cameras, can be equipped on VTOL aircraft **108**. The onboard computer can process these sensor data to facilitate the control of taking off, landing, and cruising of VTOL aircraft **108**. Moreover, the sensor data collected during the flight can be transmitted to control center **102**, which is configured to monitor the status of VTOL aircraft **108** during the flight based on the received sensor data.

[0050] In some implementations, when a disclosed VTOL aircraft **108** needs to be recharged, the VTOL aircraft flies back to a hangar **104** for battery charging. The recharging request can be generated by the on-board computer of the VTOL aircraft **108** upon detecting a low battery condition. The recharging request can also be generated by control center **102** upon receiving sensor data from the VTOL aircraft indicating a low battery condition. After the VTOL aircraft is fully charged at the hangar, the aircraft sets off from the hangar to carry out new flight tasks.

Ground Facilities: Control Center

[0051] In various embodiments, control center **102** of the disclosed passenger transport system **100** includes one or more computers, or a cluster of computers, and various control programs stored on the one or more computers. In some embodiments, control center **102** is a computer system that is configured to: receive service requests from passengers for transport services of VTOL aircraft **108**, process passenger service requests, generate flight plans/tasks, locate and dispatch VTOL aircraft **108** (e.g., from hangar **104**) to serve the passenger requests within a control range of control center **102**, program the flight tasks into the dispatched VTOL aircraft **108**, control the VTOL aircraft flight missions including monitoring flight status, and program new instructions into the dispatched VTOL aircraft **108** during the flight if necessary. Although only one control center **102** is shown in the system **100** of FIG. **1**, other embodiments of passenger transport system **100** can include more than one control center located at multiple locations within an urban area.

[0052] Control center **102** can be operated either fully automatically or under human control. In some implementations, just one control center is set up at a single location in a given urban area. In some embodiments, after processing a received passenger request, control center **102** generates both dispatch commands and flight tasks. Control center **102** subsequently sends dispatch commands to one of the hangars **104** that store VTOL aircraft **108** or to other locations where VTOL aircraft **108** are known to be located to assign and dispatch an available VTOL aircraft **108**. Control center **102** additionally transmits the generated flight tasks to the assigned aircraft for serving users' service requests.

[0053] After receiving the dispatch commands and the flight task from control center **102**, an assigned VTOL aircraft **108** departs from a hangar **104** and flies to the passenger's pick up location based on the flight task. Control center **102** is configured to monitor real time conditions of the assigned aircraft **108** and change an existing flight task programmed on the assigned aircraft **108** if necessary. In some embodiments, control center **102** is capable of initiating, changing, and aborting any of the services if emergency situations arise, including weather threat, aircraft malfunction, passenger emergency, etc. Control center **102** can also send notifications regarding schedule changes to the passengers who are waiting for the VTOL services.

[0054] Control center **102** can process the sensor data received from the assigned aircraft **108** in flight to identify any safety issue which can affect the flight. Some safety issues can include weather threat along the flight route, aircraft malfunction, and passenger emergency, among others. If a safety issue is identified from the received sensor data, control center **102** can generate a modified flight task, which can include changing the flight route. The modified flight task can be then transmitted from control center **102** to the assigned aircraft **108** in-flight to reprogram the onboard computer of the aircraft. The onboard computer can be configured to subsequently control the remaining flight of the aircraft based on the modified flight task, for example, to change the course according to the new flight route, or to interrupt the flight by landing the aircraft at a safe location.

Ground Facilities: Landing Pads

[0055] In some embodiments, each of landing pads **106** of the disclosed passenger transport system **100** includes a solid patch of surface and necessary equipments for VTOL aircraft **108** to take off and land. Landing pads **106** can be widely distributed in an urban area. For example, landing pads **106** can be set up in locations including, but are not limited to: backyards of residential homes, roofs of buildings, car parking lots, and any other places that meet taking off and landing conditions. Landing pads **106** can be either permanent or temporary. Equipments associated with a landing pad **106** can include, but are not limited to: (1) special markings for position indication; (2) signal lights for giving off safety warnings to passengers and pedestrians; (3) signal emitters and receivers for assisting VTOL aircraft **108** to take off and land; (4) fastening devices for secure VTOL aircraft **108** on the ground, and (5) radio communication devices for communicating with a VTOL aircraft **108** in a landing procedure and with control center **102**. In some embodiments, a landing pad **106** can be located remotely by a landing VTOL aircraft **108** during daytime or nighttime, for example, using the signals from the aforementioned signal lights, signals emitters, and radio communication devices.

