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Murray et al.

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(54) **SYSTEM AND METHOD FOR CONTROLLING SWARM OF REMOTE UNMANNED VEHICLES THROUGH HUMAN GESTURES**

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G06F 19/00 (2006.01)

(52) **U.S. Cl.** **701/23**; 701/28; 701/514; 382/103; 382/107

(58) **Field of Classification Search** 701/23, 701/27, 28, 70, 220, 223, 33.7–34.2, 514; 382/100, 103, 107, 117, 118, 153, 170; 348/95, 348/222.1

See application file for complete search history.

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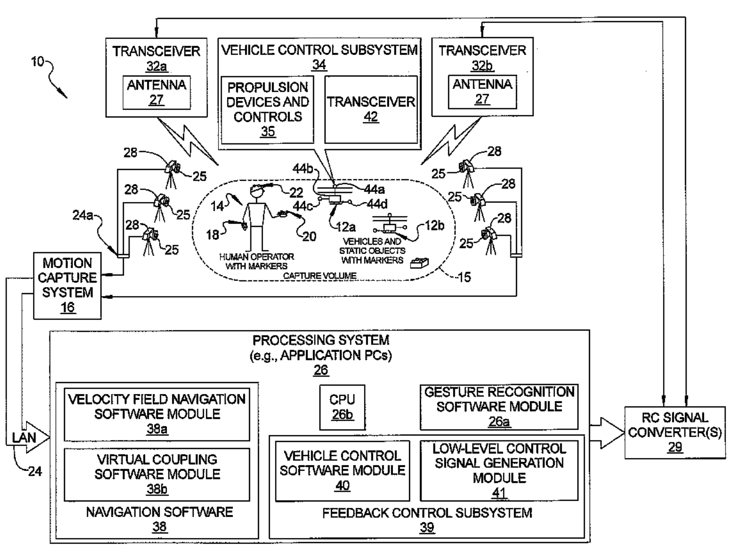
(57) **ABSTRACT**

A method is disclosed for controlling at least one remotely operated unmanned object. The method may involve defining a plurality of body movements of an operator that correspond to a plurality of operating commands for the unmanned object. Body movements of the operator may be sensed to generate the operating commands. Wireless signals may be transmitted to the unmanned object that correspond to the operating commands that control operation of the unmanned object.

20 Claims, 16 Drawing Sheets



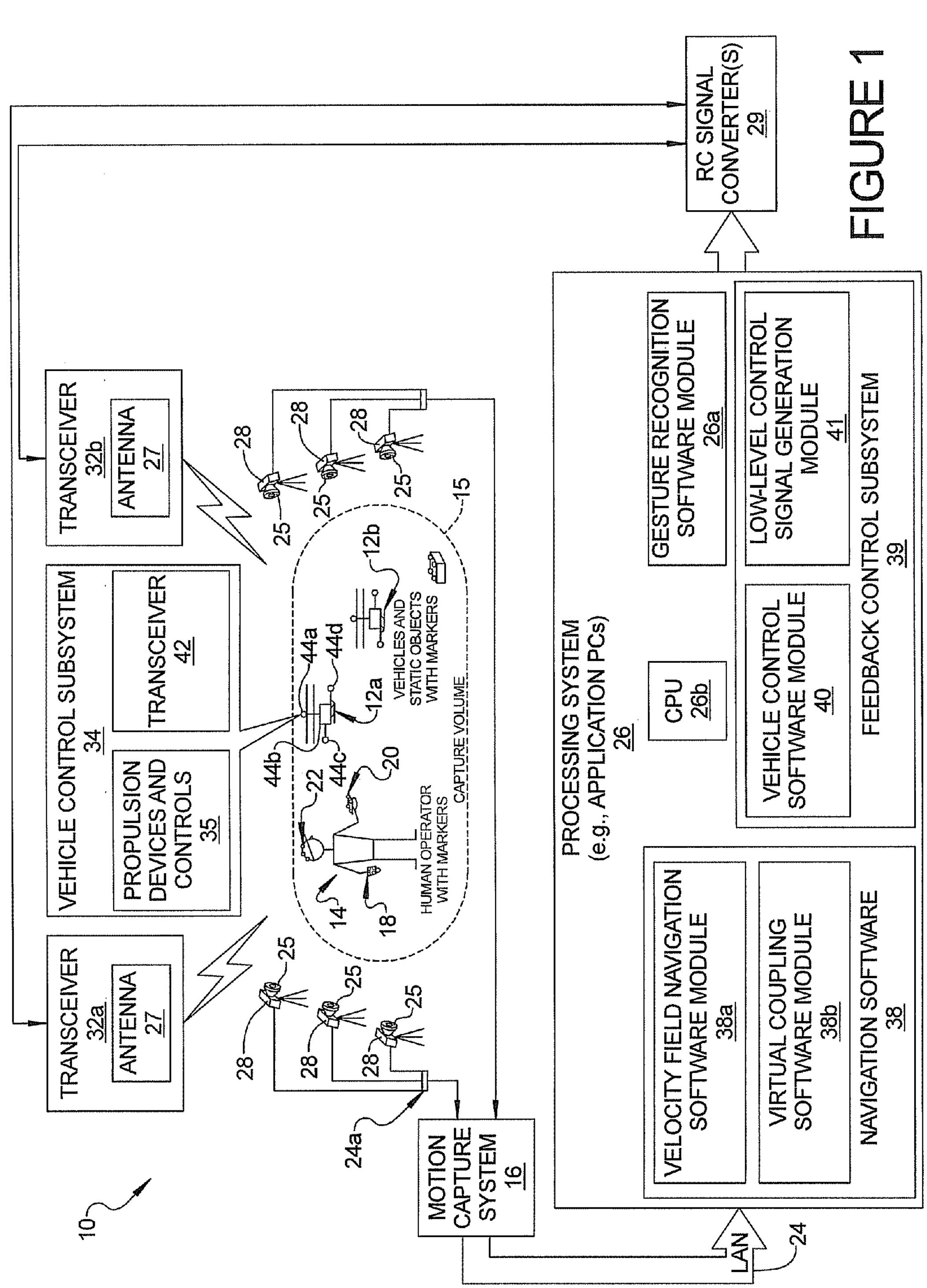

10
MOTION CAPTURE SYSTEM 16
24a
LAN
24
TRANSCEIVER 32a
ANTENNA 27
TRANSCEIVER 32b
ANTENNA 27
VEHICLE CONTROL SUBSYSTEM 34
PROPULSION DEVICES AND CONTROLS 35
TRANSCEIVER 42
28
25
15
14
18
22
20
44a
44b
44c
44d
12a
12b
HUMAN OPERATOR WITH MARKERS
VEHICLES AND STATIC OBJECTS WITH MARKERS
CAPTURE VOLUME
PROCESSING SYSTEM (e.g., APPLICATION PCs) 26
CPU 26b
GESTURE RECOGNITION SOFTWARE MODULE 26a
VELOCITY FIELD NAVIGATION SOFTWARE MODULE 38a
VIRTUAL COUPLING SOFTWARE MODULE 38b
NAVIGATION SOFTWARE 38
VEHICLE CONTROL SOFTWARE MODULE 40
LOW-LEVEL CONTROL SIGNAL GENERATION MODULE 41
FEEDBACK CONTROL SUBSYSTEM 39
RC SIGNAL CONVERTER(S) 29

