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(54) **IMAGE STABILIZATION MECHANISM**

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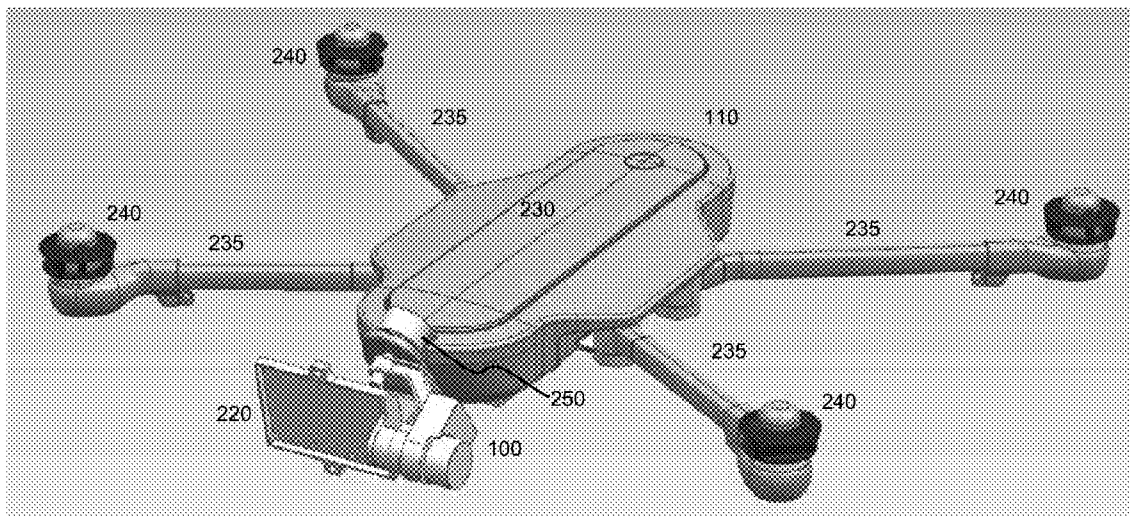
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(57) **ABSTRACT**

Disclosed is an electronic gimbal with camera and mounting configuration. The gimbal includes an inertial measurement unit which can sense the orientation of the camera and three electronic motors which can manipulate the orientation of the camera. The gimbal can be removably coupled to a variety of mount platforms, such as an aerial vehicle or a handheld grip. Moreover, a camera can be removably coupled to the gimbal and can be held in a removable camera frame. Also disclosed is a system for allowing the platform, to which the gimbal is mounted, to control settings of the camera or to trigger actions on the camera, such as taking a picture, or initiating the recording of a video. The gimbal can also provide a connection between the camera and the mount platform, such that the mount platform receives images and video content from the camera.



