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Doane

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(54) **UNINHABITED AIRBORNE VEHICLE IN-FLIGHT REFUELING SYSTEM**

(75) Inventor: **Paul M. Doane**, Balwin, MO (US)

(73) Assignee: **The Boeing Company**, Chicago, IL (US)

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(52) **U.S. Cl.** .... **701/3**; 701/9; 701/300; 701/301; 244/135 A; 340/961

(58) **Field of Search** .... 701/3, 4, 9, 10, 701/14, 300, 301; 244/135 A, 195, 17.13; 340/903, 945, 958, 961, 979, 435, 436

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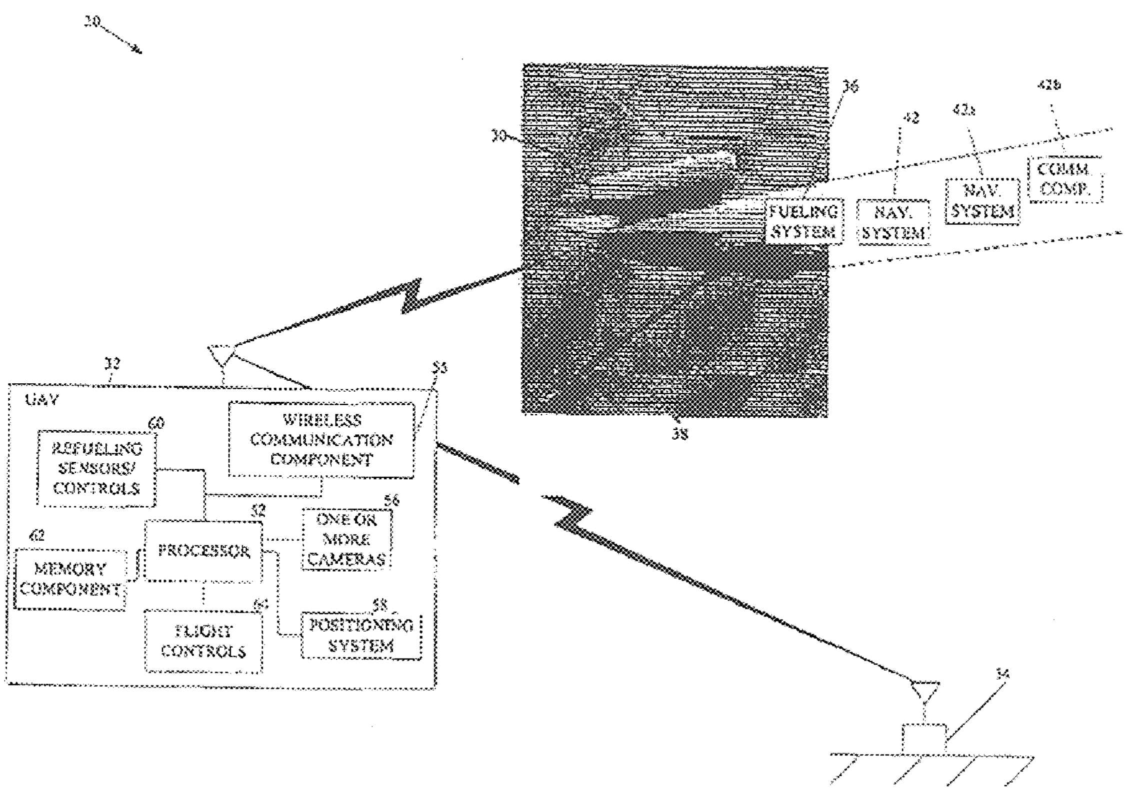
Primary Examiner—Tan Q. Nguyen
(74) *Attorney, Agent, or Firm*—Black Lowe & Graham PLLC

(57) **ABSTRACT**

A method and system is provided for performing automated air refueling of uninhabited airborne vehicles (UAVs). The method and system includes any combination of a positioning system component, an air collision avoidance system (ACAS) component, a voice processing component, an image processing component, a flight controller, a wireless data link connecting the UAV with the tanker, and refueling components. The ACAS component receives position information of other aircraft, such as UAVs and tankers, over the wireless data link, and generates navigation instructions based on the received position information, and sends the generated navigation instructions to the flight controller. The refueling components include sensors that determine the status of the refueling components. Refueling of the UAV is based on the determined status.