FIGURE 1

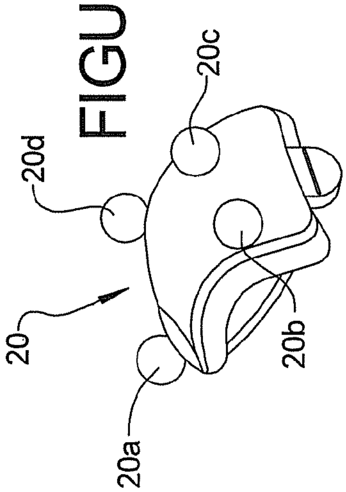


FIGURE 3

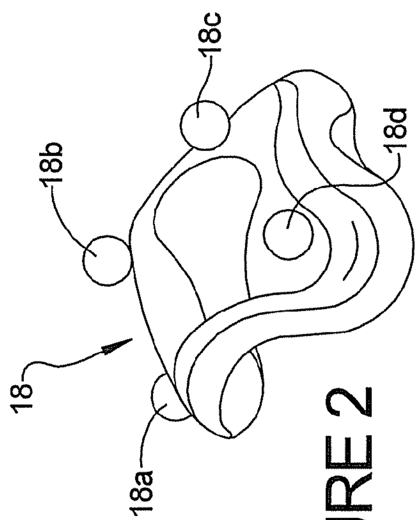


FIGURE 2

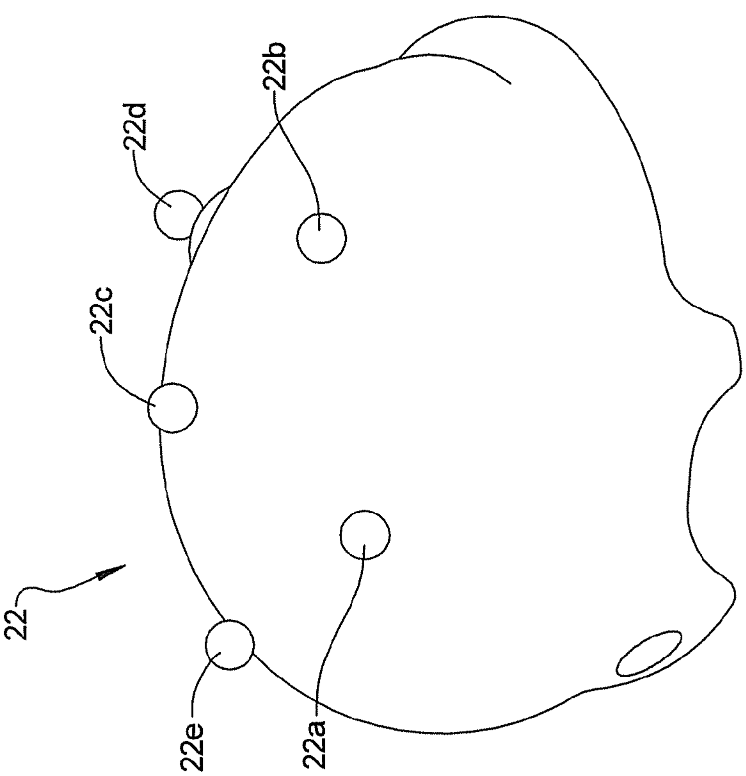


FIGURE 4

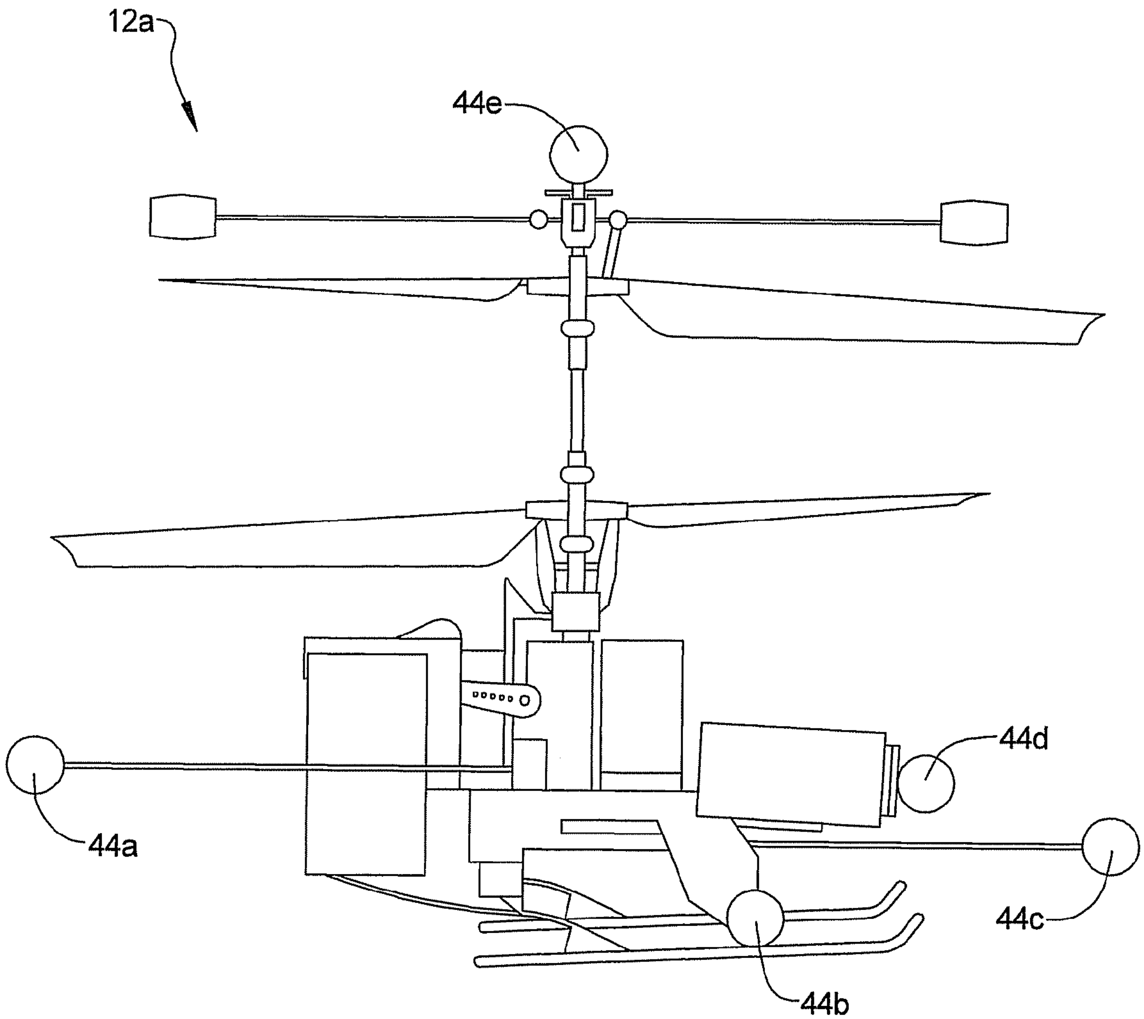


FIGURE 5

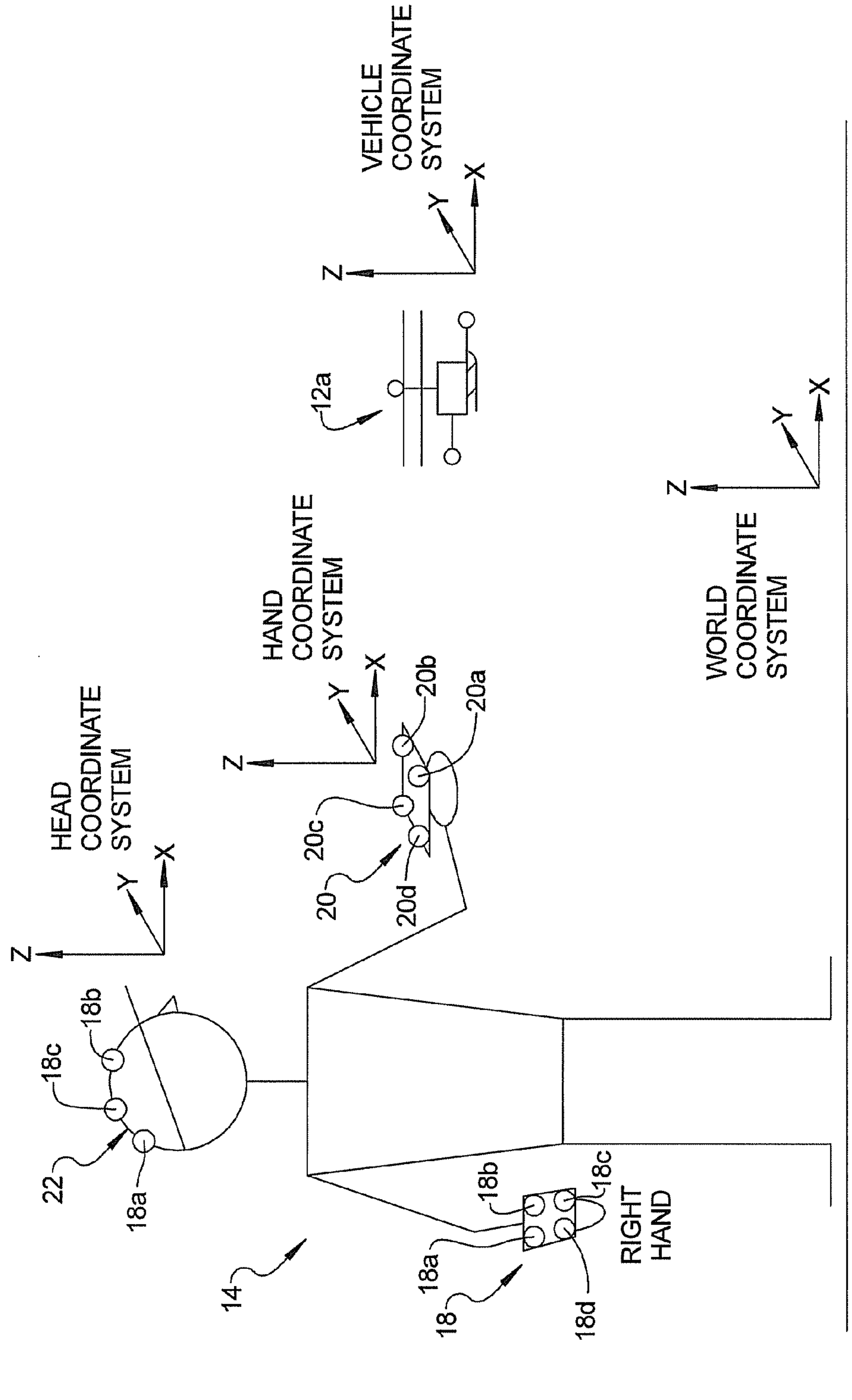

VEHICLE COORDINATE SYSTEM
Z
Y
X
12a
HAND COORDINATE SYSTEM
Z
Y
X
20b
20a
20c
20
20d
WORLD COORDINATE SYSTEM
Z
Y
X
HEAD COORDINATE SYSTEM
Z
Y
X
18c
18b
22
18a
14
18b
18c
18a
RIGHT HAND
18
18d

FIGURE 6

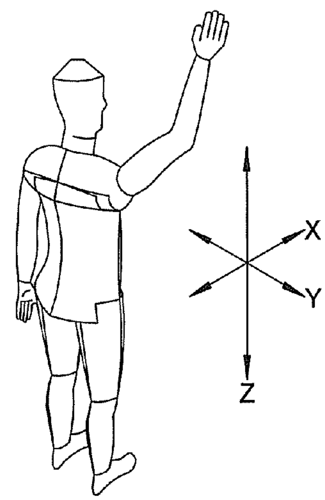
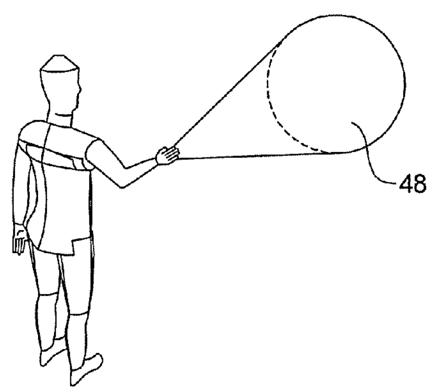
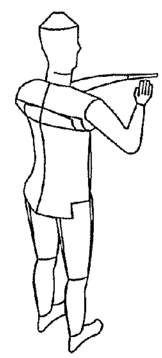
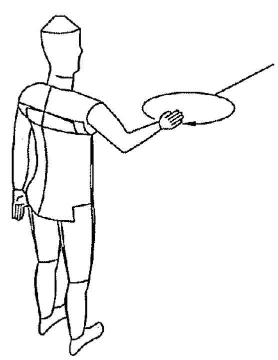
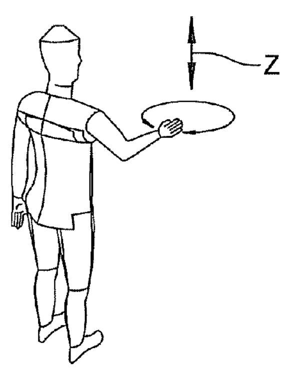
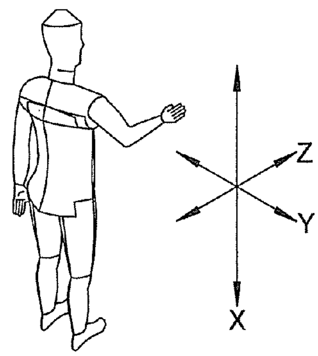
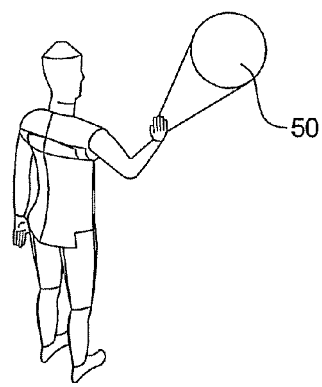
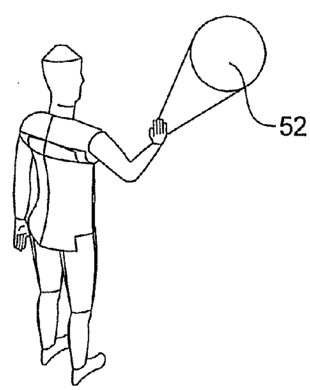
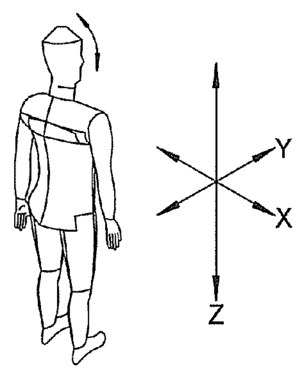
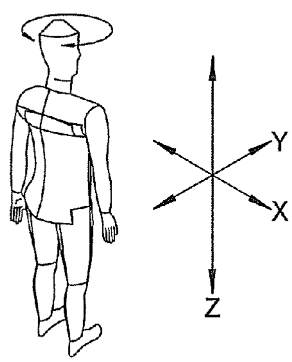
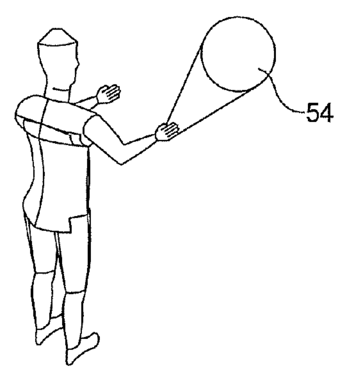
GESTURE NAME EVENT ACTION	EXAMPLE ILLUSTRATION
a. HAND RAISED BEGIN ENTER NORMAL MODE FROM WAIT MODE.	
b. POINT NONE THIS GESTURE IS ALWAYS ACTIVE IN NORMAL MODE AND ESTABLISHES THE ORIENTATION OF THE SELECTION CONE.	