Ground Facilities: Hangars

[0056] In some implementations, each of hangars **104** of the disclosed passenger transport system **100** can be used to store, launch, retrieve, maintain, and recharge batteries of VTOL aircraft **108**. Each hangar **104** can be operated either fully automatically or under human operation. There can be just one hangar **104** or multiple hangars **104** in an urban area. VTOL aircraft **108**, when not in service, can be stored at a hangar **104**, as illustrated in FIG. **1**.

[0057] As mentioned above, control center **102**, hangars **104** and landing pads **106** can be collectively referred to as the ground facilities of passenger transport system **100**. For example, FIG. **2** presents a block diagram illustrating an exemplary configuration of ground facilities **200** of the disclosed passenger transport system in accordance with one embodiment described herein. As can be seen in FIG. **2**, ground facilities **200** of the exemplary passenger transport system includes one control center **202**, three hangars **204-1**, **204-2**, and **204-3** located within the control range of control center **202**, and numerous landing pads **206**.

Software Control System

[0058] FIG. **3** illustrates various modules of an exemplary software control system **300** of the disclosed passenger transport system **100** in accordance with one embodiment described herein. As can be seen in FIG. **3**, software control system **300** can include the following subsystems: a passenger reservation system **302**, an aircraft scheduling and dispatching system **304**, a flight task generation system **306**, a flight control system **308**, and an airborne collision avoidance system (ACAS) **310**. However, other embodiments of passenger transport system **100** can include greater or fewer modules than the embodiment of FIG. **3**.

[0059] In some embodiments, passenger reservation system **302** is configured to receive VTOL service requests from passengers, send the requests to aircraft scheduling and dispatch system **304**, receive a response which includes VTOL aircraft scheduling information from aircraft scheduling and dispatch system **304**, and then send response back to the requesting passengers. Passenger reservation system **302** can be implemented in a client/service architecture including both a client-side application and a server-side module. For example, the client-side application of passenger reservation system **302** can be installed and run on PCs, smartphones, laptops, tablets, or other personal computing devices of passengers. The service-side module of passenger reservation system **302** can be located and run on a computer at the disclose control center **102**.

[0060] In some embodiments, aircraft scheduling and dispatch system **304** is configured to locate and assign a VTOL aircraft for a service request and subsequently assigns a new flight task to the assigned VTOL aircraft. In some embodiments, scheduling and dispatch system **304** is configured to locate and assign a VTOL aircraft based on optimizing time and cost factors. For example, scheduling and dispatch system **304** can locate a VTOL aircraft by taking into account such factors as aircraft's current positions to a pick up location, aircraft's current flight tasks, aircraft's battery conditions, weather conditions, passengers' special requests, among others. In some implementations, when a VTOL aircraft is selected to execute the scheduled service, flight task generation system **306** takes over the control of aircraft scheduling and dispatch system **304** to generate a concrete flight task (or a "flight plan," which is used interchangeably with the term "flight task"). In various embodiments, aircraft scheduling and dispatch system **304** is located on a computer at the disclose control center **102**.

[0061] In some embodiments, flight task generation system **306** is configured to generate a concrete flight plan based on the passenger service request and the conditions of the VTOL aircraft assigned to carry out the passenger service request. Flight task generation system **306** can generate the flight plan after receiving information from aircraft scheduling and dispatch system **304** indicating that an aircraft has been assigned to the passenger service request. The content of a flight plan can include time schedule, route to pick up location, route to drop-off location, flight height, flight speed, among others. A flight plan can also include a set of procedures in response to other factors, such as weather conditions, battery conditions, and passengers' special request, among others. In various embodiments, flight task generation system **306** is located on a computer at the disclose control center **102**.

[0062] In some embodiments, flight control system **308** is configured to carry out a flight plan programmed onto an assigned VTOL aircraft **108** after control center **102** transmits the flight plan generated by flight task generation system **306** to the VTOL aircraft **108**. In some embodiments, flight control system **308** includes at least an onboard flight control subsystem **308-1** stored in memories or other storage devices on the onboard computers of VTOL aircraft **108** as an onboard flight control system. In these embodiments, onboard flight control subsystem **308-1** automatically controls the flights of the VTOL aircraft **108**, such as during taking off, landing, cruising, based on the received flight plan. To control the flight of a given VTOL aircraft **108**, onboard flight control subsystem **308-1** receives the flight plan sent by control center **102**, and converts the flight plan into a sequence of flight instructions corresponding to the taking off, landing, cruising and other flight procedures. When the VTOL aircraft **108** performs each flight procedure based on the flight instructions, the sensors installed on the VTOL aircraft capture flight status in real-time. Onboard flight control subsystem **308-1** can read sensor data and adjust the flight conditions of the aircraft to achieve desired flight status. In some embodiments, onboard flight control subsystem **308-1** is also responsible for sending flight status to control center **102** through radio communication channels for flight monitoring purposes.