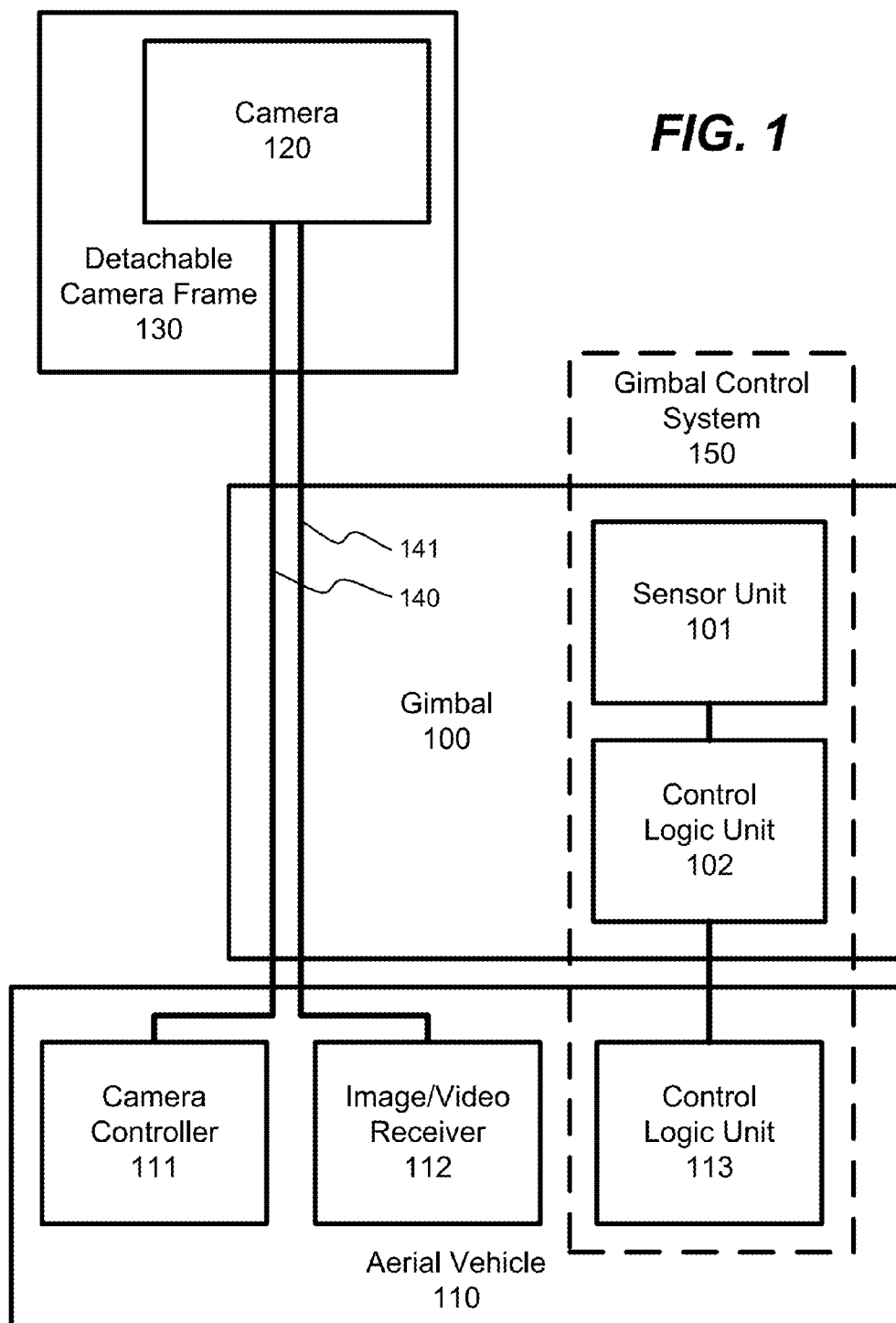


FIG. 2

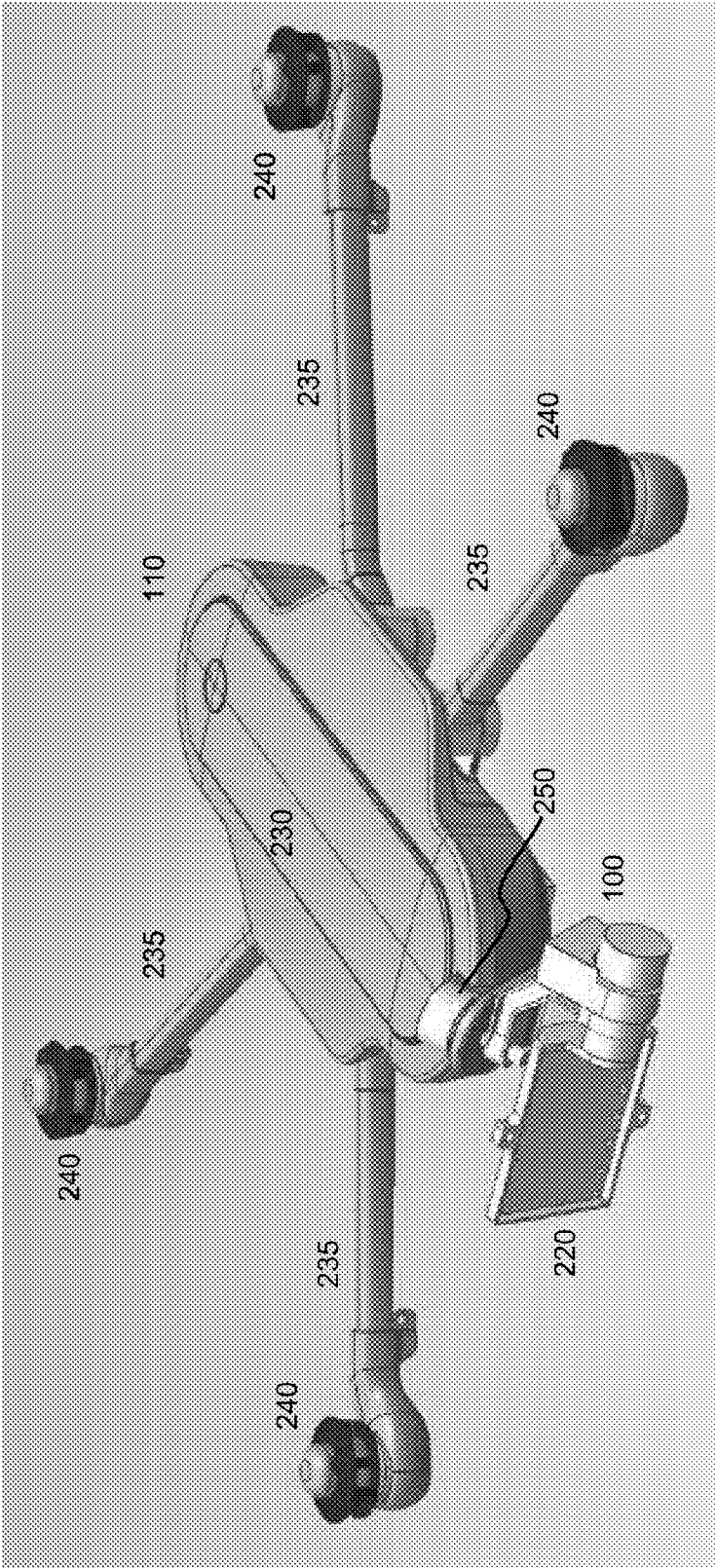