FIGURE 7

FIGURE 8

GESTURE NAME EVENT ACTION	EXAMPLE ILLUSTRATION	
c. TIME OUT TIME OUT STOP TRACKING ANY GESTURES FOR THIS SUBJECT INDEPENDENT OF MODE.		FIGURE 9
d.TRACK MODE ON TRACK MODE ON ENTER TRACKING MODE FROM NORMAL MODE.		FIGURE 10
e. TRACK ON TRACK ON TRACK HAND WITH SELECTED VEHICLES IN TRACK MODE.		FIGURE 11

GESTURE NAME EVENT ACTION	EXAMPLE ILLUSTRATION	
f. TRACK OFF TRACK OFF STOP TRACKING THE HAND WITH SELECTED VEHICLES IN TRACK MODE.		FIGURE 12
g. STOP STOP BRING SELECTED VEHICLES TO A HALT IN NORMAL MODE.		FIGURE 13
h. MOVE MOVE ON MOVE SELECTED VEHICLES IN INDICATED DIRECTION IN NORMAL MODE.		FIGURE 14

GESTURE NAME EVENT ACTION	EXAMPLE ILLUSTRATION	
i. HEAD NOD INCLUDE ADD SELECTED VEHICLE TO GROUP IN NORMAL MODE. TRACK MODE OFF EXIT TRACK MODE AND ENTER NORMAL MODE.		FIGURE 15
j. HEAD SHAKE EXCLUDE REMOVE SELECTED VEHICLE FROM GROUP IN NORMAL MODE.		FIGURE 16
k. NEXT NEXT ITERATIVELY SELECT VEHICLES IN SELECTION CONE SCANNING LEFT TO RIGHT, TOP TO BOTTOM AND FRONT TO BACK IN NORMAL MODE.		FIGURE 17

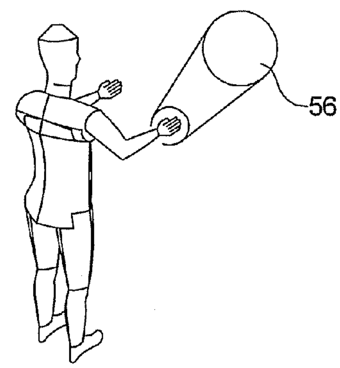
GESTURE NAME EVENT ACTION	EXAMPLE ILLUSTRATION
l. PREVIOUS PREVIOUS ITERATIVELY SELECT VEHICLES IN SELECTION CONE SCANNING BACK TO FRONT, BOTTOM TO TOP AND LEFT TO RIGHT IN NORMAL MODE.	
m. GROUP GROUP GROUP SELECTED VEHICLES INTO A FORMATION IN NORMAL MODE.	
n. UNGROUP UNGROUP DISPERSE VEHICLES FROM A FORMATION IN NORMAL MODE.	