20 Claims, 5 Drawing Sheets



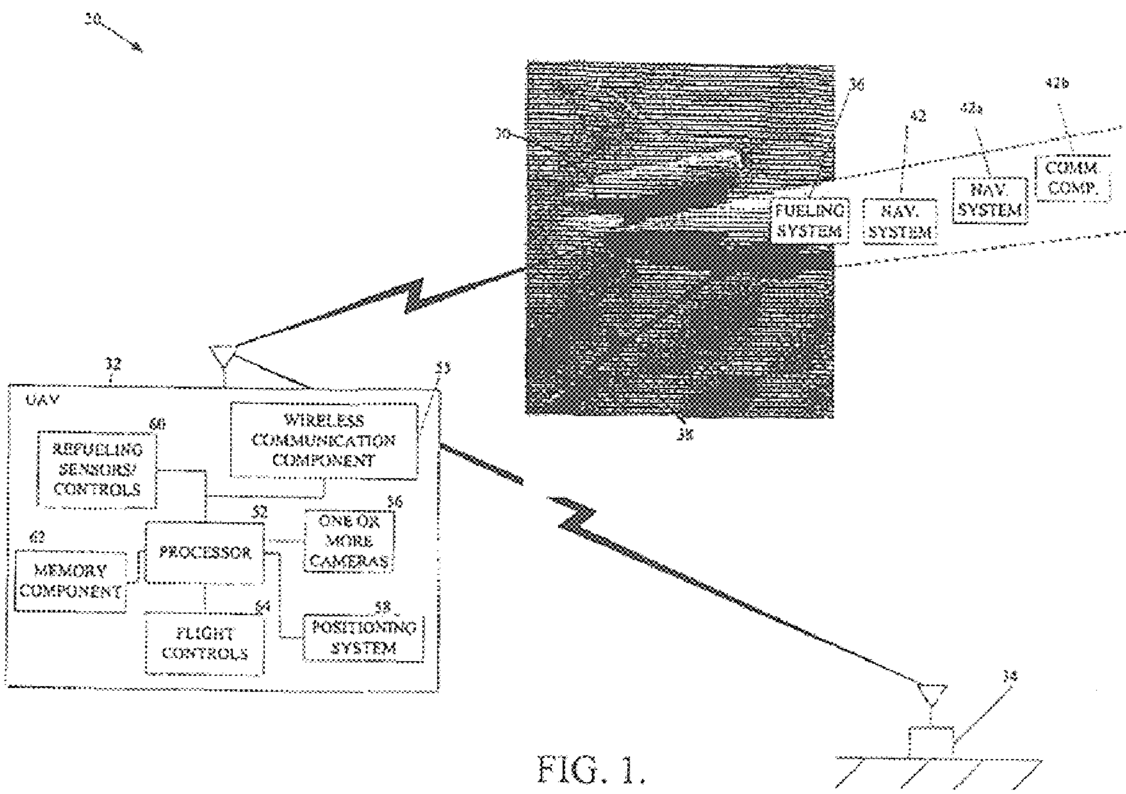

30
36
42
42a
42b
FUELING SYSTEM
NAV. SYSTEM
NAV. SYSTEM
COMM. COMP.
38
32
UAV
53
WIRELESS COMMUNICATION COMPONENT
60
REFUELING SENSORS/ CONTROLS
52
PROCESSOR
56
ONE OR MORE CAMERAS
62
MEMORY COMPONENT
54
FLIGHT CONTROLS
58
POSITIONING SYSTEM
34

FIG. 1.

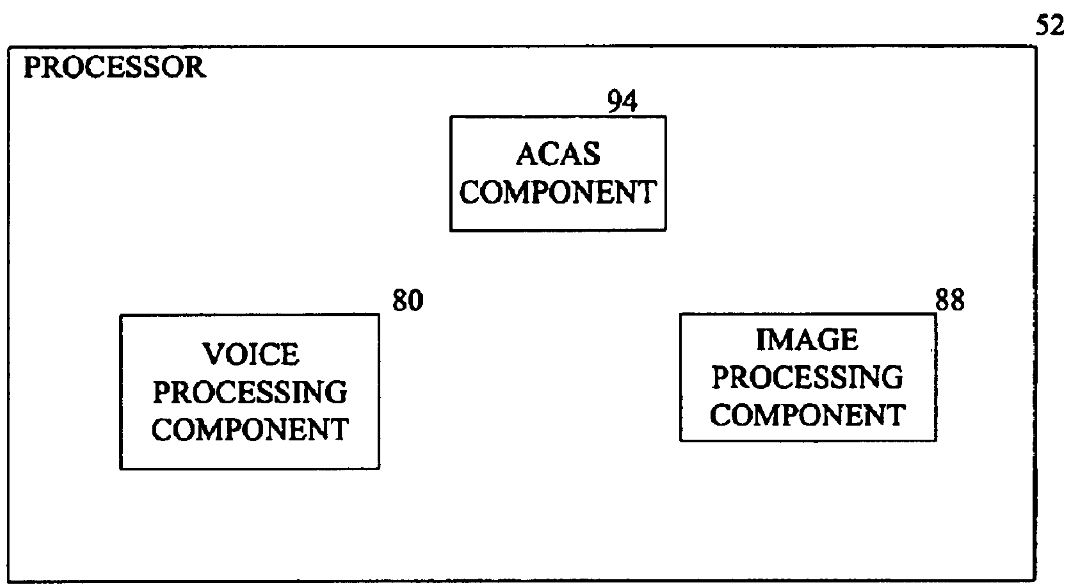

52
PROCESSOR
94
ACAS COMPONENT
80
VOICE PROCESSING COMPONENT
88
IMAGE PROCESSING COMPONENT

FIG. 2.