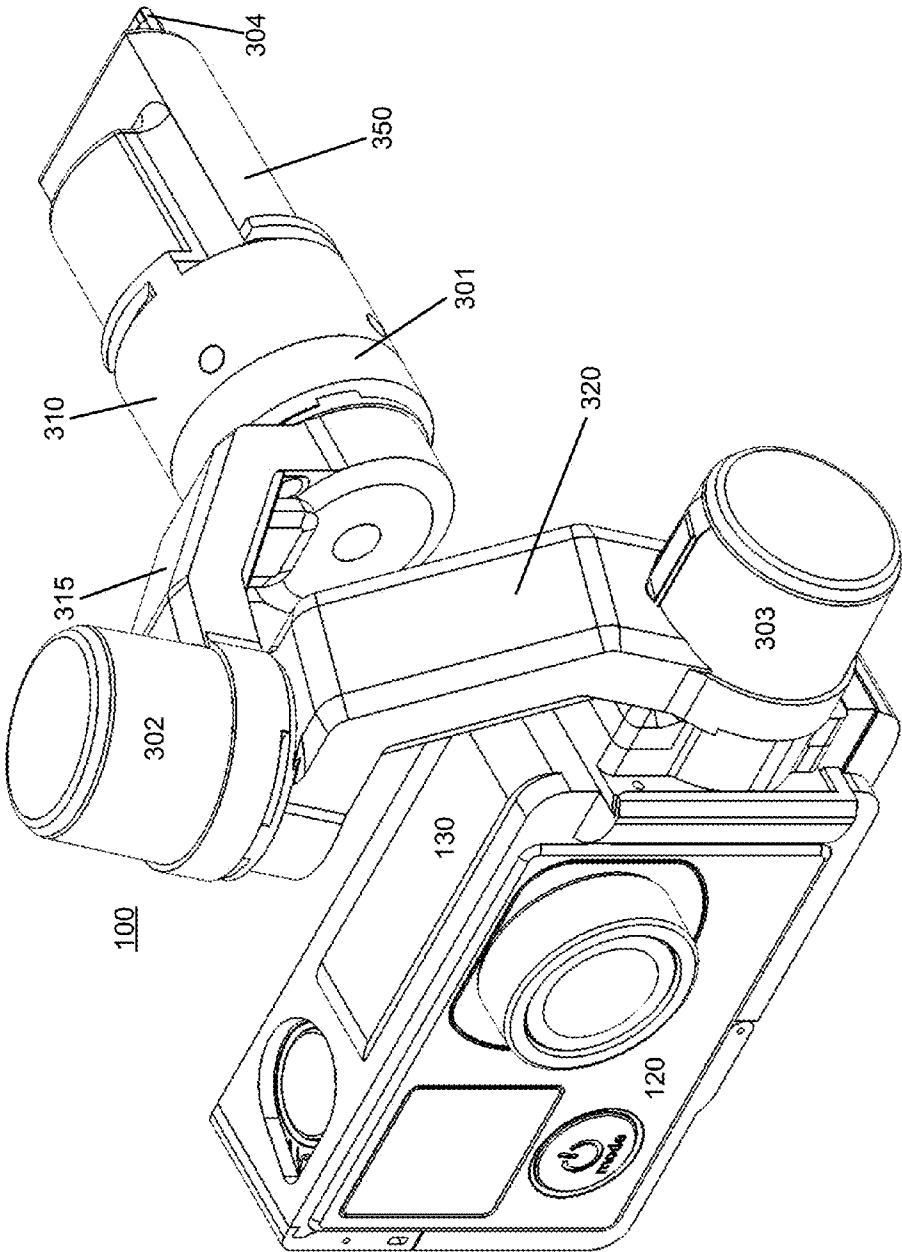
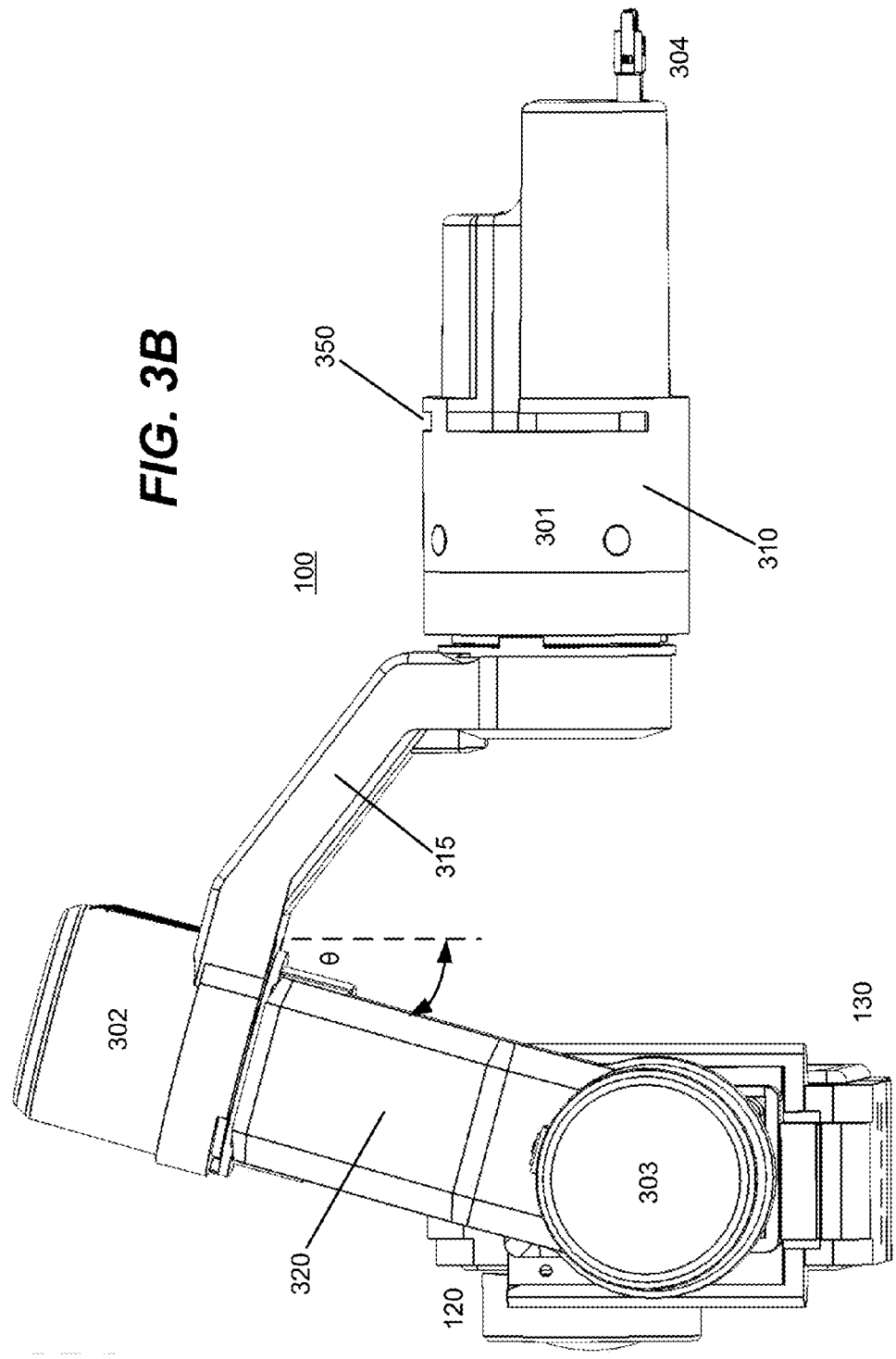