FIGURE 18

FIGURE 19

FIGURE 20

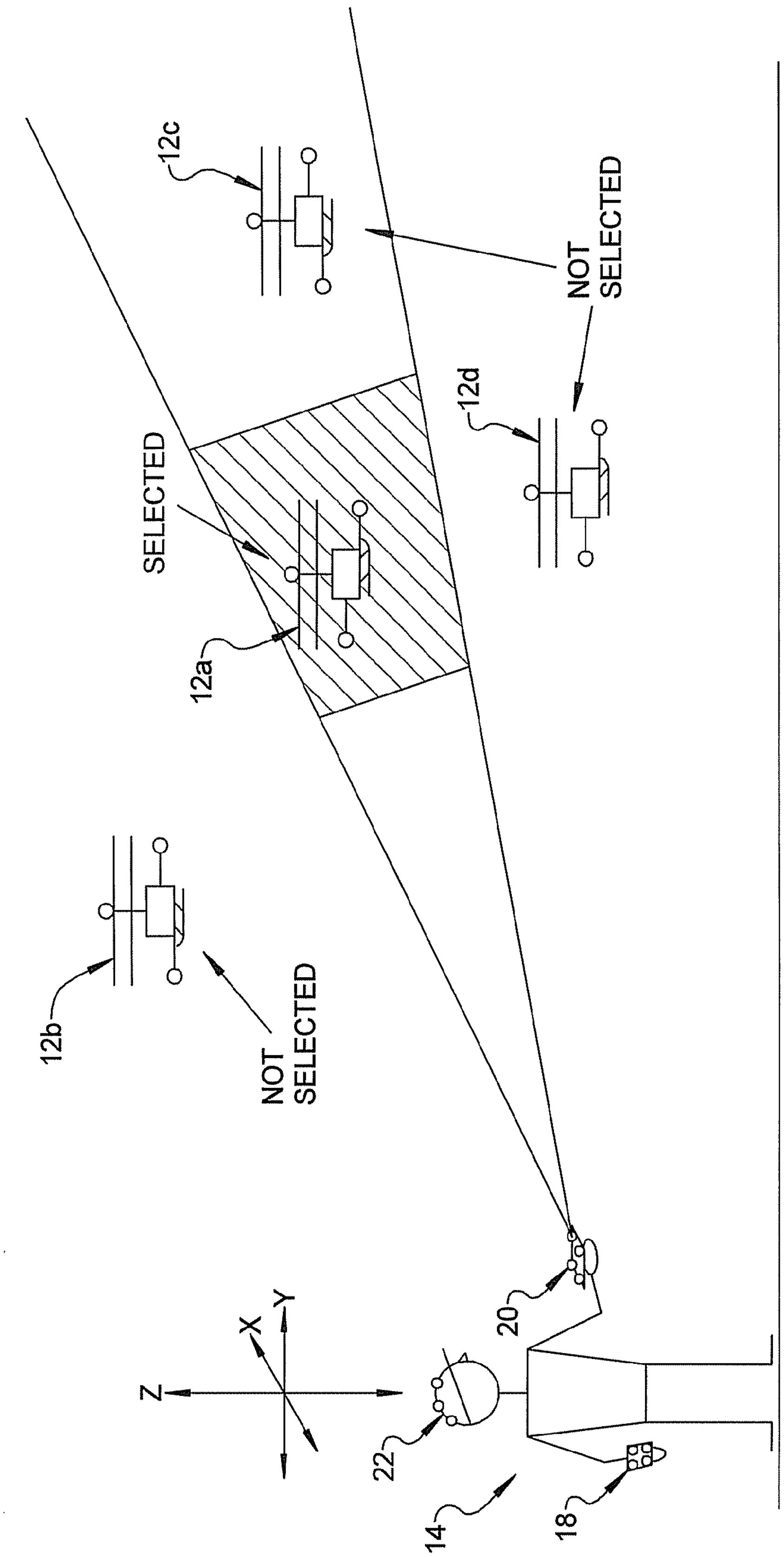

12c
NOT
SELECTED
12d
SELECTED
12a
12b
NOT
SELECTED
Z
X
Y
20
22
14
18

FIGURE 21

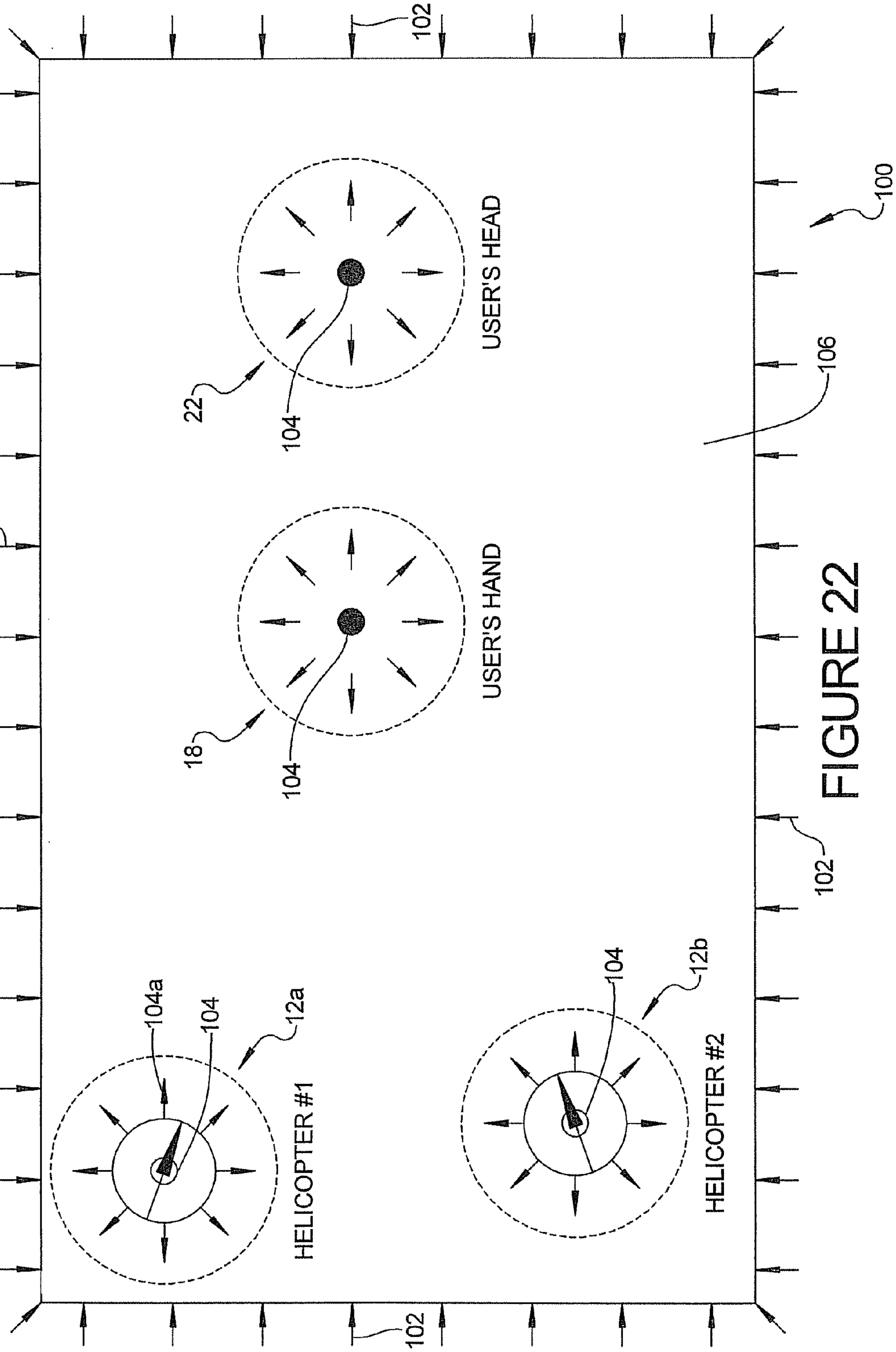

102
102
100
USER'S HEAD
22
104
106
USER'S HAND
18
104
102
104a
104
12a
104
12b
HELICOPTER #1
HELICOPTER #2
102

FIGURE 22

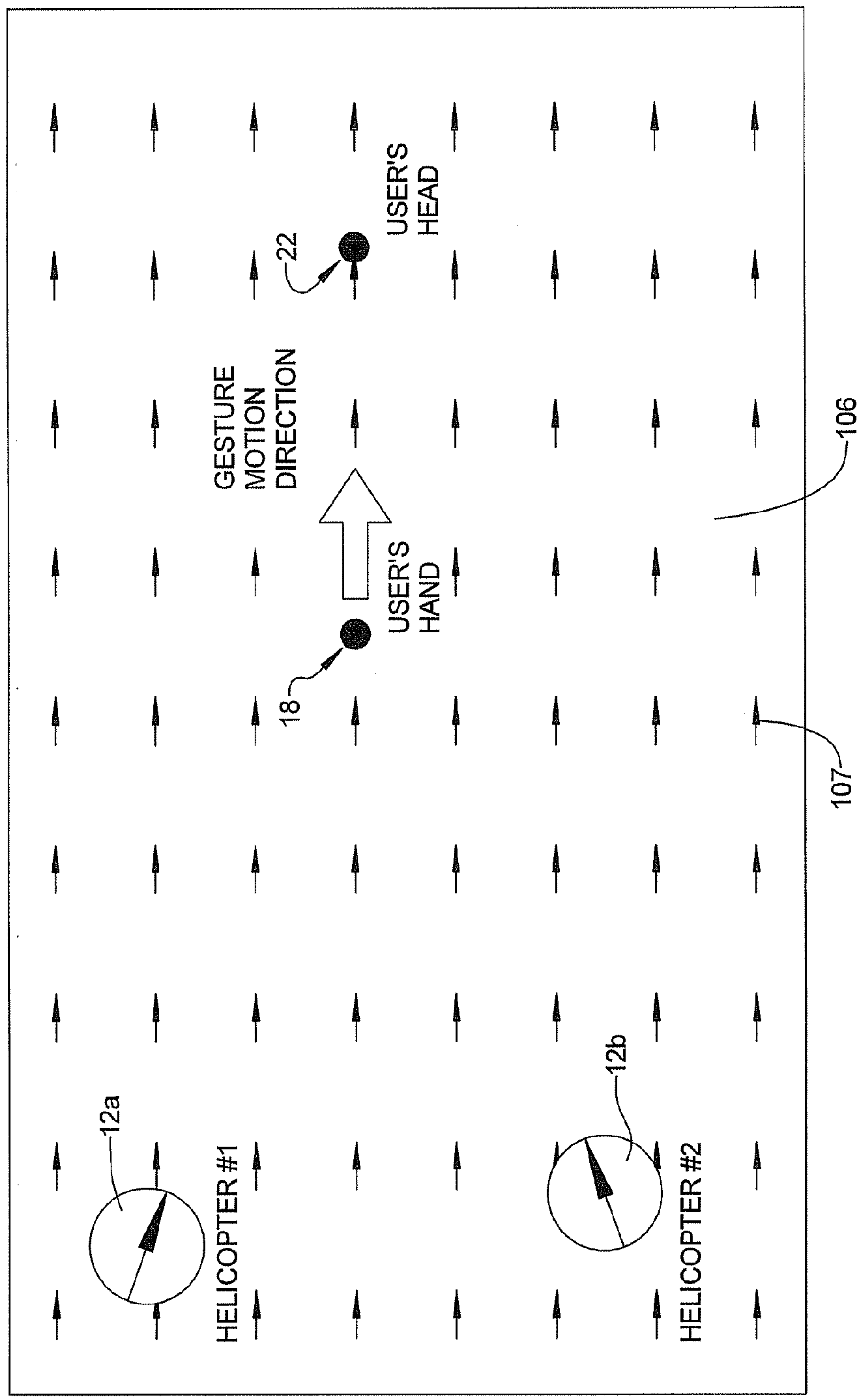

USER'S HEAD
22
GESTURE MOTION DIRECTION
106
USER'S HAND
18
107
12a
HELICOPTER #1
12b
HELICOPTER #2

FIGURE 23

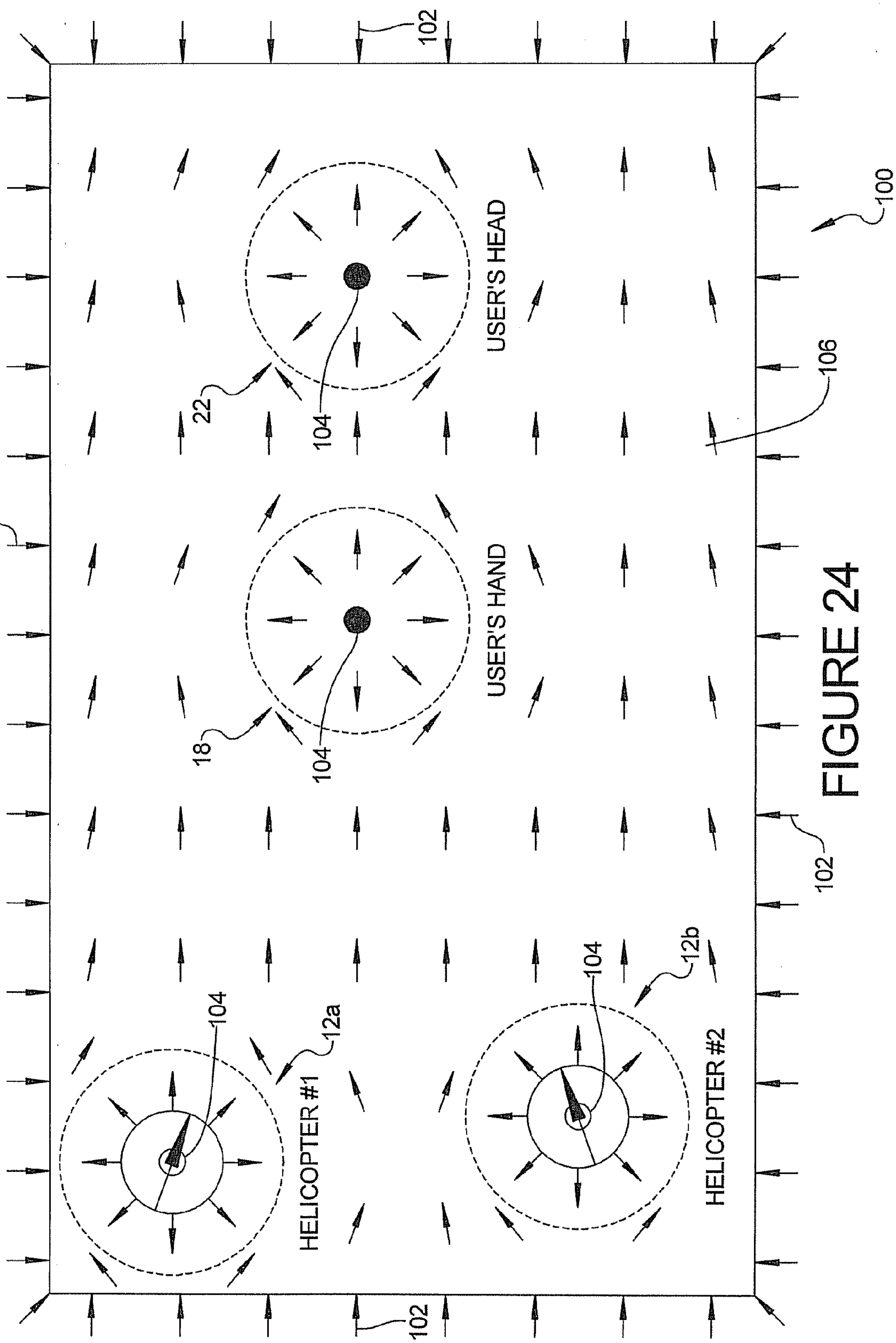

102
100
USER'S HEAD
22
104
106
102
USER'S HAND
18
104
102
HELICOPTER #1
104
12a
HELICOPTER #2
104
12b
102

FIGURE 24

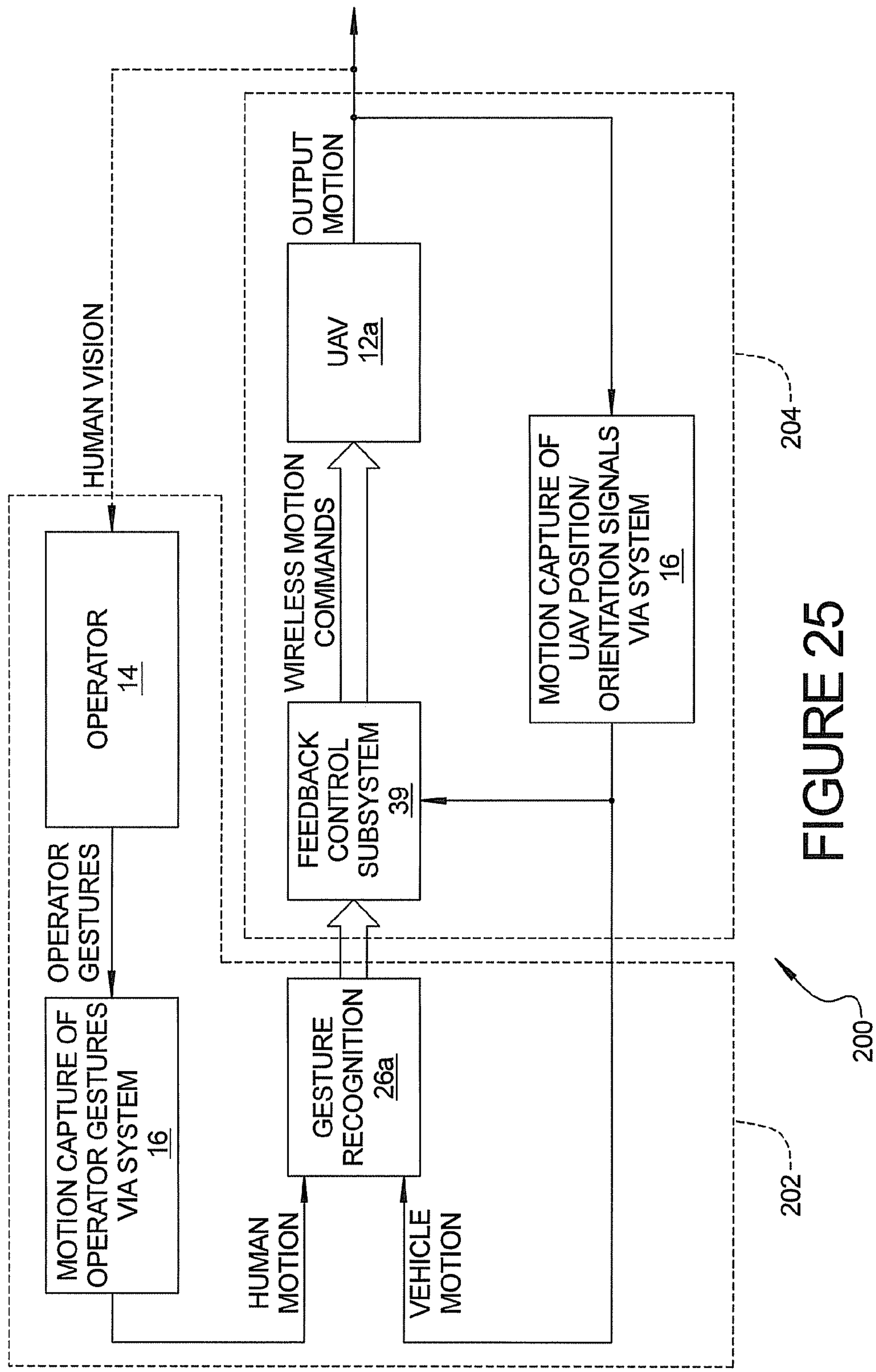

HUMAN VISION
OPERATOR 14
OPERATOR GESTURES
MOTION CAPTURE OF OPERATOR GESTURES VIA SYSTEM 16
HUMAN MOTION
VEHICLE MOTION
GESTURE RECOGNITION 26a
FEEDBACK CONTROL SUBSYSTEM 39
WIRELESS MOTION COMMANDS
UAV 12a
OUTPUT MOTION
MOTION CAPTURE OF UAV POSITION/ ORIENTATION SIGNALS VIA SYSTEM 16
204
202
200