[0063] In some embodiments, flight control system **308** also includes a ground flight control subsystem **308-2** located on a computer at control center **102** to monitor real time conditions of the assigned aircraft **108** and change an existing flight task programmed on the assigned aircraft **108** if necessary. As mentioned above, this ground flight control subsystem can process the sensor data received from an assigned aircraft **108** in flight to identify any safety issue which can affect the flight. If a safety issue is identified, ground flight control subsystem **308-2** can generate a modified flight task, which can include changing the flight route. Ground flight control subsystem **308-2** can then transmit the modified flight task from control center **102** to the assigned aircraft **108** to reprogram the onboard computer of the aircraft **108**. Hence, onboard flight control subsystem **308-1** can then control the flight of the aircraft **108** based on the modified flight task, for example, to change the course according to the new flight route, or to interrupt the flight by landing the aircraft at a safe location.

[0064] In some embodiments, ACAS **310** operates to prevent VTOL aircraft **108** from colliding with other aircraft by assigning a VTOL aircraft under a threat of collision to a different height and/or routes. In some embodiments, ACAS system **310** takes effect after flight task generation system **306** assigns a new flight plan to a VTOL aircraft **108**. In one embodiment, ACAS **310** runs during the entire flight of an assigned VTOL aircraft **108** from takeoff to landing to ensure no collision risk can happen at anytime during the entire execution of the flight task.

Exemplary Operations of the Passenger Transport System

[0065] FIG. **4** presents a flow diagram illustrating an exemplary operation **400** of the disclosed passenger transport system **100** in accordance with one embodiment described herein. FIG. **4** can be understood in conjunction with passenger transport system **100** of FIG. **1**.

[0066] As shown in FIG. **4**, passenger **110** uses an online reservation system **402**, such as a reservation website, to schedule a VTOL aircraft service by generating a service request **404**. In some embodiments, service request **404** can include: (1) a pickup location; (2) a pickup time; (3) a drop-off location; and (4) other information related to the VTOL transportation service. Next, control center **102** receives and processes service request **404** and assigns an available VTOL aircraft **108** to provide the requested service. The assignment of the aircraft can be optimized based on the aircraft's current distribution, battery condition, weather, and other considerations. For example, if an aircraft is found to be near the scheduled pickup location with good service condition, this aircraft can be assigned to provide the requested service.

[0067] After sending the processed service request **406** to the assigned VTOL aircraft **108**, control center **102** waits for the response from the assigned aircraft. If control center **102** receives a successful response **408** from the assigned VTOL aircraft **108** indicating that the processed service request **406** is accepted, control center **102** subsequently generates confirmation information **410** which can include: (1) a reservation confirmation; (2) a rescheduled pick up time (if necessary); (3) cost information; and (4) other instructions related to the service. Confirmation information **410** is then sent to passenger **110** and/or displayed on the user interface of online reservation system **402**.

[0068] Next, control center **102** transmits a generated flight plan **412** based on the service request **404** to the assigned VTOL aircraft **108**. Control center **102** then waits for an acknowledgement **414** from the assigned VTOL aircraft **108** indicating that the flight plan has been successfully received. After successfully receiving the flight plan **412**, the assigned VTOL aircraft **108** travels to the pickup location **416**, for example, by landing on a landing pad at pickup location **416**, at the scheduled pickup time and waits for passenger **110** (if passenger **110** has not arrived).

[0069] Continuing referring to FIG. **4**, after receiving confirmation information **410**, passenger **110** arrives at the pickup location **416** and subsequently enters the assigned VTOL aircraft **108**. In some implementations, after passenger **110** enters the assigned VTOL aircraft **108** and prior to takeoff, the aircraft is configured to perform a pre-takeoff passenger safety procedure **418**. For example, the assigned VTOL aircraft **108** can be configured to detect if passenger **110** is seated with seatbelt fastened. In some embodiments, aircraft **108** performs the seating and seatbelt detections using one or more onboard/cabin sensors. For example, the one or more cabin sensors can include: (1) a pressure sensor positioned on the passenger seat configured to detect the weight of a passenger; (2) a seatbelt sensor integrated with the seatbelt and configured to determine whether the seatbelt is in the buckled state or the unbuckled state; and (3) an image sensor which is configured to visually detect passenger's position and/or gesture. In some embodiments, instead of using cabin sensors to detect if passenger **110** has securely seated, aircraft **108** includes one or more buttons in the cabin configured to allow passenger **110** to press to indicate that he/she has securely seated. In further embodiments, the assigned VTOL aircraft **108** can use a combination of cabin sensor detections and passenger self-confirmations to ensure that passenger **110** has securely seated. An exemplary process of performing pre-takeoff passenger safety procedure is described below in conjunction with FIG. **5**.