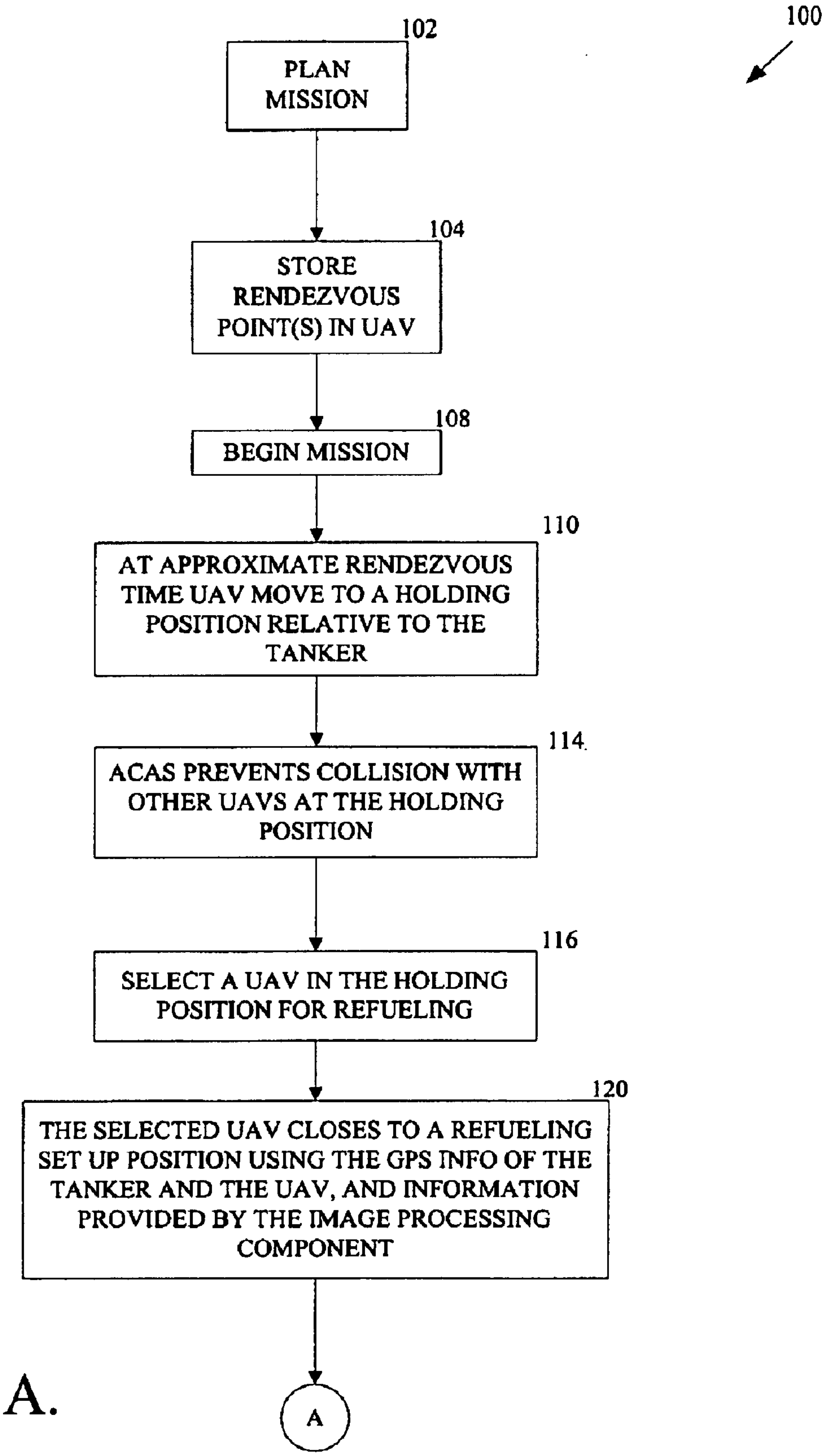

100
102
PLAN MISSION
104
STORE RENDEZVOUS POINT(S) IN UAV
108
BEGIN MISSION
110
AT APPROXIMATE RENDEZVOUS TIME UAV MOVE TO A HOLDING POSITION RELATIVE TO THE TANKER
114
ACAS PREVENTS COLLISION WITH OTHER UAVS AT THE HOLDING POSITION
116
SELECT A UAV IN THE HOLDING POSITION FOR REFUELING
120
THE SELECTED UAV CLOSES TO A REFUELING SET UP POSITION USING THE GPS INFO OF THE TANKER AND THE UAV, AND INFORMATION PROVIDED BY THE IMAGE PROCESSING COMPONENT
A

FIG. 3A.