FIGURE 25

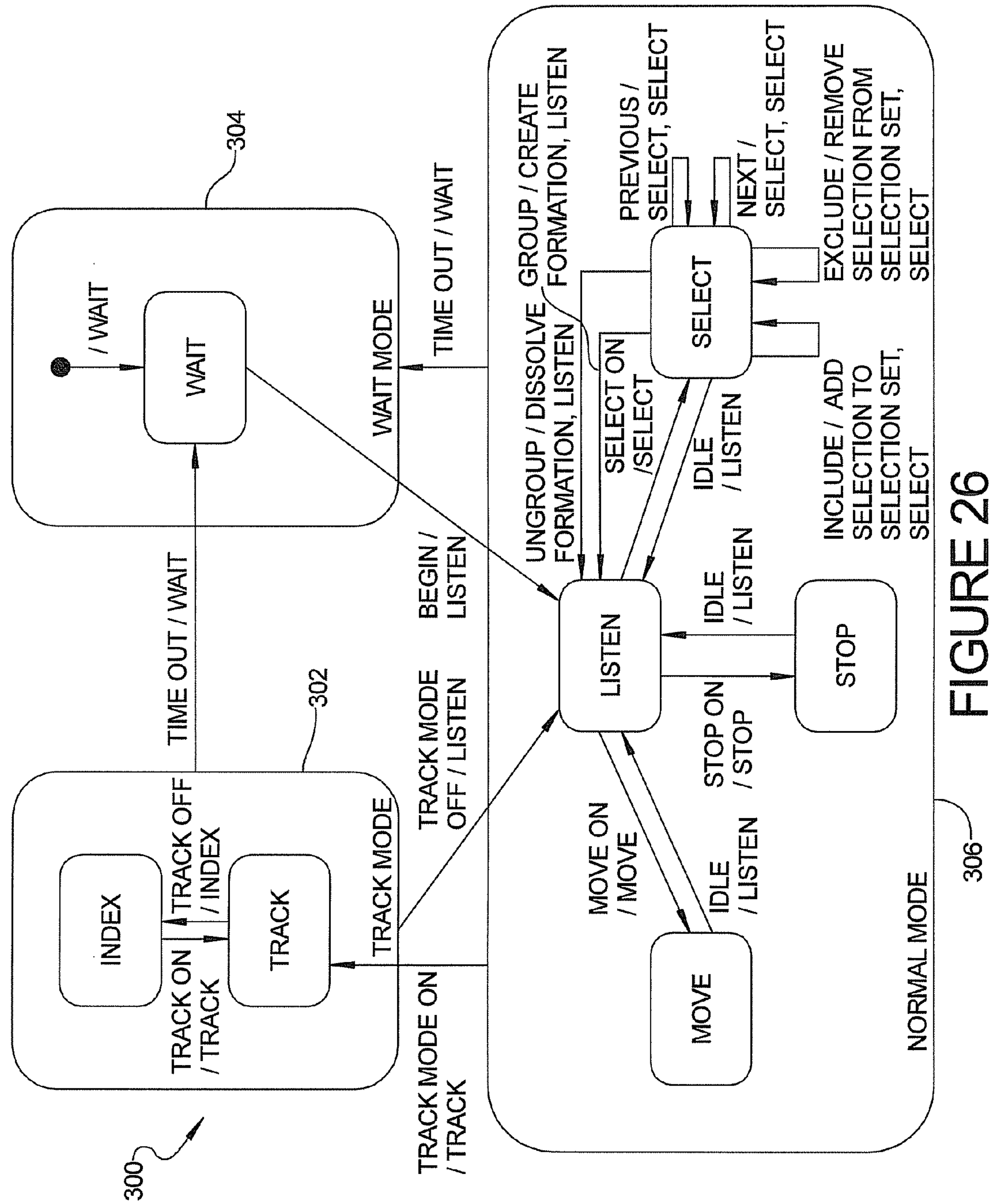
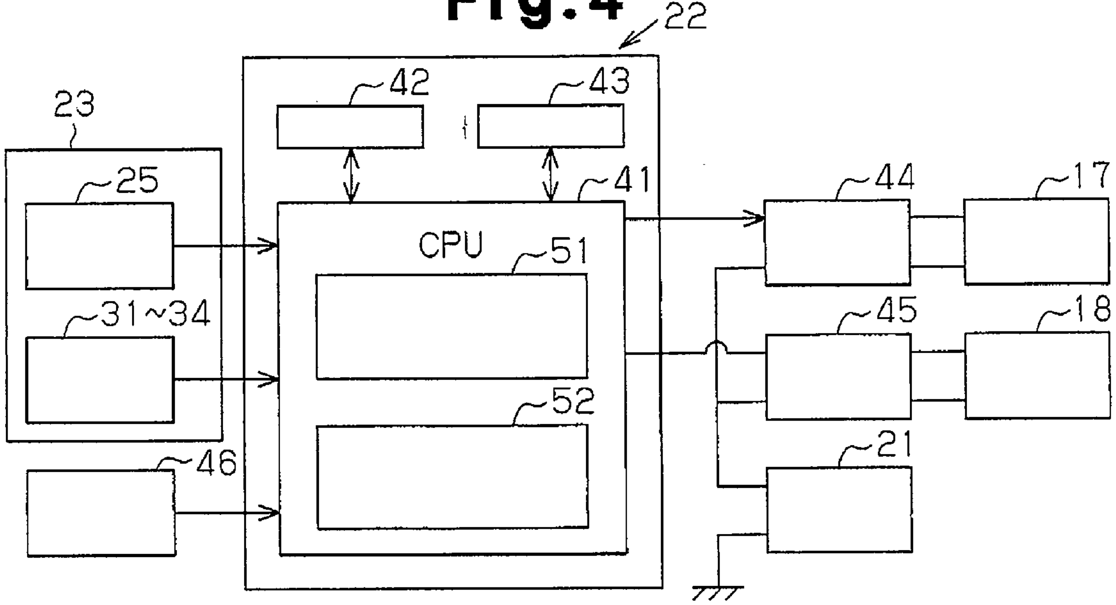

300
302
304
306
WAIT
/ WAIT
WAIT MODE
TIME OUT / WAIT
TIME OUT / WAIT
INDEX
TRACK
TRACK ON / TRACK
TRACK OFF / INDEX
TRACK MODE
TRACK MODE ON / TRACK
TRACK MODE OFF / LISTEN
BEGIN / LISTEN
LISTEN
SELECT
STOP
MOVE
UNGROUP / DISSOLVE FORMATION, LISTEN
GROUP / CREATE FORMATION, LISTEN
SELECT ON /SELECT
PREVIOUS / SELECT, SELECT
NEXT / SELECT, SELECT
EXCLUDE / REMOVE SELECTION FROM SELECTION SET, SELECT
INCLUDE / ADD SELECTION TO SELECTION SET, SELECT
IDLE / LISTEN
IDLE / LISTEN
STOP ON / STOP
MOVE ON / MOVE
IDLE / LISTEN
NORMAL MODE

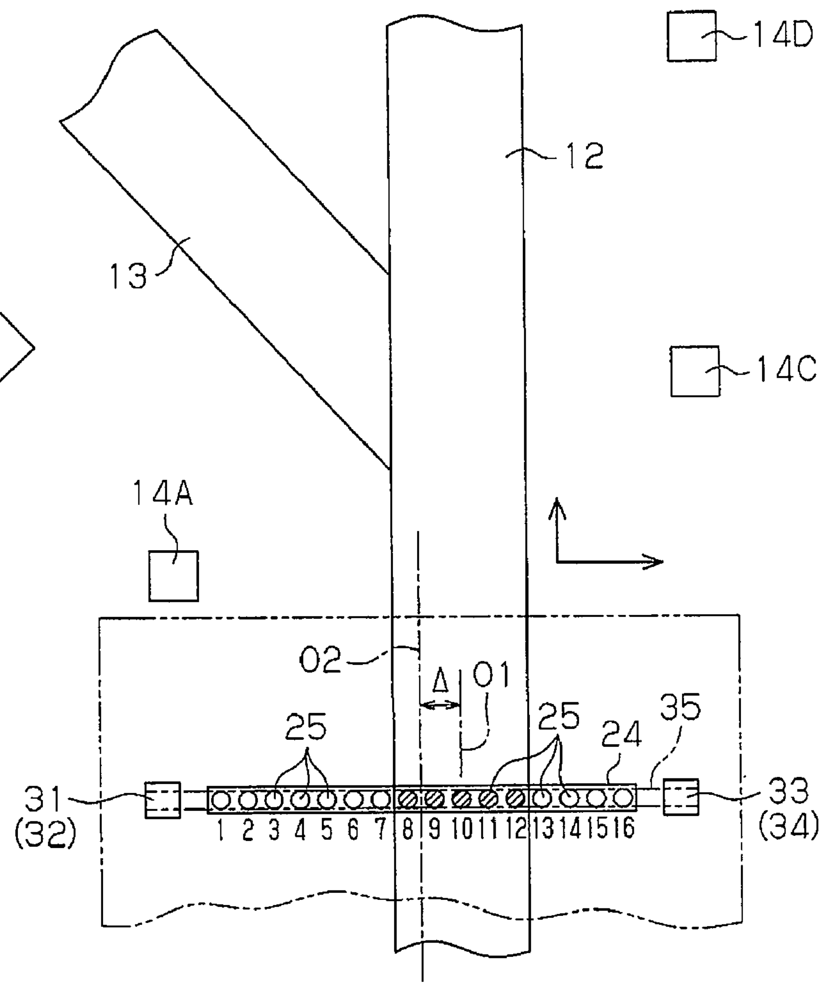
FIGURE 26

Fig.4



22
42
43
23
25
41
44
17
CPU
51
31~34
45
18
52
46
21

Fig.5



14D
12
14B
13
14C
14A
02
Δ
01
25
25
24
35
31
(32)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
33
(34)

SYSTEM AND METHOD FOR CONTROLLING SWARM OF REMOTE UNMANNED VEHICLES THROUGH HUMAN GESTURES

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority from U.S. Provisional Patent Application Ser. No. 61/032,313, filed Feb. 28, 2008, the disclosure of which is hereby incorporated by reference into the present application.

FIELD

The present disclosure relates to systems and methods for controlling remotely operated vehicles, and more particularly to systems and methods for enabling human gestures to be used to control various operations of remotely operated unmanned vehicles.

BACKGROUND

The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

At the present time there is significant interest in the use of remote, unmanned vehicles for various surveillance and exploration activities. The use of remotely controlled, unmanned vehicles enables searching, surveillance and exploration operations to be carried out in situations or environments that might be too dangerous or hazardous for human piloted vehicles. Such applications might include battlefield applications to survey movements of equipment or individuals, or surveillance of fixed structures such as dams, bridges, power plants, or any other area of interest. Further applications might include the exploration of areas contaminated with fallout from biological or chemical weapons. Still further applications may involve the exploration of areas such as caves, the interiors of buildings, mountainous regions, or any other geographic area where movement by human piloted vehicles would be difficult, impossible or unnecessarily hazardous to humans.

The control of remotely operated unmanned vehicles has traditionally relied on the use of joystick-based user interfaces. This type of user interface typically allows only one-to-one control of a single unmanned vehicle. Put differently, the joystick-based control system typically requires a single individual to monitor and control the motion of a single unmanned vehicle. The joystick-based interface typically controls the unmanned remote vehicles through direct actuator and motor control. The vehicle motion is accomplished by varying servo actuators for direction control and drive motors that can produce thrust in the case of aerial vehicles, or wheel rotation for ground vehicles. In the case of aerial vehicles, or wheel rotation for ground vehicles. The use of any form of joystick controlled vehicle also typically requires considerable practice with the joystick control device by the individual before the individual becomes proficient at maneuvering the unmanned vehicle.

SUMMARY

In one aspect the present disclosure relates to a method for controlling at least one remotely operated unmanned object. The method may involve defining a plurality of body movements of an operator that correspond to a plurality of operating commands for the unmanned object. Body movements of the operator may be sensed to generate the operating commands. Wireless signals may be transmitted to the unmanned object that correspond to the operating commands that control operation of the unmanned object.