[0070] After confirming that passenger **110** has securely seated, the assigned VTOL aircraft **108** takes off and travels toward destination **420**. In some embodiments, during the flight toward destination **420**, passenger **110** has no access to the controls of the aircraft. As described above, the flight route is included in the flight plan which is generated by control center **102** and programmed into the aircraft's onboard computer. In some embodiments, the onboard computer of aircraft **108** collects aircraft sensor data during the flight and controls the flight based on the flight plan and the sensor data at all time. In some embodiments, during the flight toward destination **420**, control center **102** receives sensor data from aircraft **108** and monitors the flight at all time. Control center **102** can generate new instructions to change the flight plan, such as flight route, flight height, flight speed, etc. based on the received sensor data and other factors that can affect the flight plan.

[0071] In some embodiments, after arriving at destination **420** and prior to landing, the onboard computer of aircraft **108** is configured to detect and determine if it is safe for landing based on a set of safe landing conditions. If one or more of the safe landing conditions are not met, the onboard computer prevents the aircraft **108** from landing. The aircraft can verify the safe landing conditions using either cabin sensors, or ground sensors placed at the landing pad, or using a combination of both cabin sensors and ground sensors.

[0072] After the aircraft **108** lands at destination **420**, passenger **110** exits the aircraft **108**. In some embodiments, the aircraft **108** is configured to determine if passenger **110** has left the cabin using cabin sensors, or buttons for passenger to press on the cabin door indicating that passenger **110** is outside of the cabin, or a combination of these two options. An exemplary process of performing a safe landing procedure is described below in conjunction with FIG. **6**. After completing the assigned flight task, control center **102** can then send new instructions to the assigned VTOL aircraft **108** for either returning to the hangar or navigating to serve a new passenger request.

Passenger Safety Procedures During Takeoff and Landing of A VTOL Aircraft

[0073] Passenger safety can be the topmost concern of using the disclosed passenger transport system. As mentioned above, passenger safety procedures can be implemented on the assigned VTOL aircraft prior to taking-off and during/after the landing to ensure the safety of the passengers and the aircraft. An exemplary passenger safety procedure prior to the takeoff can include directing the passengers into the aircraft and ensure that the passengers are ready to fly with the aircraft. Another exemplary passenger safety procedure after landing may be implemented to direct the passengers to exit the aircraft and ensures that the aircraft can depart after finishing the current service.

[0074] FIG. **5** presents a flowchart illustrating an exemplary process **500** of performing a pre-takeoff passenger safety procedure in accordance with one embodiment described herein.

[0075] The process starts when a passenger arrives at a pickup location and attempts to enter the cabin of a VTOL aircraft, for example, by attempting to open the cabin door. The VTOL aircraft then receives a form of authentication/identification from the passenger to identify the passenger as the authorized passenger who has reserved that VTOL aircraft (step **502**). In some embodiments, if multiple passengers have reserved the same service of the VTOL aircraft, each of the passengers needs to provide a corresponding authentication/identification to the VTOL aircraft. In some embodiments, the techniques for providing authentication/identification information by a person to access the VTOL aircraft can include, but are not limited to: entering a reservation confirmation number or a password, e.g., using a PIN pad outside the cabin; tapping an Radio Frequency Identification (RFID) or Near Field Communication (NFC) card/key-fob to a RFID/NFC reader outside the cabin; scanning a barcode using a handheld device, such as a smartphone; providing a biometric-based authentication, such as fingerprints, facial recognition, or eye scan; and using a physical key to open the cabin door.

[0076] Next, the received authentication/identification information is authenticated (step **504**). The authentication process can be performed either at the aircraft or at the control center. In one embodiment, when the authentication takes place at the aircraft, the onboard computer of the aircraft receives the authentication/identification information and compares it to the pre-stored authentication/identification information. In another embodiment, when the authentication takes place at the control center, the control center receives the authentication/identification information and compares it to the pre-stored information. In both cases, the cabin door of the aircraft is unlocked if the authentication is successful (step **506**). In some embodiments, when there are multiple passengers, the authentication is successful only if the authentication/identification information of all the passengers has been authenticated. If the authentication fails, the cabin door remains locked and an alarm may be set off.

[0077] After the passenger has entered the cabin, the cabin door is closed either by the passenger or automatically. Next, the passenger takes a seat and fastens the seatbelt. In some embodiments, the onboard computer uses multiple sensors installed inside the cabin to perform pre-takeoff checks to determine if the aircraft and the passengers are safe for takeoff (step **508**). Some of the necessary checks inside the cabin can include, but are not limited to: whether the cabin door is securely closed and/or locked, and whether the passengers' seatbelts are securely fastened. If any of these pre-takeoff checks fails, reminders and instructions can be issued to the passengers in the form of voice, signal light, displayed text messages, etc (step **510**). Before these pre-takeoff checks can be successfully completed, no takeoff will take place.