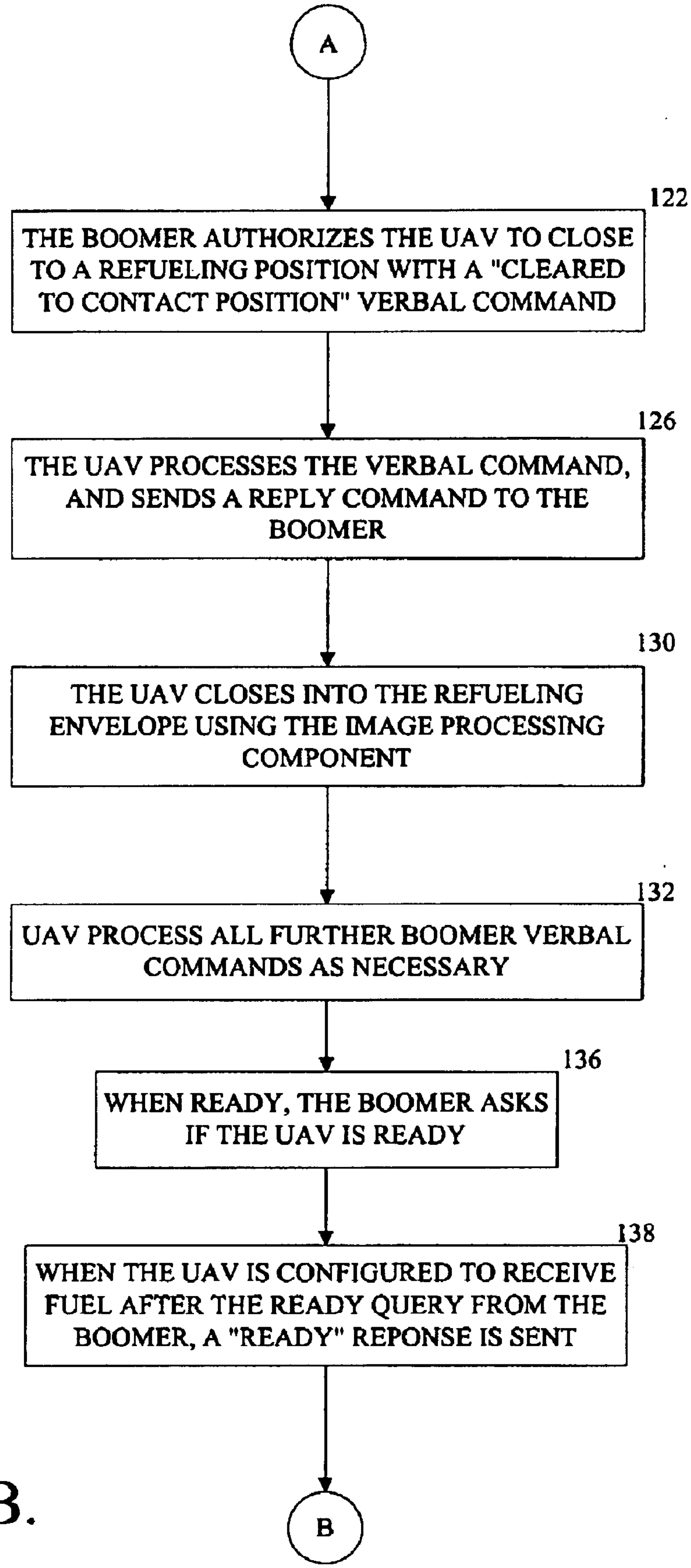

A
122
THE BOOMER AUTHORIZES THE UAV TO CLOSE TO A REFUELING POSITION WITH A "CLEARED TO CONTACT POSITION" VERBAL COMMAND
126
THE UAV PROCESSES THE VERBAL COMMAND, AND SENDS A REPLY COMMAND TO THE BOOMER
130
THE UAV CLOSES INTO THE REFUELING ENVELOPE USING THE IMAGE PROCESSING COMPONENT
132
UAV PROCESS ALL FURTHER BOOMER VERBAL COMMANDS AS NECESSARY
136
WHEN READY, THE BOOMER ASKS IF THE UAV IS READY
138
WHEN THE UAV IS CONFIGURED TO RECEIVE FUEL AFTER THE READY QUERY FROM THE BOOMER, A "READY" REPONSE IS SENT
B

FIG. 3B.