In another aspect the present disclosure relates to a method for controlling operation of an unmanned vehicle. The method may comprise providing an unmanned vehicle having a plurality of optically reflective markers thereon. At least one gesture of a body part of an operator may be defined that corresponds to an operating command for controlling motion of the unmanned vehicle. An article worn by an operator, the article having optically reflective markers, may be used to enable the operator responsible for remotely controlling operation of the unmanned vehicle to signal the gesture through movement of the article. Optical signals may be directed at the unmanned vehicle and the article worn by the operator. Sensed reflections of optical signals from the markers of the unmanned vehicle and the markers on the article may be obtained. A motion capture system may be used to interpret the sensed reflections of the optical signals and to generate data representing a position of the unmanned vehicle and a motion of the article. Processing of the data may be performed to interpret the gesture being given by the operator via motion of the article and to determine a position of the unmanned vehicle, and to generate a command for controlling the unmanned vehicle in accordance with the gesture. The command may be wirelessly transmitted to the unmanned vehicle.

In another aspect the present disclosure relates to a system for remotely controlling at least one unmanned vehicle through body movements of an operator. The system may comprise an article worn on a body part of the operator, the article having a first plurality of optically reflective markers secured thereto. A second plurality of optically reflective markers may be secured to the unmanned vehicle. A motion capture system may be used for wirelessly tracking a position and an orientation of the article via the first plurality of optically reflective markers, and a position and orientation of the unmanned vehicle via the second plurality of optically reflective markers, and generating data representing positions of each of the optically reflective markers. A processing system, adapted to process the data from the motion capture system, may be used to generate commands for controlling motion of the unmanned vehicle. The processing system may include a gesture recognition module for interpreting portions of the data received from the motion capture system that define positions and orientations of the markers on the article being worn by the operator, as predefined operating commands to be provided to the unmanned vehicle. The processing system may also include a feedback control subsystem that receives the command signals from the gesture recognition module and generates low-level vehicle control commands for controlling the unmanned vehicle.

Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

FIG. **1** is a block diagram of one embodiment of a system in accordance with the present disclosure;

FIG. **2** is a perspective view of an article that may be worn as a glove on the left hand of an operator;

FIG. **3** is a perspective view of an article that may be worn as a glove on the right hand of an operator;

FIG. **4** is a perspective view of an article that may be work has a head piece on the head of an operator;

FIG. **5** is a perspective view of an exemplary UAV, in this example a rotorcraft, incorporating a plurality of retro-reflective markers;

FIG. **6** is a view of an operator wearing the two gloves and head piece, and showing the three dimensional coordinate system associated with each of the two gloves, the head piece, as well as the three dimensional coordinate system for the UAV and a world coordinate system that the all the other coordinate systems are keyed to;

FIG. **7** is a perspective drawing of an operator issuing a Hand Raised command that may be used with the present system;

FIG. **8** is a perspective drawing of an operator issuing a Point command that may be used with the present system;

FIG. **9** is a perspective drawing of an operator issuing a time-out gesture that may be used with the present system;

FIG. **10** is a perspective drawing of an operator issuing the Point command Track Mode On command that may be used with the present system;

FIG. **11** is a perspective drawing of an operator issuing the Track On command that may be used with the present system;

FIG. **12** is a perspective drawing of an operator issuing the Track Off command that may be used with the present system;

FIG. **13** is a perspective drawing of an operator issuing the Stop command that may be used with the present system;

FIG. **14** is a perspective drawing of an operator issuing type of Move command that may be used with the present system;

FIG. **15** is a perspective drawing of an operator issuing the Head Nod command that may be used with the present system;

FIG. **16** is a perspective drawing of an operator issuing the Head Shake command that may be used with the present system;

FIG. **17** is a perspective drawing of an operator issuing the Next command that may be used with the present system;

FIG. **18** is a perspective drawing of an operator issuing the Previous command that may be used with the present system;

FIG. **19** is a perspective drawing of an operator issuing the Group command that may be used with the present system;

FIG. **20** is a perspective drawing of an operator issuing the Ungroup command that may be used with the present system;

FIG. **21** is a perspective view illustrating an exemplary selection cone (i.e., conical three dimensional area) that an operator may select through a specific gesture, together with the position and orientation of the operators hand and head relative to their respective coordinate systems;

FIG. **22** is a two dimensional illustration of a collision avoidance repulsion field that may be implemented to assist with flight envelope protection and autonomous flight of the UAVs within a predetermined region;

FIG. **23** is a two dimensional illustration of a motion gesture constant field implemented by a suitable gesture control with the hand of the operator;

FIG. **24** is a two dimensional illustration of the repulsion field and the motion gesture constant field combined into a composite navigation field;

FIG. **25** is a block diagram illustrating in more detail the inputs used by the system and the control feedback loop implemented for enabling gesture based control of the UAVs;

FIG. **26** is a diagram illustrating certain ones of the gesture commands that may be used to in each of the Track Mode, Wait Mode and Normal Modes of operation of the system; and

FIG. **27** is a flow diagram of major operations that may be performed by the system of FIG. **1**.

DETAILED DESCRIPTION

The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses. Referring to FIG. **1** there is shown a system **10** for controlling the motion of objects **12**. The objects **12** may operate within a defined or enclosed environment **15**. At least one operator **14** present within the environment **15** may wirelessly control operation (i.e., flight) of the objects **12** through human gestures. The objects **12** may be autonomous vehicles, and in this example the objects **12** are illustrated as autonomous, unmanned airborne vehicles, and more specifically as rotorcraft **12***a* and **12***b* (hereinafter referred to simply as UAVs **12**). However, it will be appreciated that virtually any type of object may potentially be controlled using the teachings discussed herein. For example, objects such as robots in a manufacturing operation may be controlled using the teachings of the present application. Virtually any form of mobile land, air or marine (surface or underwater) vehicle is contemplated as being within the scope of the present disclosure. Also, while only two UAVs **12***a* and **12***b* are illustrated, it will be appreciated that a greater or lesser plurality of UAVs **12** may be controlled. In practice it is anticipated that hundreds or more UAVs **12** may be controlled by a single individual, both as a single group or as a plurality of subgroups.

It will also be appreciated that while a single operator **14** is illustrated in FIG. **1** for controlling the UAVs **12**, that two or more operators may be used to control the UAVs. For example, one operator may be designated to control a first subplurality of the UAVs **12** while the second operator controls a different subplurality. It is also possible that each of two or more operators may be provided with the capability to control any one or more of the UAVs **12** whether they are operating as a single group or as a plurality of subgroups.

In FIG. **1** the system **10** further includes an object tracking system, that in one embodiment may comprise a commercially available motion capture system **16**. The motion capture system **16** may use passive retro-reflective markers, to be discussed momentarily, that are attached to the tracked UAVs **12**. The motion capture **16** may also be used for wireless real time monitoring (i.e., essentially continuous and instantaneous monitoring) of the position and orientation of body parts of the operator **14**.

The system **10** may also include a plurality of articles that may be worn by the operator **14** and which are monitored for position and orientation by the motion capture system **16**. In the present example, the articles may involve a right glove **18** worn on the right hand of the operator **14** as shown in detail FIG. **2**, a left glove **20** worn on the left hand of the operator **14** as shown in detail in FIG. **3**, and a head piece **22** worn on the operator's head as shown in detail in FIG. **4**. The right glove **18** may include one or more retro-reflective markers **18***a*-**18***d*, which may typically be round or spherical in shape and may be covered with a retro-reflective material similar to the SCOTCHLITE™ reflective tape made by 3M of St. Paul, Minn. While four reflective markers **18***a*-**18***d* are shown, it will be appreciated that a greater or lesser plurality of the markers may be used to suit the needs of specific applications. In the present example the left glove **20** similarly may include four retro reflective markers **20***a*-**20***d* and the head piece **22** may include five retro reflective markers **22***a*-**22***e*. The gloves **18** and **20** are preferably worn with a specific orientation on the hands to allow the object motion capture system **16** to track the metacarpal plane of each hand. In this example the position and orientation of the fingers of the hands of the operator **14** are not tracked.

It will be appreciated that other articles could be worn on other body parts of the operator **14**. For example, shoes on the feet of the operator **14** may include their own retro-reflective markers, or arm bands may be worn by the operator that similarly include one or more retro reflective markers. Thus, the system **10** should not be interpreted to incorporating only the three specifically mentioned operator worn articles **18**, **20** and **22**. Furthermore, each article **18**, **20** and **22** may include virtually any number of markers needed to meet the needs of a specific application.

As will be described in greater detail in the following paragraphs, each UAV **12***a* and **12***b* also includes retro reflective markers **44***a*-**44***d*. However, depending on the specific application, a greater or lesser number of reflective markers **44** may be used, and the illustration of four such markers **44***a*-**44***d* is meant to illustrate one specific example.

A plurality of light regenerating components **25** may be used that function as the sources of the light that is directed at the retro-reflective markers **18***a*-**18***d*, **20***a*-**20***d* and **22***a*-**22***e*, as well as at the markers **44***a*-**44***d* on each UAV **12***a* and **12***b*. To capture light reflecting off the retro-reflective markers **18***a*-**18***d*, **20***a*-**20***d*, **22***a*-**22***e* and **44***a*-**44***d*, a plurality of cameras **28** are used. The cameras **28** are each associated with a specific one of the light generating components **25**, and each light generating component **25** is preferably placed closely adjacent to a lens of its associated camera **28**. The cameras **28** may provide output signals to the motion capture system **16** which analyzes and processes the pixel data from the supplied camera images, which at this point provides a 2D representations of the positions of the retro reflective markers **18***a*-**18***d*, **20***a*-**20***d*, **22***a*-**22***e* and **44***a*-**44***d*. The motion capture system **16** uses information stored in a memory (not shown) thereof concerning the configuration of each of the markers **18***a*-**18***d*, **20***a*-**20***d*, **22***a*-**22***e* and **44***a*-**44***d* to generate data that provides a 3D representation of the positions and orientations of all the markers **18***a*-**18***d*, **20***a*-**20***d*, **22***a*-**22***e* and **44***a*-**44***d* within the environment **15**.

The data output from the motion capture system **16** may be provided as an input over a local area network (LAN) **24** to a processing system **26** having a gesture recognition software module **26***a* and central processing unit (CPU) **26***b*. The gesture recognition software module **26***a* is used by the processing system **26** to analyze the 3D position and orientation data and to interpret which commands are being signaled by the operator. The gesture recognition software module **26***a* uses the 3D position and orientation data along with stored information from a memory (not shown) of the processing system **26** involving various hand and head gestures to interpret which commands are being signaled by the operator **14** through the operator's **14** various hand and head gestures. The processing system **26** then determines the appropriate command signal(s) to send to the UAVs **12***a* and **12***b*. The signals may be sent wirelessly using transceivers **32***a* and **32***b* that receive outputs from the processing system **26**. In one embodiment each transceiver **32***a* and **32***b* is associated with a predetermined one of the UAVs **12***a* and **12***b*. The transceivers **32***a* and **32***b* may be interfaced to the processing system **26** using conventional RC signal converters **29**, which in one form may comprise a conventional USB to PPM signal converter assembly.

The cameras **28** may communicate with the motion capture system **16** via a wireless local area network **24**. Optionally, a wired network could be employed to facilitate communication between the object motion capture system **16** and the cameras **28**.