[0078] If the pre-takeoff checks are successfully, the onboard computer prompts the passenger to confirm whether the aircraft can take off, e.g., through voice prompts, lights, or a display (step **512**). The passenger can respond the inquiry by a voice command, by pressing a button, or by touch a touchscreen in the cabin as a confirmation that the passenger is ready to take off. The above confirmation inquiry can take place after the onboard pre-takeoff checks have been completed. After receiving the readiness confirmation, the onboard computer sends a takeoff request to the control center (step **514**). After receiving the permission/confirmation from the control center, the onboard computer initiates takeoff procedure and reminds the passenger that the aircraft will take off shortly (step **516**). Next, the onboard system operates the aircraft to take off. In some implementations, the aircraft sends a takeoff request to the control center without requiring the passenger to provide the takeoff confirmation.

[0079] FIG. **6** presents a flowchart illustrating an exemplary process **600** of performing a landing passenger safety procedure in accordance with one embodiment described herein.

[0080] The process starts when the VTOL aircraft is approaching the landing pad of the destination location. The onboard computer initiates landing preparation and issues a pre-landing notification to the passenger indicating that the aircraft will be landing shortly (step **602**). Next, the onboard computer guides the aircraft to land on the ground or a landing pad safely (step **604**). As this point, the onboard computer can shut down the aircraft engines, including stopping all propeller rotation. The onboard computer then unlocks the cabin door and notifies the passenger that the flight service is completed (step **606**). The onboard computer can also issue instructions on how to safely exit the aircraft. At this time, the passenger can remove the seatbelt, open the cabin door, and exit the cabin. The onboard computer next determines if all passengers have left the aircraft (step **608**). If so, the onboard system locks the cabin door and controls the aircraft to return to the hangar or navigate to the next service pickup location (step **610**). If not, the onboard system waits and repeats step **608** until all passengers have left the aircraft.

[0081] In some implementations, prior to taking off after finishing the current passenger transport service, the onboard computer of the VTOL aircraft is configured to inspect the aircraft cabin by performing following checks: (1) if all passengers have left the aircraft; (2) if the cabin doors are closed; and (3) any other conditions that can affect the safety of the next flight. If any of the checks fails, the onboard computer keeps the aircraft grounded and waits for the above conditions to be satisfied. For example, the onboard computer can be configured to repeat these checks after a predetermined time duration. In some embodiments, when the onboard computer verifies that the conditions of the aircraft have met the required takeoff conditions, the aircraft takes off and returns to the hangar or depart to a new destination to execute the next assigned passenger service.

Obstacle Detection During Takeoff and Landing

[0082] In various embodiments, before and during the takeoff and during landing, a disclosed VTOL aircraft is configured to avoid any obstacle on its moving path. Obstacles can include objects on the ground (e.g., pedestrians, cars, etc.) or above the ground (e.g., wires, poles, trees, etc). In some embodiments, when an obstacle is detected in the moving path, the aircraft's onboard flight control system, such as onboard subsystem **308-1** described in FIG. **3** is configured to guide the aircraft to maneuver away from the obstacle. If the onboard flight control system determines that aircraft cannot avoid the obstacle, the takeoff or landing procedure would be aborted.

[0083] In some exemplary systems, additional sensors having 3D sensing capability for obstacle detection can be installed on the VTOL aircraft. These obstacle detection sensors can be installed on the top, on the side, or on the bottom of the VTOL aircraft. Some sensors that can be used for this function include radars, LIDARs, and stereo cameras. In some embodiments, the sensors' field of view is configured to be at least greater than the projected area of the full aircraft profile.

[0084] In one example, during a landing procedure, the obstacle detection sensors installed on the bottom of the VTOL aircraft detect if there is any obstacle below the aircraft. If the obstacle detection system determines that the aircraft cannot land onto the designated landing pad after a few attempts because of the detected obstacles, the onboard computer of the aircraft sends notification back to the control center. The control center may then assign another landing pad which is close to the current landing pad. The aircraft then navigates to the new landing pad and attempts to land at the new location. In another example, during a takeoff procedure, the obstacle detection sensors installed on the top of the aircraft detect if there is any obstacle above the aircraft. If the obstacle detection system determines that the aircraft cannot take off after a few attempts because of detected obstacles, the onboard computer of the aircraft controls the aircraft to return to the landing pad and sends notification to the control center.