FIG. 3A





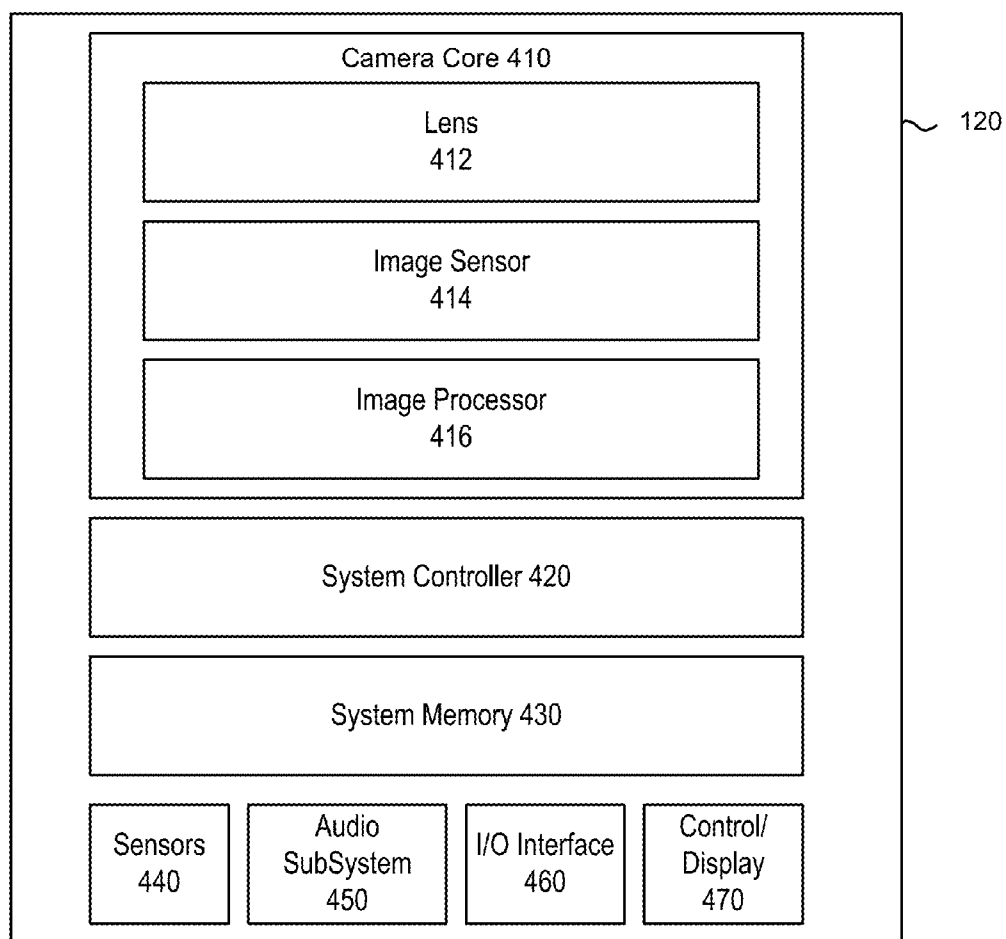
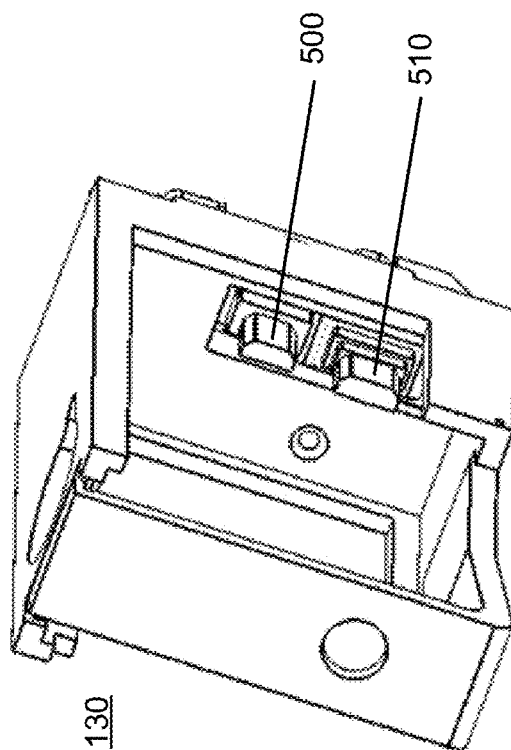
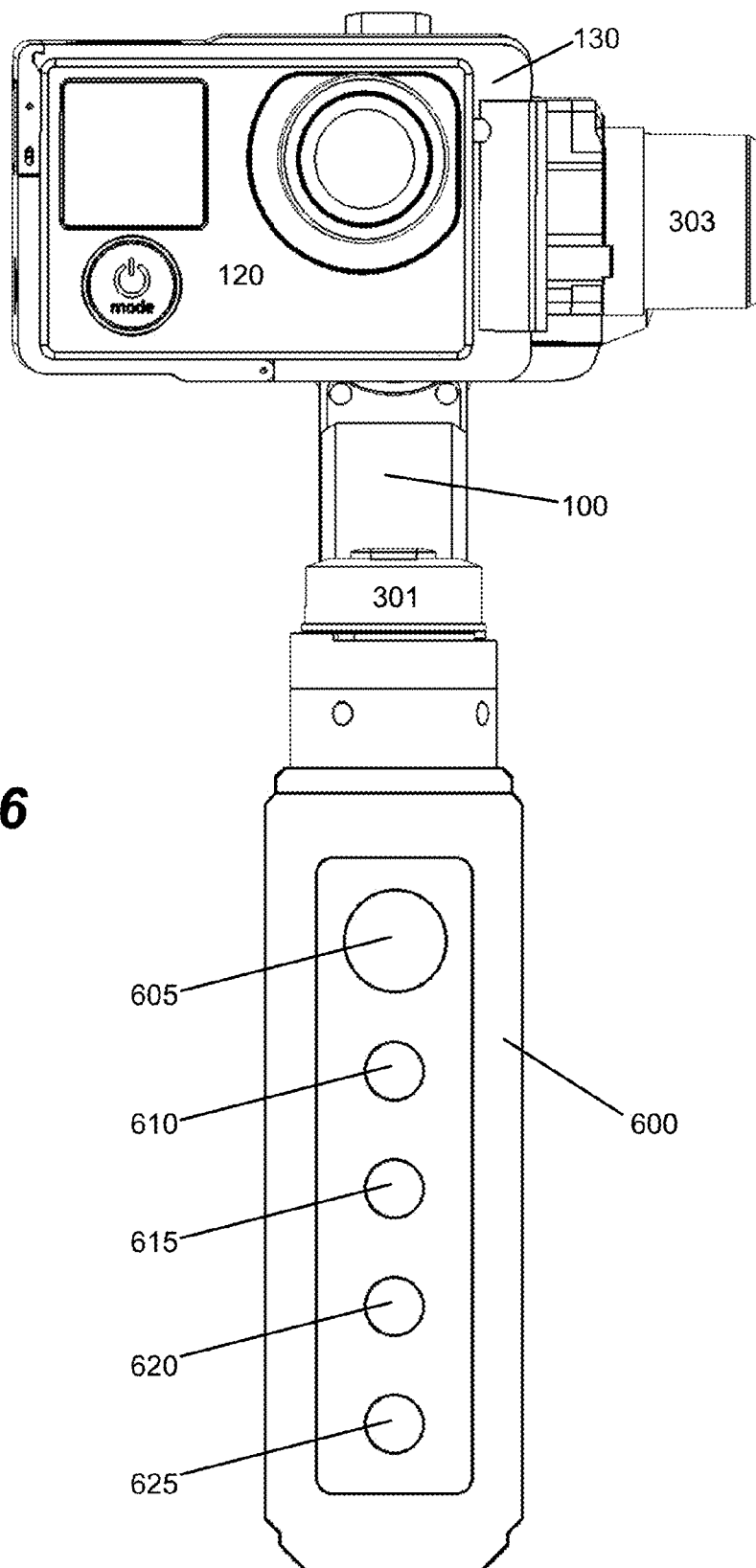
405**FIG. 4**