One three dimensional motion sensing and capture system suitable for use with the present system is commercially available from Vicon of Los Angeles, Calif. The specific motion capture system **16** chosen for use may provide an update rate of at least about 40 Hz, which in many applications will be ample for tracking the UAVs **12**. In one embodiment the light generating elements **25** each may comprise circumferential LED light assemblies having 100-200 LEDs that are pulsed at a rate of about 120 Hz, so that the motion capture system **16** is able to provide an update rate of about 120 Hz. The lens of each camera **28** may have a suitable field of view, for example about 60 degrees in one embodiment of the system **10**. The cameras **28** provide a high contrast image and the lens of each camera **28** essentially recognizes (i.e., "sees") only reflected light from any one or more of the markers **18***a*-**18***d*, **20***a*-**20***d*, **22***a*-**22***e* and **44***a*-**44***d*, rather than the light emitted directly from other ones of the light generating components **25**. It will be appreciated also that greater or lesser update rates may be needed for monitoring and controlling the motion of other types of objects or devices.

As indicated in FIG. **1**, each UAV **12** may include an on-board vehicle control subsystem **34** for controlling the operation of one or more propulsion devices and controls **35** in response to wireless signals received from the transceivers **32**. However, depending on the needs of a specific application, each UAV **12** may have a position and orientation control subsystem which differs slightly in its configuration. Thus, while in this example it may be assumed that all of the UAVs **12** have identical vehicle control subsystems **34** with identical propulsion and control subsystems **35**, it should be understood that the these subsystems need not be identical.

Referring further to the processing system **26**, a navigation software module **38** may be included as part of the processing system **26** for providing navigational directives for each UAV **12**. Navigation module **38** may include a Velocity Field Navigation Module **38***a* and a Virtual Coupling module **38***b*. Navigation directives may originate from either **38***a* or **38***b*. A gesture recognition software module **26***a* may be used to classify human gestures and to generate high level navigational inputs for the Navigational Software module **38**. A low level control signal generator module **41** has an internal feedback control loop (not shown) that receives the operational commands from the vehicle control software module **40** and determines the specific low-level control signals to send to the propulsion devices (e.g., motors and actuators) of each UAV **12***a* and **12***b*. These control signals are sent wirelessly by the transceivers **32** to the wireless transceiver **42** of the vehicle control subsystem **34** located on a designated one of the UAVs **12***a* and **12***b*. The vehicle control software module **40** and the low level control signal generator may cooperatively be viewed as forming a feedback control subsystem **39**.

Referring further to FIG. **1**, as mentioned previously, each UAV **12***a* and **12***b* may also include the retro-reflective markers **44***a*-**44***e*. The markers are also shown in one exemplary implementation on the UAV **12***a* in FIG. **5**. The retro-reflective markers **44** may be disposed at various positions on the UAV **12**. The retro-reflective markers **44** may be implemented on the UAVs **12** when they are to be operated within a predetermined flight volume (such as volume **15** in FIG. **1**) where pre-located navigation field elements have been calculated to define the boundaries of the area to be monitored. The use of the reflective markers **44** ensures that the UAVs can be tracked

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(54) **UNMANNED AERIAL VEHICLE CATCHER**

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(58) **Field of Classification Search** .... 244/110 C, 244/110 F, 110 G, 114 R; 89/1.11; 446/30, 446/31
See application file for complete search history.

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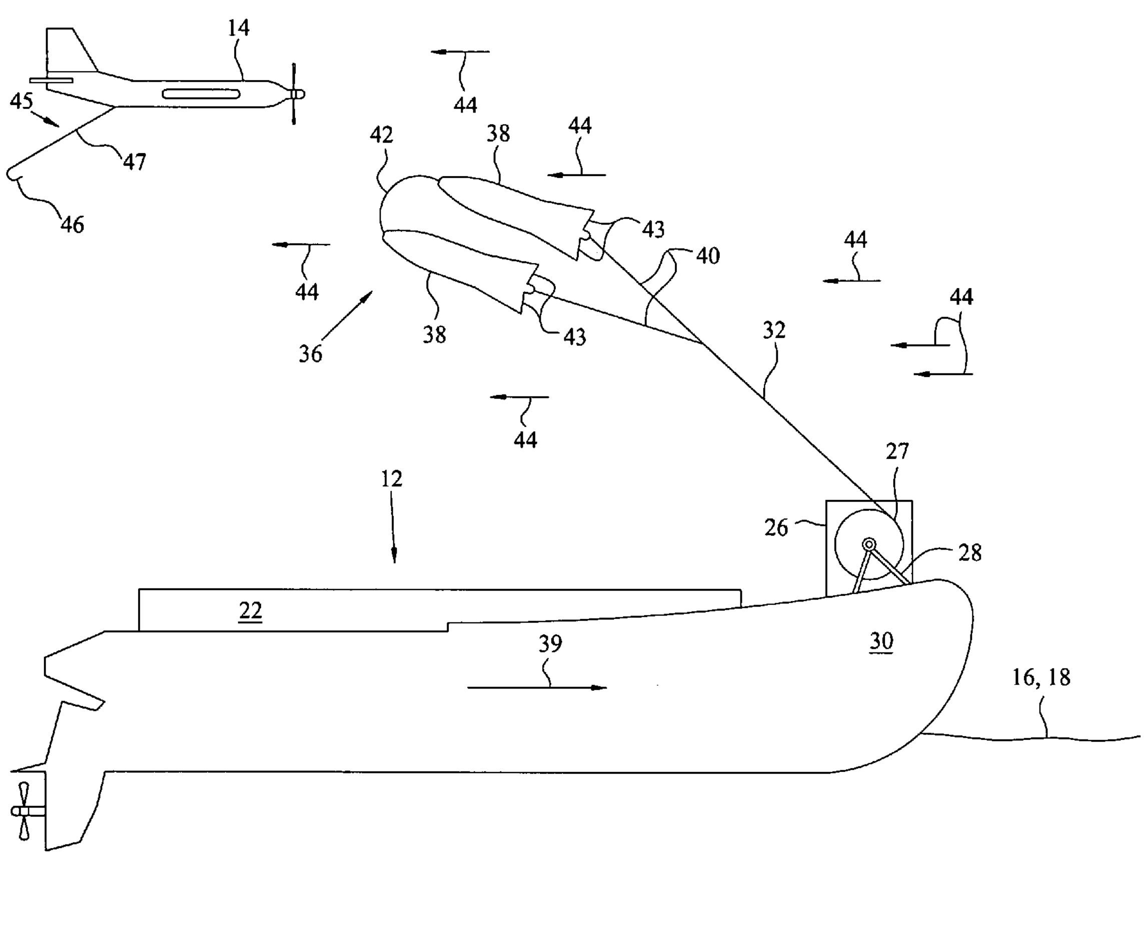
(57) **ABSTRACT**

Launch and recovery of an aerial vehicle by a forwardly moving surface vehicle relies on a winch module having a winch to selectively reel out and reel in a towline and a sensor capable of sensing tension in the towline. A lifting body assembly having a pair of lifting bodies and a snagging wire is connected to the towline. The lifting bodies lift and laterally extend the snagging wire between the lifting bodies. An aerial vehicle flying through the air engages the snagging wire by a hook. A first signal representative of tension of the towline causes the winch to reel in the towline and to bring the aerial vehicle to the surface vehicle, and a second sensor associated with the hook generates a second signal representative of tension in the hook and causes the aerial vehicle to cut its motor.

18 Claims, 11 Drawing Sheets



done by using the position and orientation of the operator's **14** head. The head's+X-axis is assumed to be pointed in the same direction as the desired selection cone. Thus in FIG. **21**, the X-axis of the operator's **14** head and the X-axis of the operator's hand are in the same general plane, which the system **16** interprets that the +X axis is the direction that the operator desires the selected cone to extend. Additionally, in the case of the use of the hand's Z-axis selection cone, the head's+X-axis is used to determine if the selection cone is pointed in the hand's+z or −z axis direction, the selected cone direction being made to match the given head direction.

Velocity Field Navigation

For autonomous flight one option is to assist in ensuring that the UAVs **12** are contained within a predefined area is to generate a constraint volume **100** as shown in FIG. **22**. The constraint volume **100** uses a potential field navigation function to move the goal point, used for the direction of motion of the UAV **12**, along its gradient. The guidance and navigation outer loop is coupled with a stabilization inner loop which controls the low-level response of the UAV **12** to external disturbances, as well as the guidance inputs provided by the gesture recognition software module **26***a*. This is a closed-loop feedback control system that uses the measured position and orientation data provided by the motion capture system **16** to regulate the UAV **12** motion. At every position in the potential field a velocity vector **102** is defined with its direction and magnitude based on the combined effect of individual navigational field elements. Such elements may be formed by, for example, physical and virtual boundaries, moving or stationary objects to avoid, and target positions or way points to move towards. These elements can be defined or repositioned by a human supervisor, an autonomous agent, or other higher-level source. Each UAV **12***a* and **12***b*, as well as the operator **14**, may be outfitted with a repulsive point source device **104** that generates a plurality of repulsive field lines, represented by arrows **104***a*, around its full circumference. FIG. **22** shows a two dimensional version of the potential field with repulsion point sources **104** and repulsive walls formed by the velocity vectors **102**. In practice, repulsion point sources and walls may be used to create protective envelopes around objects whose geometric shapes correspond to points and surfaces. Clearly other geometric figures may be used as well to create envelopes around real world objects with other shapes.

FIG. **23** illustrates the combination of gesture based teleoperation and potential field navigation. The human operator **14** issues a motion gesture which generates a constant velocity field on the part of the UAVs **12***a* and **12***b* in the direction of arrows **107**. Arrows **107** indicate the direction of motion of the UAVs **12** within a predetermined motion capture volume **106**. The repulsive containment field formed by the velocity vectors **102**, the repulsive collision avoidance fields formed by the repulsive point sources **104** and the constant directed motion fields are combined as shown in FIG. **24**. The combination of these systems provides an effective teleoperation capability for the operator **14** while also maintaining a protective envelope about the operator **14**. It also ensures that the UAV(s) **12** will not escape the motion capture volume **106** of the predefined environment or possibly collide with one another or the operator **14**.

It will be appreciated that when generated, field components must be given a scope in which they are to be applied. Some field components, such as the repulsive containment field represented by velocity vectors **102** that form the motion capture volume **106**, include all autonomous UAVs **12** in their scope. Other field components, such as the constant fields associated with motion commands, are applied only to the currently selected UAV(s) **12** for the operator **14** issuing the motion command. Accordingly, the field of the navigation function is a weighted linear combination of fields both shared by all UAVs **12** in the operator environment and those targeting a given particular UAV **12**. This produces several distinct behaviors, namely, containment in the motion capture volume; point-to-point navigation; collision avoidance with other vehicles; and teleoperation through a variety of mechanisms including gesture control.

FIG. **25** shows a feedback diagram **200** for the presently described embodiment using gesture-based control of rotorcraft acting as the UAVs **12**. It consists of a gesture motion sensing and recognition loop (hereinafter "outer control loop") **202** on the upper left side of the diagram feeding UAV **12** input states to an inner feedback control and stabilization loop (hereinafter "inner control loop") **204** on the lower right. The inner control loop **204** uses position and orientation data from the motion capture system **16** to calculate the command signals to send to the UAV **12**. One embodiment of the present disclosure may use proportional-integral-derivative (PID) control to generate the required vehicle command signals.

The UAV **12** inner control loop **204** may update at a constant rate, but the outer control loop **202** update rate can range from a first rate that is synchronized with the inner control inner loop **204** for direct position control tasks, to a second (i.e., lower), asynchronous rate for other tasks like mode or way-point selection. The gesture input is based on the gestures by the operator **14** as described herein, and sensed by the motion capture system **16**. The operator **14** selects which gesture to perform based on the desired task as well as reactions to the environment in which the UAVs **12** are operating.

The rotorcraft (i.e., UAV **12**) control model used in this example implementation may be a point mass model with decoupled PID feedback **204**. Independent controllers may be implemented for each controlled degree-of-freedom: X, Y, Z, and Yaw. The feedback control subsystem **205** may include the PID elements for a single controlled degree-of-freedom. This works well for small changes in velocity and acceleration (i.e. quasi-static motion). The pendulum-like motion of the center of mass hanging below each UAV's **12** center of lift causes oscillations about the X and Y axes of the UAV **12** (pitch and roll) when velocity is changed suddenly, but this oscillation dies out quickly due to the damping effect of the stabilization linkage on the upper rotor of the UAV **12**.