Landing Pad Localization

[0085] In some embodiments, the landing pads of the disclosed passenger transport system can include landing assistant equipments, such as visual markers. In particular embodiments, the visual makers can be made of LEDs or other light sources that can emit visible or invisible lights toward the sky. In these embodiments, the VTOL aircraft also includes light detectors to receive the lights from the visual makers to identify the location of the landing pad. In some embodiments, the landing assistant equipments on the land pads include radio wave emitters that can emit RF signals at particular frequencies. The landing pads with landing assistant equipments may be used in those places where landing accuracy is crucial, such as in residential areas, parking lots, roofs of buildings, etc. These landing assistant equipments are designed to guide the aircraft to land in the designated areas with high accuracy.

[0086] In some embodiments, the VTOL aircraft performs landing pad localization maneuver by using a GPS and/or inertial sensors to localize itself onto the land pad. In some exemplary systems, the accuracy of the GPS is around 30 feet. The accuracy of inertial sensors may depend on how long the aircraft travels. In some cases, both types of sensors cannot provide enough accuracy for landing the aircraft in a relative narrow area. In such cases, a three-step landing pad localization procedure can be used. FIG. **7** presents a flowchart illustrating a VTOL aircraft landing process **700** based on a three-step landing pad localization procedure in accordance with one embodiment described herein.

[0087] The process starts when the VTOL aircraft determines an estimated landing spot based on the information collected by GPS and/or onboard inertial sensors (step **702**). Next, the aircraft reduces the height to a first level and roughly approaches the landing pad (step **704**).

[0088] Next, an imaging camera sensor on the VTOL aircraft facing downward is used to locate the landing pad with a higher accuracy (step **706**). In some embodiments, the captured images by the camera are continuously compared to the pre-stored images of and around the same landing pad. The aircraft gradually maneuvers itself to a place where a minimum matching error is obtained (step **708**). The place with this minimum matching error indicates that the aircraft is roughly above the desired land spot. The aircraft additionally reduces the height above the land pad to a second level during this step.

[0089] Next, the imaging camera facing downward begins to search for visual markers placed on the landing pad (step **710**). These visual markers indicate the geometrical shape and boundary of the landing pad. In some embodiments, a dedicated program stored on the onboard computer is used to locate these visual markers and subsequently estimates the deviation to the landing pad. The aircraft continues to move based on the visual markers until the center of the aircraft aligns with the center of the landing pad (step **712**). This step can achieve the highest localization accuracy. Finally, the aircraft lands onto the landing pad by directly lowering the aircraft with minimum side movement toward the landing pad (step **714**).

[0090] In some implementations, the aircraft can also land on areas without landing assistant equipments. This setup may be used in the situations where landing accuracy is not crucial, such as on open ground without any obstacles. In such cases, the localization of landing areas may primarily rely on GPS and/or inertial sensors. However, obstacle detection may still be necessary in these cases to prevent human trespassing on the ground during takeoff and landing.

Flight Safety Subsystems

[0091] In various embodiments, to reduce the flight safety risks to the passengers and to the VTOL aircraft as much as possible, one or more of the flight safety subsystems can be implemented in the disclosed passenger transport system, wherein each of the safety subsystems can be implemented in software, hardware which can include sensors and/or detectors, or a combination of software and hardware. FIG. **8** illustrates an exemplary flight safety system **800** implemented in the disclosed passenger transport system in accordance with one embodiment described herein. Note that the software components of flight safety system **800** can be implemented on both ground flight control subsystem **308-2** and onboard flight control subsystem **308-1** described in FIG. **3**.

[0092] As can be seen in FIG. **8**, flight safety system **800** includes an airborne collision avoidance subsystem (ACAS) **802**, which is configured to prevent the risk of aircraft collision as describe above. Flight safety system **800** also includes a weather thread alert subsystem **804**. In some embodiments, weather thread alert subsystem **804** collects weather information in an urban area from third party weather report providers. Using the collected weather threat information by weather thread alert subsystem **804**, during the flight task generation process, the control center can generate planned flight routes which would prevent the VTOL aircraft from flying through airspaces where hazardous weather exists. In some implementations, the weather thread alert subsystem **804** checks those VTOL aircraft in the air iteratively to ensure all the in-flight aircraft operate in safe zones. In some embodiments, if a weather threat is predicted on a VTOL aircraft's planned route, weather thread alert subsystem **804** operates to notify the flight task generation system (e.g., flight task generation system **308** in FIG. **3**) at the control center to make a new flight route for the assigned VTOL aircraft.