FIG. 5





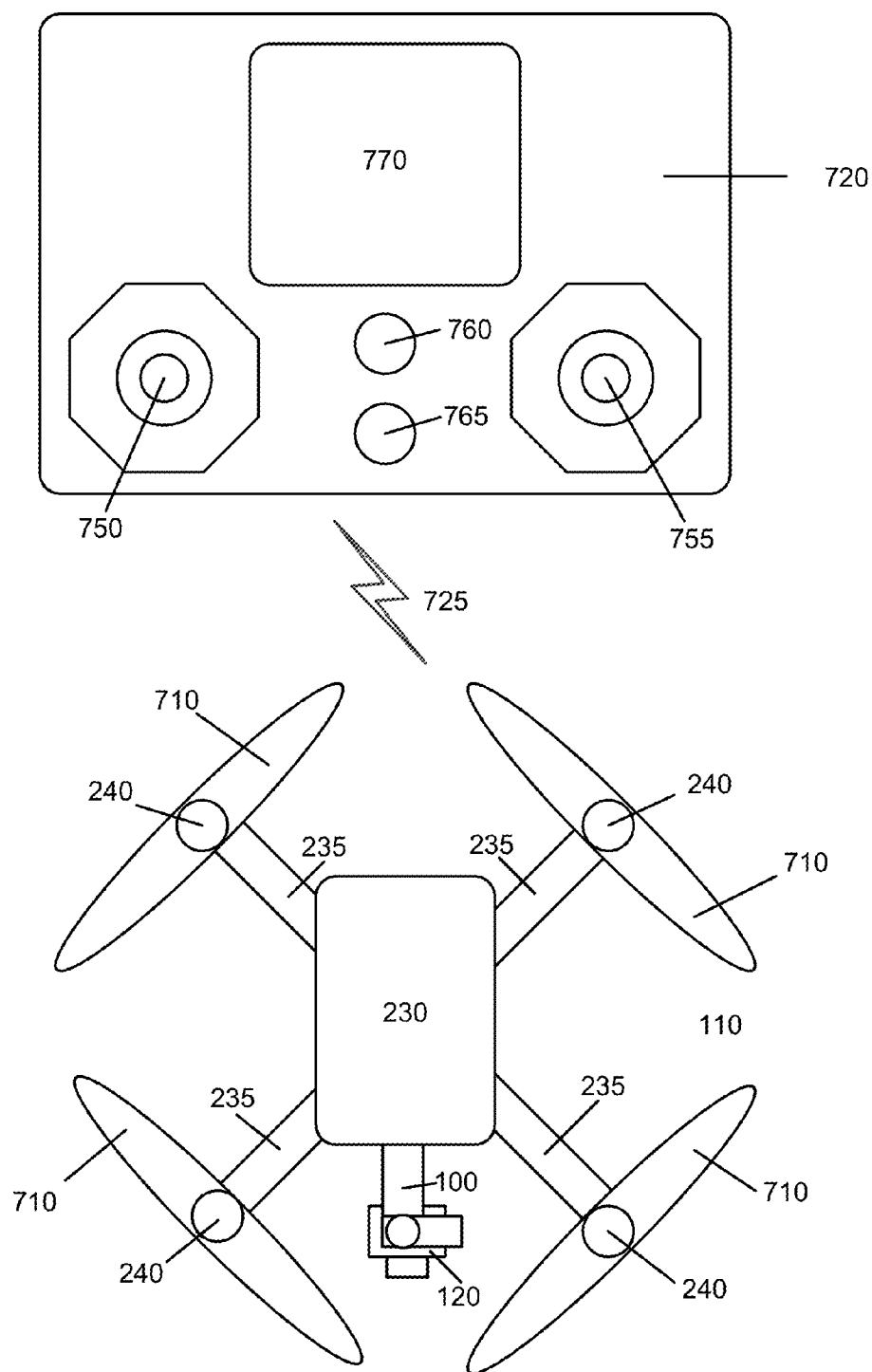


FIG. 7

FIG. 8A

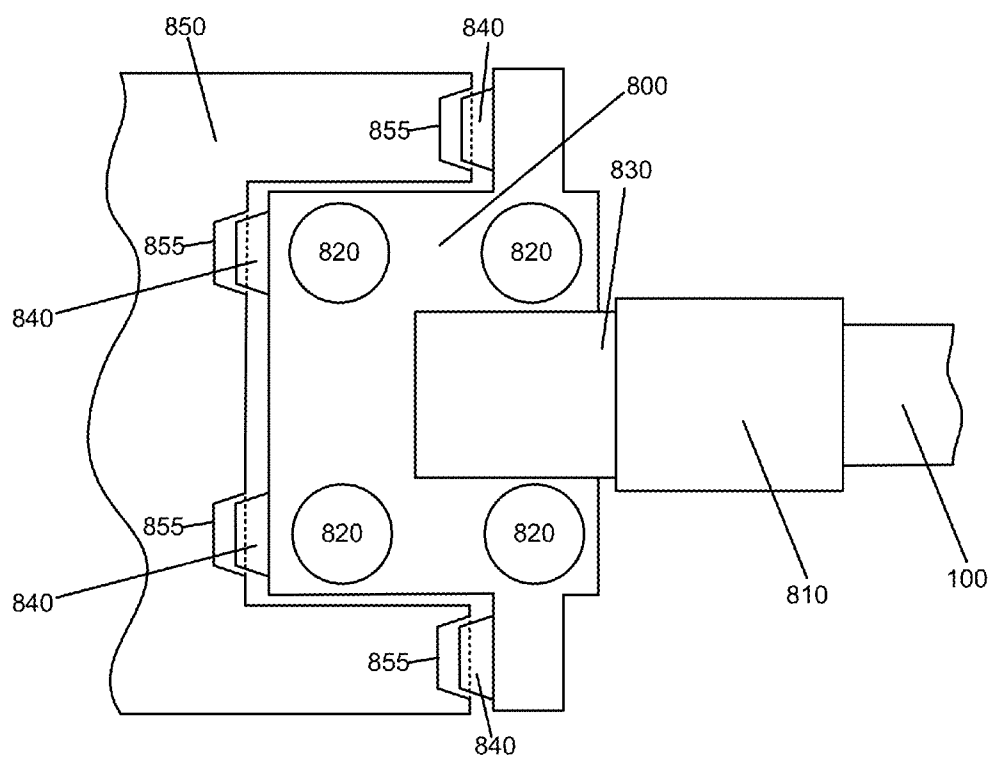


FIG. 8B

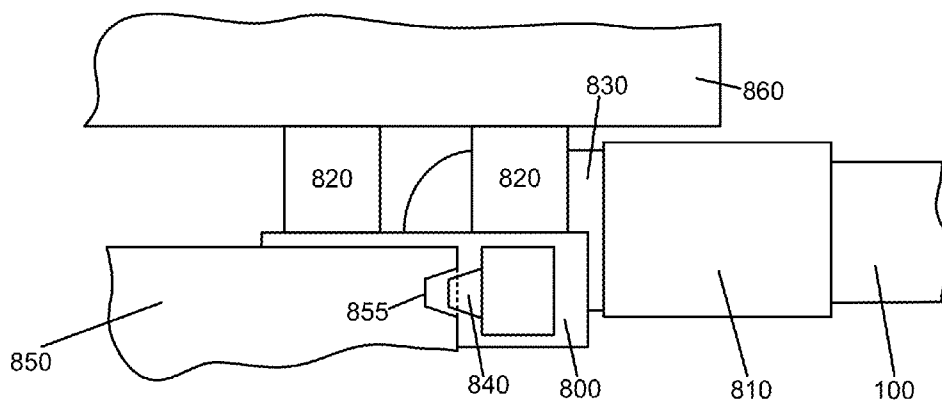


IMAGE STABILIZATION MECHANISM

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/167,241 filed on May 27, 2015, U.S. Provisional Patent Application No. 62/249,879 filed on Nov. 2, 2015, and U.S. Provisional Patent Application No. 62/302,170 filed on Mar. 2, 2016, the contents of which are each incorporated by reference herein.

BACKGROUND

[0002] Field of Art

[0003] The disclosure generally relates to the field of camera gimbals and in particular to a detachable gimbal which can be connected to a camera and to a remote controlled aerial vehicle and to other mounting configurations.

[0004] Description of Art

[0005] An electronic gimbal may stabilize or set the orientation of a camera. A gimbal can be mounted to a platform such as an electronic vehicle. For example, a camera can be mounted via a gimbal to a remote control road vehicle or aerial vehicle to capture images as the vehicle is controlled remotely by a user. A gimbal can allow the recording of stable video even when the platform is unstable.

[0006] Most camera gimbals mounted on remote controlled vehicles do not take into a consideration a multitude of issues involving the camera itself in relation to the vehicle to which it is mounted. These issues include, for example, allowing for a multiplicity of different cameras to be mounted to the gimbal, using a securing mechanism that will allow the gimbal to connect to a variety of platforms, preventing or minimizing obstruction of the field of view of the camera by components of the gimbal, and allowing communication between the vehicle and the mounted camera.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The disclosed embodiments have advantages and features which will be more readily apparent from the detailed description, the appended claims, and the accompanying figures (or drawings). A brief introduction of the figures is below.

[0008] FIG. 1 is a functional block diagram illustrating an example configuration of a camera mounted on a gimbal which is, in turn, mounted to an aerial vehicle.

[0009] FIG. 2 illustrates an example of a gimbal coupled to a remote controlled aerial vehicle.

[0010] FIG. 3A and FIG. 3B illustrate an example of a gimbal and camera.

[0011] FIG. 4 illustrates a block diagram of an example camera architecture.

[0012] FIG. 5 illustrates an embodiment of a detachable camera frame.

[0013] FIG. 6 illustrates a handheld grip coupled to a gimbal and camera.

[0014] FIG. 7 illustrates an example configuration of remote controlled aerial vehicle in communication with a remote controller.

[0015] FIGS. 8A and 8B illustrates an example of a dampening connection for coupling a gimbal to a mount platform.

DETAILED DESCRIPTION

[0016] The Figures (FIGS.) and the following description relate to preferred embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of what is claimed.