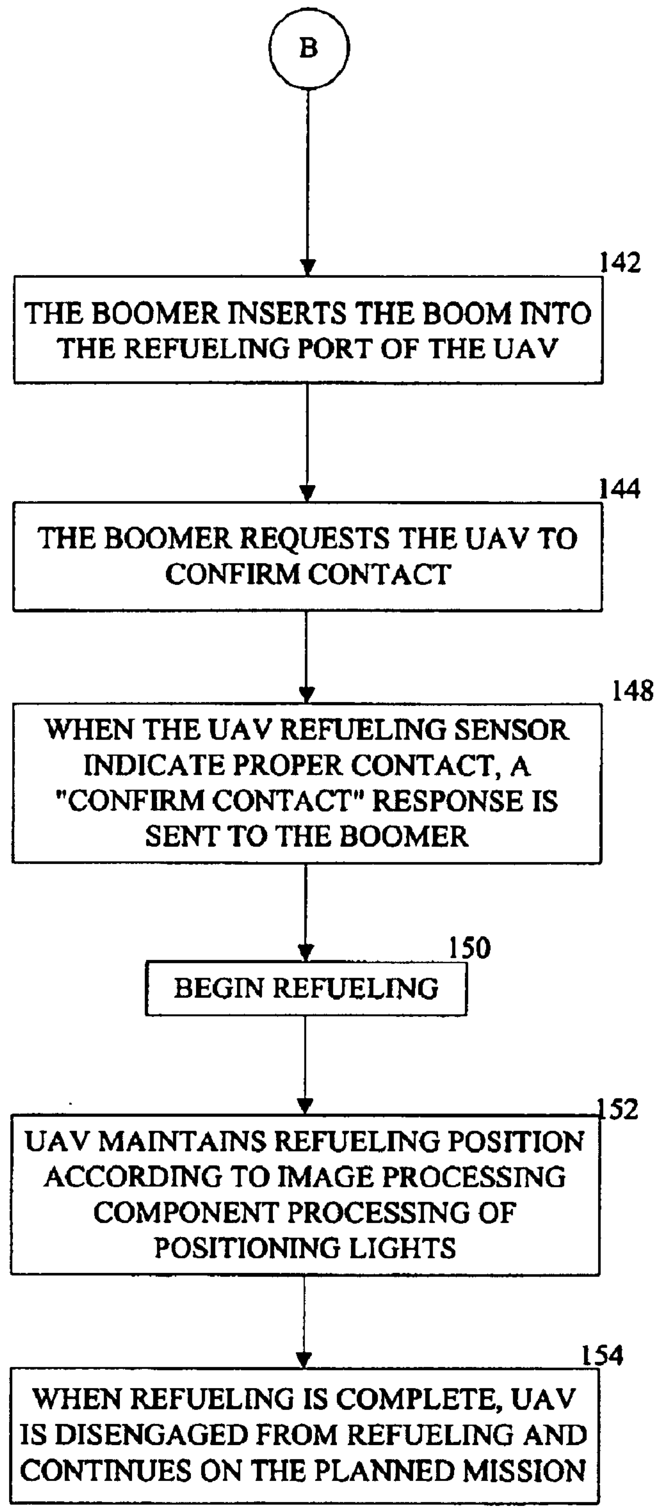

B
142
THE BOOMER INSERTS THE BOOM INTO THE REFUELING PORT OF THE UAV
144
THE BOOMER REQUESTS THE UAV TO CONFIRM CONTACT
148
WHEN THE UAV REFUELING SENSOR INDICATE PROPER CONTACT, A "CONFIRM CONTACT" RESPONSE IS SENT TO THE BOOMER
150
BEGIN REFUELING
152
UAV MAINTAINS REFUELING POSITION ACCORDING TO IMAGE PROCESSING COMPONENT PROCESSING OF POSITIONING LIGHTS
154
WHEN REFUELING IS COMPLETE, UAV IS DISENGAGED FROM REFUELING AND CONTINUES ON THE PLANNED MISSION

FIG. 3C.

UNINHABITED AIRBORNE VEHICLE IN-FLIGHT REFUELING SYSTEM

FIELD OF THE INVENTION

This invention relates generally to aircraft refueling and, more specifically, to uninhabited airborne vehicle refueling.

BACKGROUND OF THE INVENTION

Uninhabited airborne vehicles (UAVs) are becoming widely used by the U.S. Navy and Air Force. Current UAV applications include surveillance, ground attack, and air interdiction. However, further expansion of UAV applications is hindered because, unlike piloted aircraft, they cannot be refueled during flight. Consequently, UAVs cannot perform applications requiring long ranges, such as deep strike interdiction, or long duration surveillance. UAVs also cannot be transported under their own power to remote locations, such as across oceans, because of their range limitations. Instead, UAVs must be flown across oceans in transport aircraft, which is expensive and ties up valuable resources needed for transporting other equipment. Because of these reasons, there exists a need to refuel UAVs in-flight. Because no UAV in-flight refueling system is currently known to exist, there is an unmet need in the art for a UAV in-flight refueling system.