[0093] Flight safety system **800** can additionally include a takeoff and landing safety subsystem **806**. As described above, takeoff and landing safety subsystem **806** identifies, resolves, and prevents threats from ground objects, passengers, and pedestrians during the takeoff and landing of the VTOL aircraft. For example, takeoff and landing safety subsystem **806** can include various light sources and/or sound sources placed outside of the VTOL aircraft and/or around the landing pads for the planned purposes. In various embodiments, takeoff and landing safety subsystem **806** is configured to perform or assist the executions of the various processes **500-700** described in conjunction with FIGS. **5-7**.

[0094] Flight safety system **800** also includes an aircraft health condition subsystem **808**. In some embodiments, aircraft health condition subsystem **808** is configured to monitor various health conditions of the VTOL aircraft, such as battery conditions, and to ensure that the VTOL aircraft operate under the desired service health conditions. Flight safety system **800** can additionally include an emergency landing subsystem **810**. In some embodiments, emergency landing subsystem **810** is configured to provide contingency plans for the VTOL aircraft during flight. For example, if a VTOL aircraft encounters an emergency situation, emergency landing subsystem **810** can allow the distressed aircraft to land on a safe location as soon as possible.

[0095] While this patent document contains many specifics, these should not be construed as limitations on the scope of any invention or of what may be claimed, but rather as descriptions of features that may be specific to particular embodiments of particular inventions. Certain features that are described in this patent document and attached appendix in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0096] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results.

[0097] Only a few implementations and examples are described and other implementations, enhancements and variations can be made based on what is described and illustrated in this patent document.

What is claimed is:

1. A computer-implemented method for safely landing a pilotless vertical takeoff and landing (VTOL) aircraft in the air onto a landing pad on the ground, the method comprising:

determining an estimated location of the landing pad with a first accuracy;

reducing a height of the VTOL aircraft in the air to a first level above the ground while approaching the estimated location of the landing pad;

determining an updated location of the landing pad with a second accuracy;

reducing the height of the VTOL aircraft in the air to a second level above the ground while approaching the updated location of the landing pad;

aligning a center point of the VTOL aircraft with a center location of the landing pad; and

landing the VTOL aircraft onto the landing pad by directly lowering the VTOL aircraft onto the landing pad.

2. The computer-implemented method of claim **1**, wherein determining the estimated location of the landing pad with the first accuracy includes determining the estimated location based on information collected by one of:

a GPS;

one or more inertial sensors installed on the VTOL aircraft; and

a combination of the above.

3. The computer-implemented method of claim **1**, wherein determining the updated location of the landing pad with the second accuracy includes using images captured by an imaging camera installed on the VTOL aircraft and facing downward toward the landing pad.

4. The computer-implemented method of claim **3**, wherein reducing the height of the VTOL aircraft to the second level above the ground while approaching the updated location of the landing pad includes:

capturing images of and around the landing pad using the imaging camera;

continuously comparing the captured images to pre-stored images of and around the landing pad; and

maneuvering the VTOL aircraft in a first horizontal direction to a location where a minimum matching error between the captured images and the pre-stored images is obtained, which indicates that the location of the VTOL aircraft is approximately directly above the landing pad.

5. The computer-implemented method of claim **1**, wherein aligning the center point of the VTOL aircraft with the center location of the landing pad includes:

locating a set of visual markers placed on the landing pad, wherein the set of visual markers indicates a geometrical shape and a boundary of the landing pad;

estimating the center location of the landing pad based on the located set of visual markers with a third accuracy; and

maneuvering the VTOL aircraft in a second horizontal direction based on the estimated center location of the landing pad until the center point of the VTOL aircraft aligns with the estimated center location of the landing pad.

6. The computer-implemented method of claim **5**, wherein the set of visual markers placed on the landing pad includes a set of light-emitting markers, and wherein locating the set of visual markers includes using a light detector installed on the VTOL aircraft and facing downward toward the landing pad.

7. The computer-implemented method of claim **5**, wherein maneuvering the VTOL aircraft based on the estimated center location of the landing pad includes estimating and reducing a deviation of the center point of the VTOL aircraft from the estimated center location of the landing pad.

8. The computer-implemented method of claim **5**,

wherein the second accuracy is higher than the first accuracy; and

wherein the third accuracy is higher than the second accuracy.

9. A pilotless vertical takeoff and landing (VTOL) aircraft, comprising:

an onboard computer, wherein the onboard computer is configured to control a landing procedure of the VTOL aircraft in the air onto a landing pad on the ground by:

determining an estimated location of the landing pad with a first accuracy;

reducing a height of the VTOL aircraft in the air to a first level above the ground while approaching the estimated location of the landing pad;

determining an updated location of the landing pad with a second accuracy;

reducing the height of the VTOL aircraft in the air to a second level above the ground while approaching the updated location of the landing pad;

aligning a center point of the VTOL aircraft with a center location of the landing pad; and

landing the VTOL aircraft onto the landing pad by directly lowering the VTOL onto the landing pad.