[0017] Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict embodiments of the disclosed system (or method) for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

Configuration Overview

[0018] Disclosed by way of example embodiments is an electronic gimbal with a camera and a mounting configuration. The gimbal may include an inertial measurement unit which can sense the orientation of the camera and three electronic motors which can manipulate the orientation of the camera. The gimbal can be removably coupled to a variety of mount platforms, such as an aerial vehicle or a handheld grip. Moreover, the camera can be removably coupled to the gimbal and can be held in a removable camera frame.

[0019] Also disclosed is a system for allowing the platform to which the gimbal is mounted to control settings of the camera or to trigger actions on the camera, such as taking a picture, or initiating the recording of a video. The gimbal can also provide a connection between the camera and the mount platform, such that the mount platform receives images and video content from the camera.

[0020] Further disclosed is a stabilizing mounting system for a camera that may include a handheld grip and an electronic gimbal. The handheld grip may include a shaft, a gimbal connection, and a control button. The gimbal connection may be at an end of the shaft and may include a first securing mechanism and a first electrical interface. The control button may be on the shaft and when activated may cause a control signal to be transmitted via the gimbal connection. The electronic gimbal may comprise a grip connection, a first motor, a second motor, a third motor, a camera connection, and an internal data base. The grip connection may include a second securing mechanism that may removably secure to the first securing mechanism of the handheld grip and a second electrical interface that may communicatively couple to the first electrical interface of the handheld grip. The first motor may be connected to the grip connection. The first motor may apply a first torque to a first motor shaft to cause the first motor shaft to rotate about a first axis of rotation. The second motor may be connected to the first motor shaft. The second motor may apply a second torque to a second motor shaft to rotate the second motor shaft about a second axis of rotation. The third motor may be connected to the second motor shaft. The third motor may apply a third torque to a third motor shaft to rotate the third motor about a third axis of rotation. The camera connection

may include a third securing mechanism that may removably secure a camera to the third motor shaft of the electronic gimbal. The camera connection may furthermore comprise a third electrical interface that may communicatively couple the electronic gimbal to the camera. The internal data bus may communicatively connect the second electrical interface to the third electrical interface. The internal data bus may furthermore transfer the control signal from the handheld grip to the camera when the control button is activated to enable the control button on the handheld grip to control an action of the camera.