SUMMARY OF THE INVENTION

The present invention provides automated air refueling (AAR) of uninhabited airborne vehicles (UAVs). According to an embodiment of the invention, a UAV AAR system includes any combination of a positioning system component, an air collision avoidance system (ACAS) component, a voice processing component, an image processing component, a flight controller, a wireless data link, refueling components, and a ground operation station. The voice processing component may be replaced by a wireless voice link to a human operator at the ground operation station using, such as, but not limited to, a satellite communications link. The positioning system component determines the absolute (longitude, latitude, altitude) location of the UAV. A similar system on the tanker determines the absolute position of the tanker, which is transmitted to the UAV over the wireless data link. The absolute position of the UAV and tanker is provided to the flight controller, which determines the relative position (azimuth, elevation, range) of the UAV relative to the tanker, and generates navigation instructions to guide the UAV into the proper position relative to the tanker such that the tanker can connect with the UAV to transfer fuel. The ACAS component also receives the absolute positions of the UAV, as well as the tanker and any other aircraft around the UAV via the wireless data link. The ACAS component also computes the relative position of the UAV relative to the tanker and other aircraft in the vicinity. The ACAS component uses that information to allow the UAV to avoid collisions with the tanker or other aircraft in the vicinity of the UAV. In the event the UAV is headed towards a collision with another aircraft, the ACAS component generates navigation instructions based on the relative position information, and sends the generated navigation instructions to the flight controller to safely fly the UAV away from the collision.

The voice processing component receives voice instructions over a voice communications channel, analyzes the received voice instructions, transmits a response according to autonomous analysis, generates navigation instructions according to the analysis, and sends the generated navigation instructions to the flight controller. The voice processing component transmits a response based on the sensed one or more conditions of the refueling components.

As an alternative, the voice processing component is replaced by a wireless voice link to a human operator at the ground operation station. For the purposes of simplification, the present invention assumes that voice processing component is used in the refueling operation, although either approach is included in this application.

The image processing component includes one or more digital cameras for generating one or more digital images, a memory, and an image processor. The image processor compares the generated one or more digital images to one or more comparable images stored in the image processing component's memory to determine the position of the UAV relative to the tanker. The relative position information is sent to the flight controller, which compares the relative position information with that generated from the data sent by the positioning system. If the two relative position calculations are consistent, the flight controller generates navigation instructions to guide the UAV into position for refueling.

Should either the image processing component or the positioning component fail during the refueling operation, the refueling can be completed using other components. When both components are operational, they provide a safety check against errors or failures in either system. Embodiments of this invention using only one of these components are covered in this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred and alternative embodiments of the present invention are described in detail below with reference to the following drawings.

FIG. **1** illustrates the components of an automatic air refueling system for uninhabited airborne vehicle (UAV) formed in accordance with the present invention;

FIG. **2** illustrates processing components included within a processor of the UAV; and

FIGS. **3**A–C illustrate a flow diagram of an air refueling operation for a UAV of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** illustrates a system **20** for performing automatic air refueling evolutions for uninhabited air vehicles (UAV) **32**, such as, without limitation, US Navy and Air Force UAVs. The system **20** includes one or more refueling aircraft (tanker) **30**, one or more UAVs **32**, and one or more ground operation stations **34**. The tanker **30** includes a navigation system **42**, a positioning system **42***a* such as without limitation a global positioning system (GPS), a wireless data communication component **42***b*, and a fueling system **36** with a boom **38**. The fueling system **36** includes components for allowing a boom operator to control the boom **38** during aircraft fueling operations and to send voice commands to a UAV **32** via radio communication (alternatively to the ground operation station operator). The positioning system **42***a* provides the absolute location of the tanker **30** to the UAV **32** via the wireless data communication component **42***b*. The wireless data communication component **42***b* allows the tanker to send and receive information to and from UAVs **32**.

Each UAV **32** includes a processor **52**, one or more digital cameras **56**, a positioning system **58**, such as without limitation a global positioning system (GPS), refueling sensors and controls **60**, a suitable memory component **62**, a wireless data communication component **55** that communicates (wireless data link) with the wireless data communication component **42***b* of the tanker **30**, and flight controls **64**. The ground operation station **34** includes voice and data communication components (not shown) for allowing communication with the tanker **30** and the UAVs **32**.

FIG. **2** illustrates some of the processing components included within the processor **52** of a UAV **32**. The processor **52** includes a voice processing component **80**, an image-processing component **88**, and an air collision avoidance system (ACAS) component **94**. The voice processing component **80** performs voice recognition processing of voice signals received from the tanker **30** or the ground operation station **34**, and sends any necessary voice replies to the tanker **30** or the ground operation station **34**. A non-limiting example of the voice processing component **80** is the ability of the UAV to understand and act upon voice commands from the tanker operator, such as "Breakaway, Breakaway". Inherent in the invention is synergistic uses of these components such as using the ACAS component to protect the UAV from acting upon unsafe voice commands from the tanker operator. The voice processor component **80** can be located on the tanker **30**.