10. The VTOL aircraft of claim **9**, wherein the onboard computer is configured to determine the estimated location of the landing pad based on information collected by one of:

a GPS;

one or more inertial sensors installed on the VTOL aircraft; and

a combination of the above.

11. The VTOL aircraft of claim **9**, wherein the onboard computer is configured to determine the updated location of the landing pad by using images captured by an imaging camera installed on the VTOL aircraft and facing downward toward the landing pad.

12. The VTOL aircraft of claim **11**, wherein the onboard computer is configured to reduce the height of the VTOL aircraft in the air to the second level above the ground by:

capturing images of and around the landing pad using the imaging camera;

continuously comparing the captured images to pre-stored images of and around the landing pad; and

maneuvering the VTOL aircraft in a first horizontal direction to a location where a minimum matching error between the captured images and the pre-stored images is obtained, which indicates that the location of the VTOL aircraft is approximately directly above the landing pad.

13. The VTOL aircraft of claim **9**, wherein the onboard computer is configured to align the center point of the VTOL aircraft with the center location of the landing pad by:

locating a set of visual markers placed on the landing pad, wherein the set of visual markers indicates a geometrical shape and a boundary of the landing pad;

estimating the center location of the landing pad based on the located set of visual markers with a third accuracy; and

maneuvering the VTOL aircraft in a second horizontal direction based on the estimated center location of the landing pad until the center point of the VTOL aircraft aligns with the estimated center location of the landing pad.

14. The VTOL aircraft of claim **13**, wherein the set of visual markers placed on the landing pad includes a set of light-emitting markers, and wherein the onboard computer is configured to locate the set of visual markers by using a light detector installed on the VTOL aircraft and facing downward toward the landing pad.

15. The VTOL aircraft of claim **13**, wherein the onboard computer is configured to maneuver the VTOL aircraft based on the estimated center location of the landing pad by estimating and reducing a deviation of the center point of the VTOL aircraft from the estimated center location of the landing pad.

16. The VTOL aircraft of claim **13**,

wherein the second accuracy is higher than the first accuracy; and

wherein the third accuracy is higher than the second accuracy.

17. A computer-implemented method for controlling a landing procedure of a pilotless vertical takeoff and landing (VTOL) aircraft during a flight of the VTOL aircraft in the air, the method comprising:

controlling the VTOL aircraft to approach a designated landing spot from the air for landing on the designated landing spot;

detecting, using an obstacle detection system installed on the VTOL aircraft, if there is any obstacle in a landing path between the VTOL aircraft and the designated landing spot that prevents a safe landing of the VTOL aircraft;

when an obstacle is detected in the landing path, guiding the VTOL aircraft to maneuver away from the detected obstacle in an attempt to land on the designated landing spot while avoiding the detected obstacle; and

when it is determined that the detected obstacle cannot be avoided, aborting the landing on the designated landing spot.

18. The computer-implemented method of claim **17**, wherein the obstacle detection system includes one or more obstacle detection sensors having three-dimensional (3D) sensing capability for obstacle detection.

19. The computer-implemented method of claim **18**, wherein the one or more obstacle detection sensors include one or more of radars, LIDARs, and stereo cameras.

20. The computer-implemented method of claim **18**, wherein each obstacle detection sensor in the one or more obstacle detection sensors is configured with a field of view at least greater than a projected area of the VTOL aircraft on the ground.

21. The computer-implemented method of claim **17**, wherein when it is determined that the detected obstacle cannot be avoided, the method further includes:

receiving an assignment of an alternative landing spot which is close to the designated landing spot; and

navigating the VTOL aircraft to the alternative landing spot for landing on the alternative landing spot.

22. The computer-implemented method of claim **17**, wherein prior to performing the landing procedure, the method further comprises:

during a takeoff procedure of the VTOL aircraft from the ground to begin the flight, detecting, using the obstacle detection system, if there is any obstacle in a takeoff path of the VTOL aircraft to prevent a safe takeoff of the VTOL aircraft;

if an obstacle is detected in the takeoff path, guiding the VTOL aircraft to maneuver away from the detected obstacle in an attempt to take off while avoiding the detected obstacle; and

if the obstacle detection system determines that the obstacle cannot be avoid, returning to the ground and sending notification to a ground control system.

23. The computer-implemented method of claim **22**, wherein detecting an obstacle in the takeoff path includes using obstacle detection sensors having 3D sensing capability installed on top of the VTOL aircraft to detect if there is any obstacle above the VTOL aircraft.

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