[0021] In another embodiment of the stabilizing mounting system, the handheld grip may comprise a shaft and a gimbal connecting means for connecting to a gimbal. The gimbal connecting means may comprise a first securing means for mechanically securing to the gimbal and may comprise a first electrical interfacing means for electrically interfacing to the gimbal. The control means on the shaft may cause a control signal to be transmitted via the gimbal connecting means. The electronic gimbal may comprise a grip connecting means for connecting to the handheld grip. The grip connecting means may include a second securing means for removably securing to the first securing means of the handheld grip and may include a second electrical interfacing means for communicatively interfacing to the first electrical interfacing means of the handheld grip. A first rotating means may be connected to the grip connecting means. The first rotating means may apply a first torque to a first motor shaft that may cause the first motor shaft to rotate about a first axis of rotation. A second rotating means may be connected to the first motor shaft. The second rotating means may apply a second torque to a second motor shaft to rotate the second motor shaft about a second axis of rotation. A third rotating means may be connected to the second motor shaft. The third rotating means may apply a third torque to a third motor shaft to rotate the third motor about a third axis of rotation. A camera connecting means may connect to a camera. The camera connecting means may include a third securing means that may removably secure the camera to the third motor shaft. The camera connecting means may further comprise a third electrical interfacing means for communicatively coupling the electronic gimbal to the camera. A data transfer means may communicatively connect the second electrical interfacing means to the third electrical interfacing means. The data transfer means may furthermore transfer the control signal from the handheld grip to the camera when the control means is activated which may enable the control means on the handheld grip to control an action of the camera.

Example System Configuration

[0022] Figure (FIG. 1 is a functional block diagram illustrating an example system framework. In this example, the system includes a camera 120 connected to a detachable camera frame 130 which is mounted on a gimbal 100 which is, in turn, coupled to an aerial vehicle 110. The coupling between the gimbal 100 and the aerial vehicle 110 can include a mechanical coupling and a communicative coupling.

[0023] The camera 120 can include a camera body, one or more camera lenses, various indicators on the camera body (such as LEDs, displays, and the like), various input mechanisms (such as buttons, switches, and touch-screen mechanisms), and electronics (e.g., imaging electronics, power

electronics, metadata sensors, etc.) internal to the camera body for capturing images via the one or more lenses and/or performing other functions. The camera 120 can capture images and videos at various frame rates, resolutions, and compression rates. The camera 120 can be connected to the detachable camera frame 130, which mechanically connects to the camera and physically connects to the gimbal 100. FIG. 1 depicts the detachable camera frame 130 enclosing the camera 120 in accordance with some embodiments. In some embodiments, the detachable camera frame 130 does not enclose the camera 120, but functions as a mount to which the camera 120 couples. Examples of mounts include a frame, an open box, or a plate. Alternately, the detachable camera frame 130 can be omitted and the camera 120 can be directly attached to a camera mount which is part of the gimbal 100.

[0024] The gimbal 100 is, in some embodiments, an electronic three-axis gimbal which rotates a mounted object (e.g., a detachable camera frame 130 connected to a camera 120) in space. In addition to providing part of an electronic connection between the camera 120 and the aerial vehicle 110, the gimbal can include a sensor unit 101 and a control logic unit 102, both of which are part of a gimbal control system 150. The gimbal control system 150 may detect the orientation of the gimbal 100 and camera 120, determine a preferred orientation of the camera 120, and control the motors of the gimbal in order to re-orient the camera 120 to the preferred position. The sensor unit 101 may include an inertial measurement unit (IMU) which measures rotation, orientation, and acceleration using sensors, such as accelerometers, gyroscopes, and magnetometers. The sensor unit 101 can also contain rotary encoders, which detect the angular position of the motors of the gimbal 100, and a magnetometer to detect a magnetic field, such as the earth's magnetic field. In some embodiments, the sensors of the sensor unit 101 are placed such as to provide location diversity. For example, a set of accelerometers and gyroscopes can be located near the camera 120 (e.g., near the connection to the detachable camera frame 130) and a set of accelerometers and gyroscopes can be placed at the opposite end of the gimbal (e.g., near the connection to the aerial vehicle 110). The outputs of these two sets of sensors can be used by the IMU to calculate the orientation and rotational acceleration of the camera, which can then be output to the gimbal control logic 150. In some embodiments, the sensor unit 101 is located on the aerial vehicle 110. In some embodiments, the gimbal control logic 150 receives data from sensors (e.g., an IMU) on the aerial vehicle 110 and from the sensor unit 101 of the gimbal 100.

[0025] The control logic unit 102 on the gimbal 100, the sensor unit 101, and the control logic unit 113 on the aerial vehicle 110 may constitute a gimbal control system 150. As discussed above, the IMU of the sensor unit 101 may produce an output indicative of the orientation, angular velocity, and acceleration of at least one point on the gimbal 100. The control logic unit 102 on the gimbal 100 may receive the output of the sensor unit 101. In some embodiments, the control logic unit 113 on the aerial vehicle 110 receives the output of the sensor unit 101 instead of, or in addition to the control logic unit 102 on the gimbal 100. The combination of the two control logic units 102 and 113 may implement a control algorithm which controls the motors of the gimbal 100 to adjust the orientation of the mounted object to a preferred position. Thus, the gimbal control

system **150** may have the effect of detecting and correcting deviations from the preferred orientation for the mounted object.

[0026] The exact configuration of the two control portions of the gimbal control system **150** may vary between embodiments. In some embodiments, the gimbal control logic **102** on the gimbal **100** implements the entire control algorithm and the control logic unit **113** provides parameters which dictate how the control algorithm is implemented. These parameters can be transmitted to the gimbal **100** when the gimbal **100** is originally connected to the aerial vehicle **110** or other mount platform. These parameters can include a range of allowable angles for each motor of the gimbal **100**, the orientation, with respect to gravity, that each motor should correspond to, a desired angle for at least one of the three spatial axes with which the mounted object should be oriented, and parameters to account for different mass distributions of different cameras. In another embodiment, the control logic unit **113** on the aerial vehicle **110** performs most of the calculations for the control algorithm and the control logic unit **102** on the gimbal **100** includes proportional-integral-derivative controllers (PID controllers). The PID controllers' setpoints (i.e., the points of homeostasis which the PID controllers target) can be controlled by the control logic unit **113** of the aerial vehicle **110**. The setpoints can correspond to motor orientations or to the orientation of the mounted object. In some embodiments, either the control logic unit **102** of the gimbal **100** or the control logic unit **113** or the aerial vehicle **110** is omitted, and the control algorithm is implemented entirely by the other control logic unit.

[0027] The aerial vehicle **110** is shown connected to the gimbal **100** in one embodiment. In addition to an aerial vehicle, the gimbal **100** can also be removably attached to a variety of platforms, such as a handheld grip, a land vehicle, and a generic mount, which can itself be attached to a variety of platforms. The aerial vehicle **110** may include a camera controller **111**, an image/video receiver **112**, and the aforementioned control logic unit **113**. The image/video receiver **112** can receive content (e.g., images captured by the camera **120** or video currently being captured by the camera **120**). The image/video receiver **112** can store the received content on a non-volatile memory in the aerial vehicle **110**. The image/video receiver **112** can also transmit the content to another device. In some embodiments, the aerial vehicle **110** transmits the video currently being captured to a remote controller, with which a user controls the movement of the aerial vehicle **110**, via a wireless communication network.