The inner control loop (i.e., low-level stabilization control loop) **204** requires a desired goal position and velocity as its input from the outer (i.e., high-level task definition) control loop **202**. In order to define this goal state for the inner control loop **204**, the velocity field can be sampled at the current location of the UAV **12** and used to generate the goal position for the next time step ($P=V\Delta t$). At each new position the velocity field is sampled and generates a new goal state that is applied to the low-level control loop **204** at the next update.

FIG. **26** represents a finite state model **300** of the system **10**. The model **300** may implement three distinct gesture input modes: Track Mode **302**, Wait Mode **304**, and Normal Mode **306**. In principle, a three-mode system offers three times the number of gestures that the operator **14** can have available for distinct human-robot interactions. The Track Mode **302**, Wait Mode **304**, and Normal Mode **306** boxes represent superstate modes in the model **300**. Superstates are states that contain a collection of substrates in standard state transition models. In principle, the same gesture may potentially mean different things in different modes. So a head nod while operating in Track Mode **302** can be used to switch to Normal Mode, since hand gestures in Normal Mode **306** will pantomime movements of the autonomous vehicles. In Normal mode **306**, the same head nod can be used like a mouse click of a computer mouse to confirm an activity such as the "Include" selection shown the Normal Mode **306** subsection in FIG. **26**. Another gesture which can be used with different means in different modes is the Hand Raised gesture (also shown in FIG. **7**). In the Wait Mode **304**, the Hand Raised gesture signals the beginning of the operator **14** gesture dialog with the system **10**, moving the system state from "WAIT" in the Wait Mode **304** to "LISTEN" in the Normal Mode **306**. In the Normal Mode **306**, a hand raised can signal a stop command moving the system from LISTEN state to STOP state. In the "Track Mode" **302**, the "Index" designation indicates that when the "Track On" features is selected, for example, the operator **14** moving a hand towards her/him may cause the selected UAV **12** (or UAVs, if more than one is selected) to move toward the operator **14**. Then issuing a "Track Off" command will interrupt the communication with the UAV **12** (or UAVs), which allows the operator to re-extend her/his arm fully, whereupon the "Track On" command can be given again, and then the operator **14** can again move her/his arm towards herself/himself. This allows the position or motion of the UAV(s) **12** to indexed, and thus moved over any distance by repeatedly having the operator **14** his her/his hand over just a relatively short distance.

By way of example and referring to FIGS. **26** and **7-20**, the following sequence of gestures may be used to begin and carry out a dialogue with two autonomous UAVs **12**. The following sequence of gestures may be used to move the group toward the operator **14**, place the group above the operator and terminate the dialog with the system **10**.

Starting with the assumption that there is a collection of autonomous UAVs **12** (for example mini-rotorcraft) hovering in a fixed position at one end of a predefined motion capture region, the operator **14** begins the dialog with the system **10** by moving into the predefined region **14** wearing the motion capture head piece **22** and gloves **18** and **20**, and raising one hand above his head (FIG. **7**). The system **10** now enters Normal Mode **306** (FIG. **26**). The operator **14** wants to select three UAVs **12**, two from the left hand side of the collection and one from the right hand side. The operator **14** raises the left hand and points in the direction of the two UAVs **12** on the left (FIG. **8**) and begins making the "Next" gesture with the right hand (FIG. **17**). Then each UAV **12** in the selection cone (FIG. **21**) moves up and down slightly as each one is selected. The operator **14** gives the Head Nod gesture, (FIG. **15**) when the selection scan reaches the desired UAVs **12**. When both of the desired UAVs **12** on the left are selected the operator **14** points the selection cone in the direction of the desired UAVs **12** on the right, repeating the above operation until all three of the desired UAVs are selected. The operator **14** then issues the Group gesture (FIG. **19**) grouping the three selected UAVs **12** into a formation. The operator **14** then issues a Move gesture (FIG. **14**) in the operator's **14** direction followed by a Stop gesture (FIG. **13**) when the three UAVs **12** have come close enough to the operator. The operator **14** then enters the Track Mode by issuing the Track Mode On gesture (FIG. **10**). The operator **14** then raises the tracking hand overhead keeping it horizontal and then issues a Track Off gesture (FIG. **12**), lowers the hand, issues a Track On gesture (FIG. **11**), and raises the hand overhead again. The three UAVs **12** are now well above the operator's head. The operator **14** issues a Head Nod gesture (FIG. **15**) placing the system **10** out of Track Mode and back into Normal Mode. The operator then issues the Time Out gesture (FIG. **9**) and moves out of the predefined motion capture region.

Implicit in the above scenario are a handful of assumptions about the effects of gestures over time. For example, while forming a group, included UAVs **12** remain included, even if no longer within the current cone of selection. This is so until they are either excluded or until the Group gesture is issued, at which time the resulting formation becomes one entity. Once set in motion by a motion gesture, the UAVs **12** follow the velocity field gradient until they are commanded otherwise. The velocity of the selected UAVs **12** can be made faster or slower proportional to the frequency of the cyclical hand motion.

Both the Motion (FIG. **14**) and Stop (FIG. **13**) gestures may be used with default vehicle selections. Clearly the operator **14** should not be forced to do a lengthy set of selection gestures when attempting to stop a collection of UAVs **12** from moving. In this case, the Motion or Stop gesture may apply simply to the UAVs **12** which are currently in the cone of selection. The strength of the resulting velocity field is descending the further away from the operator **14** the target vehicle is but the operator can adjust this by increasing or decreasing the amplitude (i.e., expansiveness) of the gestures.

Referring to the flow diagram **400** of FIG. **27**, major operations **402-414** are illustrated that may be performed by the system **10**.

While various embodiments have been described, those skilled in the art will recognize modifications or variations which might be made without departing from the present disclosure. The examples illustrate the various embodiments and are not intended to limit the present disclosure. Therefore, the description and claims should be interpreted liberally with only such limitation as is necessary in view of the pertinent prior art.

What is claimed is:

1. A method for controlling at least one remotely operated unmanned object, comprising:

defining a plurality of body movements of an operator that correspond to a plurality of operating commands for said unmanned object;

optically illuminating the unmanned object and an article worn by the operator;

optically illuminating a marker on said unmanned object;

sensing said body movements of said operator by first optical reflections from said article, and sensing movements of said unmanned object by second optical reflections from said unmanned object;

based on said reflected first and second optical signals, generating said operating commands; and

transmitting signals that correspond to said operating commands to said unmanned object to control operation of said unmanned object.

2. The method of claim **1**, wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises defining a hand position of said operator as a stop command.

3. The method of claim **1**, wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises defining a hand motion of said operator as a command for said unmanned object to move in a predetermined direction.

4. The method of claim **1**, wherein said defining a plurality of body movements of an operator that correspond to a plurality of operating commands for an unmanned object comprises defining a plurality of body movements that correspond to a plurality of operating commands for an unmanned vehicle.

5. The method of claim **1**, further comprising using a plurality of unmanned objects; and

wherein said defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises defining a motion of the head of the operator as a command to select a specific one of said unmanned objects to be controlled.

6. The method of claim **5**, wherein defining a head motion of the operator comprises defining a side to side rotation of said head as a command to reject a selection of a specific one of said unmanned objects, and wherein an nodding motion of said head defines a command to confirm a selection of a specific one of said unmanned objects as being a recipient of further commands of from said operator.

7. The method of claim **1**, wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises defining a circular hand motion in a plane, said circular hand motion defining a command to cause said unmanned object to begin moving from a stationary condition.

8. The method of claim **1**, wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises using both hands of said operator to form a T shape, to designate a command that causes said unmanned object to ignore subsequent commands.

9. The method of claim **1**, wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises defining a position of a hand of said operator being positioned over the head of said operator as a command to begin a dialog with said unmanned object.

10. The method of claim **1**, wherein controlling said unmanned object comprises controlling a plurality of unmanned objects; and

wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprise defining a pointing motion of one hand of said operator as defining a three dimensional conical area, and wherein further commands by said operator are limited to ones of said unmanned objects present within said conical area.

11. The method of claim **1**, wherein said controlling an unmanned object comprises controlling a plurality of unmanned objects; and

wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises defining the placement of the palms of the hands of the operator together against one another as a command to group a plurality of ones of said unmanned objects together as a group, to enable said group of unmanned objects to be controlled by subsequently received commands from said operator.

12. The method of claim **1**, wherein said controlling an unmanned object comprises controlling a plurality of unmanned objects; and

wherein defining a plurality of body movements of an operator that correspond to a plurality of operating commands comprises defining a circular motion of a hand of said operator about an axis of a coordinate system associated with the hand as a command that defines a three dimensional conical area and selects only specific ones of said unmanned objects that are present within said conical area, and that selects said ones of said unmanned objects in a predetermined spatial order.

13. The method of claim **12**, wherein said predetermined spatial order comprises one of:

top to bottom, front to back, and left to right; and

back to front, bottom to top and left to right.

14. The method of claim **1**, wherein said controlling said unmanned object comprises controlling an unmanned airborne vehicle (UAV).

15. The method of claim **14**, wherein controlling an unmanned airborne vehicle comprises controlling an unmanned rotorcraft.

16. A method for controlling operation of an unmanned vehicle, comprising:

providing an unmanned vehicle having a plurality of optically reflective markers thereon;

defining at least one gesture of a body part of an operator that corresponds to an operating command for controlling motion of the unmanned vehicle;

using an article worn by an operator, the article having optically reflective markers, to enable the operator responsible for remotely controlling operation of the unmanned vehicle to signal the gesture through movement of the article;

optically illuminating the unmanned vehicle and the article worn by the operator;

sensing optical reflections from the markers of the unmanned vehicle and the markers on the article;

using a motion capture system to interpret the sensed optical reflections and to generate data representing a position of the unmanned vehicle and a motion of the article; and

processing the data to interpret the gesture being given by the operator via motion of the article and to determine a position of the unmanned vehicle, and to generate a command for controlling the unmanned vehicle in accordance with the gesture; and

wirelessly transmitting the command to the unmanned vehicle.

17. A system for remotely controlling at least one unmanned vehicle through body movements of an operator, the system comprising:

an article worn on a body part of said operator, the article having a first plurality of optically reflective markers secured thereto;

a second plurality of optically reflective markers secured to said unmanned vehicle;

a plurality of lights for illuminating the first and second pluralities of optically reflective markers;

a motion capture system for optically tracking a position and an orientation of said article via first reflected optical signals from said first plurality of optically reflective markers, and a position and orientation of said unmanned vehicle via second reflected optical signals from said second plurality of optically reflective markers, and generating data representing positions of each of said first and second pluralities of optically reflective markers;

a processing system adapted to process the data from said motion capture system and to generate commands for controlling motion of the unmanned vehicle, the processing system including:

a gesture recognition module for interpreting portions of said data received from said motion capture system that define positions and orientations of said first plurality of markers on said articles being worn by said operator, as predefined operating commands to be provided to said unmanned vehicle; and

a feedback control subsystem that receives the navigation signals from the gesture recognition module and generates low-level vehicle control commands for controlling the unmanned vehicle.

18. The system of claim **17**, further comprising a transmitter for wirelessly transmitting the low level vehicle control commands to the unmanned vehicle.

19. The system of claim **17**, wherein the unmanned vehicle includes a control system for receiving the wirelessly transmitted low level vehicle control commands.

20. The system of claim **17**, wherein said article comprises at least one of an article worn on a hand of said operator and an article worn on a head of said operator.

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