The image processing component **88** analyzes digital images generated by the one or more digital cameras **56** to determine aircraft position relative to the tanker **30**. The UAV **32** receives from the tanker **30** a tanker identification code using the data communication component **55**. The imaging processing component **88** suitably compares the digital images received from the digital camera **56** with digital images of the tanker type aircraft that are retrieved from memory (not shown) based on the received tanker identification code. The imaging processing component **88** determines where the UAV **32** is relative to the tanker **30** (range, azimuth, and elevation). The processor **52** also determines the closure rate of the UAV with the tanker. The processor **52** provides the relative position information to the flight controls **64**, which produces flight commands based on position the UAV **32** at a necessary optimum position relative to the tanker **30** for refueling. A non-limiting example of the image processing component **88** determines that the UAV is located too far to one side and too far below the desired position for refueling relative to the tanker. The image processing component **88** can also process information from lights on the bottom of the tanker used to communicate with pilots of the receiving aircraft. These lights are currently used to affect in-flight refuelings in the event that no electronic emission is permitted from the tanker due to security considerations.

The ACAS component **94** receives absolute position information from one or more nearby UAVs **32** or piloted aircraft (not shown) over a wireless data link between the communication components **42***b* and **55**, and generates signals for the flight controls **64** that keep the UAV **32** from colliding with other nearby UAVs **32** or with the tanker **30**. A non-limiting example of an ACAS component **94** determines that the UAV **32** has too great a closure rate with the tanker **30**, and is at risk of an incipient collision with the tanker **30**, such that the ACAS component **94** must send steering commands to the flight controls **64** to maneuver the UAV **32** away from the tanker **30**.

FIGS. **3**A-C illustrate an exemplary process performed by the system **20** shown in FIGS. **1** and **2**. First, at block **102**, a mission is planned and developed. The planned mission includes one or more rendezvous points for refueling of UAV **32**. At a block **104**, the rendezvous points of the planned mission are stored in the memory component **62** in each of the participating UAVs **32**. At a block **108**, the mission begins. At a block **110**, at about the rendezvous time, the UAV **32** moves into a holding position relative to the tanker **30**. Approximately 500 feet aft of the tanker and approximately 100 feet below the tanker is a non-limiting example of a holding position.

During the rendezvous, and throughout the refueling operation, at a block **114**, the ACAS component **94** of each of the UAV **32** provides flight control signals for preventing collision with any other UAV **32** at the holding position, or with the tanker **30**. At a block **116**, a UAV **32** that is in the holding position is selected for refueling. The selection of UAV **32** can be performed by an operator at the ground operation station **34**, or an operator on the tanker **30**. In an alternate embodiment, the UAVs **32** exchange information about each of their fuel levels over the wireless data link. The UAVs **32** automatically determine which UAV **32** needs to be refueled first according to the lowest amount of fuel, or other considerations as determined from the information exchanged over the data link. At a block **120**, the selected UAV **32** closes to a refueling set-up position using flight control (navigation) information determined using the positioning system **42***a* information of the tanker **30** and the positioning system **58** information of the UAV **32**, or flight control information provided by the image processing component **88**, or the voice processing component **80**.

As shown in FIG. **3**B, at a block **122**, the boom operator (boomer) authorizes the UAV **32** that is in the refueling set-up position to close to a refueling position. The boomer suitably performs this authorization by providing a verbal command or digital command sent over the wireless data link to the UAV **32** or as an alternative, through voice contact with the ground station operator **34**. "Clear to contact position", or an equivalent digital message, is a suitable command provided by the boomer. At a block **126**, the UAV **32** processes the verbal command at the voice processing component **80**, or at the processor **52** for a digital command, and sends a reply command, such as "Roger, cleared," or its digital equivalent, to the tanker **30**. At a block **130**, the UAV **32** navigates into the refueling envelope using flight control information suitably provided by the image processing component **88** that is backed up or checked by an analysis of tanker and UAV **32** position information. At block **132**, the UAV **32** processes any further verbal commands sent by the boomer as necessary. The following is a non-limiting example of verbal commands provided by the boomer:

"Forward X"
"Up X"
"Back X"
"Down X"
"Left X"
"Right X"
where X=a distance value

The UAV **32** sends a repeat of the command back to the boomer/tanker. At a block **136**, when the boomer determines that the UAV **32** is in the proper position for refueling, the boomer provides a verbal query asking if the UAV **32** is ready to receive fuel. At a block **138**, the UAV **32** receives the query from the boomer, prepares the refueling controls **60**, and sends a ready response when the UAV **32** is properly configured to receive fuel.

As shown in FIG. **3**C, at a block **142**, the boomer inserts the boom into the refueling port of the UAV **32**. At a block

144, the boomer verbally or digitally requests the UAV 32 to confirm contact with the boom. At a block 148, in response to the boomer's query request to confirm contact, the UAV 32 checks the refueling sensors to determine if proper contact is indicated. If proper contact is indicated, a "confirmed contact" response is suitably sent to the boomer. At block 150, refueling begins. At block 152, the UAV 32 maintains refueling position according to flight control signals generated by the image processing component 88. In one embodiment, the image processing component 88 receives digital images from the digital camera 56 of the tanker 30. The image processing component 88 generates flight control signals in order to maintain the tanker in a geometric format that places in the UAV 32 in the refueling envelope. At block 154, when refueling is complete, the UAV 32 disengages from the tanker and continues on the planned mission.

While the preferred embodiment of the invention has been illustrated and described, as noted above, many changes can be made without departing from the spirit and scope of the invention. Accordingly, the scope of the invention is not limited by the disclosure of the preferred embodiment. Instead, the invention should be determined entirely by reference to the claims that follow.

What is claimed is:

1. An uninhabited airborne vehicle (UAV) comprising:
- a position component for determining absolute position;
- a memory component for storing flight plan information and one or more images of tanker aircraft;
- an air collision avoidance system (ACAS) component;
- a voice processing component for analyzing;
- a wireless communication component for communicating between a tanker and other UAVs in a predefined vicinity;
- an image processing component; and
- a flight control component.

2. The UAV of claim 1, further comprising refueling components for receiving fuel airborne and refueling sensors for sensing one or more conditions of the refueling components.

3. The UAV of claim 2, wherein the ACAS component receives position information of other aircraft, generates navigation instructions based on the received position information, and sends the generated navigation instructions to the flight control component for the purpose of avoiding collisions with the tanker or the other proximate UAVs.

4. The UAV of claim 3, wherein the voice processing component receives voice instructions over a voice communications channel, analyzes the received voice instructions, transmits a response according to the analysis, generates navigation instructions according to the analysis, and sends the generated navigation instructions to the flight control component.

5. The UAV of claim 4, wherein the voice processing component transmits a response based on the sensed one or more conditions of the refueling components.

6. The UAV of claim 4, wherein the image processing component includes:
- one or more digital cameras for generating one or more digital images;
- a memory; and
- an image processor for comparing the generated one or more digital images to one or more comparable images stored in the memory, generating navigation instructions according to the comparison, and sending the generated navigation instructions to the flight control component.

7. The UAV of claim 6, wherein the flight control component receives position information of at least one of a tanker aircraft or air refueling operation, and navigates according to at least one of the received navigation instructions or the received position information.

8. The UAV of claim 1, further comprising refueling components and a refueling sensor control component for determining status of the refueling components, wherein refueling of the UAV is based on the determined status.

9. A method of navigating an uninhabited airborne vehicle (UAV), the method comprising:
- receiving at the UAV position information for a tanker aircraft;
- analyzing the received position information;
- generating one or more digital images;
- retrieving from memory one or more digital images associated with the generated one or more digital images;
- comparing the generated one or more digital images to the retrieved one or more digital images; and
- navigating according to one or more of the analyzed position information, or the comparison.

10. The method of claim 9, further comprising:
- receiving voice instructions from an operator on the tanker aircraft; and
- analyzing the received voice instructions.

11. The method of claim 10, wherein navigating is further performed according to the analyzed voice instructions.

12. The method of claim 10, further comprising transmitting a response according to the analyzed voice instructions.

13. The method of claim 10, further comprising:
- sensing condition of refueling components of the UAV; and
- transmitting a response according to the analyzed voice instructions and the sensed condition.

14. An air refueling system comprising:
- a tanker; and
- one or more uninhabited airborne vehicles (UAVs) comprising:
- an air collision avoidance system (ACAS) component; a voice processing component;
- an image processing component; and
- a flight control component for controlling flight of the UAV based on information provided by one or more of the ACAS component, the voice component, or the image processing component.

15. The system of claim 14, wherein each UAV further includes refueling components for receiving fuel airborne and refueling sensors for sensing one or more conditions of the refueling components.

16. The system of claim 15, wherein the ACAS component receives position information of at least one of other UAVs or the tanker, generates navigation instructions based on the received position information, and sends the generated navigation instructions to the flight control component.

17. The system of claim 16, wherein the voice processing component receives voice instructions from the tanker over a voice communications channel, analyzes the received voice instructions, transmits a response according to the analysis, generates navigation instructions according to the analysis, and sends the generated navigation instructions to the flight control component.

18. The system of claim 17, wherein the voice processing component transmits a response based on the sensed one or more conditions of the refueling components.

19. The system of claim **17**, wherein the image processing component includes:

one or more digital cameras for generating one or more digital images;

a memory; and

an image processor for comparing the generated one or more digital images to one or more comparable images stored in the memory, generating navigation instructions according to the comparison, and sending the generated navigation instructions to the flight control component.

20. The system of claim **14**, wherein the one or more UAVs further comprises refueling components and a refueling controls component for determining status of the refueling components, wherein refueling of the UAVs is based on the determined status.

* * * * *