[0028] The gimbal **100** can be coupled to the camera **120** and to the mount platform in such a way that the mount platform (e.g., a remote controlled aerial vehicle **110** or a hand grip) can generate commands via a camera controller **111** and send the commands to the camera **120**. Commands can include a command to toggle the power of the camera **120**, a command to begin recording video, a command to stop recording video, a command to take a picture, a command to take a burst of pictures, a command to set the frame rate at which a video is recording, or a command to set the picture or video resolution. Another command that can be sent from the mount platform through the gimbal **100** to the camera **120** can be a command to include a metadata tag in a recorded video or in a set of pictures. In this example configuration, the metadata tag contains information such as a geographical location or a time. For example, a remote-controlled aerial vehicle **110** can send a command through

the gimbal **100** to record a metadata tag while the camera **120** is recording a video. When the recorded video is later played, certain media players may be configured to display an icon or some other indicator in association with the time at which the command to record the metadata tag was sent. For example, a media player might display a visual queue, such as an icon, along a video timeline, wherein the position of the visual queue along the timeline is indicative of the time. The metadata tag can also instruct the camera **120** to record a location, which can be obtained via a GPS receiver (Global Positioning Satellite receiver) located on the aerial vehicle **110** or the camera **120**, in a recorded video. Upon playback of the video, the metadata can be used to map a geographical location to the time in a video at which the metadata tag was added to the recording.

[0029] Signals, such as a command originating from the camera controller **111** or video content captured by a camera **120** can be transmitted through electronic connections which run through the gimbal **100**. In some embodiments, telemetric data from a telemetric subsystem of the mount platform (e.g., aerial vehicle **110**) can be sent to the camera **120** to associate with video captured and stored on the camera **120**. A camera control connection **140** can connect the camera controller **111** module to the camera **120** and a camera output connection **141** can allow the camera **120** to transmit video content or pictures to the image/video receiver **112**. The connections can also provide power to the camera **120**, from a battery located on the aerial vehicle **110**. The battery of the aerial vehicle **110** can also power the gimbal **100**. In an alternate embodiment, the gimbal **100** contains a battery, which can provide power to the camera **120**. The connections between the camera **120** and the gimbal **110** can run through the gimbal **100** and the detachable camera frame **130**. The connection between the camera **120** and the mount platform can constitute a daisy chain or multidrop topology in which the gimbal **100** and detachable camera frame **130** act as buses. The connections can implement various protocols such as HDMI (High-Definition Multimedia Interface), USB (Universal Serial Bus), or Ethernet protocols to transmit data. In one embodiment, the camera output connection **141** transmits video data from the camera **120** via the HDMI protocol connection and the camera control connection **140** is a USB connection. In some embodiments, the connection between the camera **120** and the mount platform is internal to the gimbal.

Example Aerial Vehicle Configuration

[0030] FIG. 2 illustrates an embodiment in which the aerial vehicle **110** is a quadcopter (i.e., a helicopter with four rotors). The aerial vehicle **110** in this example includes housing **230** for payload (e.g., electronics, storage media, and/or camera), four arms **235**, and four rotors **240** (shown without rotor blades). Each arm **235** mechanically couples with a rotor **240** to create a rotary assembly. When the rotary assembly is operational, all the rotor blades (not shown) spin at appropriate speeds to allow the aerial vehicle **110** lift (take off), land, hover, and move (forward, backward) in flight. Modulation of the power supplied to each of the rotors can control the trajectory and torque on the aerial vehicle **110**. **[0031]** The gimbal **100** is coupled to the housing **130** of the aerial vehicle **110** through a removable coupling mechanism that mates with a reciprocal mechanism at a point **250** on the aerial vehicle having mechanical and communicative capabilities. The gimbal **100** can be removed from the aerial

vehicle 110. The gimbal 100 can also be removably attached to a variety of other mount platforms, such as a handheld grip, a vehicle, and a generic mount, which can itself be attached to a variety of platforms. In some embodiments, the gimbal 100 can be attached or removed from a platform without the use of tools. In the embodiment shown in FIG. 2, a camera mount 220, to which a camera can be mounted, is shown attached to the gimbal 100. In this example, the camera mount 220 is a plate to which the camera or camera housing is mechanically coupled.

Example Gimbal

[0032] FIG. 3A and FIG. 3B illustrate an example embodiment of the gimbal 100 attached to a removable camera frame 130, which itself is attached to a camera 120. The example gimbal 100 includes a base arm 310, a middle arm 315, a mount arm 320, a first motor 301, a second motor 302, and a third motor 303. Each of the motors 301, 302, 303 can have an associated rotary encoder, which will detect the rotation of the axle of the motor. Each rotary encoder can be part of the sensor unit 101. The base arm 310 may be configured to include a mechanical attachment portion 350 at a first end that allows the gimbal 100 to securely attach to a reciprocal component on another mount platform (e.g., an aerial vehicle, a ground vehicle, or a handheld grip), and also be removable. The base arm 310 may include the first motor 301. The base arm 310 may couple to the middle arm 315. A first end of the middle arm 315 may couple to the base arm 310, and a second end by the first motor 301. A second end of the middle arm 315 may be where the second motor 302 is coupled. A first end of the mount arm 320 may be coupled with the second end of the middle arm 315 at the second motor 302. The second end of the mount arm 320 may be where the third motor 303 is coupled as well as the camera frame 130. Within the camera frame 130, the camera 120 may be removably secured.

[0033] The gimbal 100 may be configured to allow for rotation of a mounted object in space. In the embodiment depicted in FIG. 3A and FIG. 3B, the mounted object is a camera 120 to which the gimbal 100 is mechanically coupled. The gimbal 100 may allow for the camera 120 to maintain a particular orientation in space so that it remains relatively steady as the platform to which it is attached moves (e.g., as an aerial vehicle 110 tilts or turns during flight). The gimbal 100 may have three motors, each of which rotates the mounted object (e.g., the camera 120) about a specific axis of rotation. Herein, for ease of discussion, the motors are numbered by their proximity to the mount platform (i.e., the first motor 301, the second motor 302, and the third motor 303).

[0034] The gimbal control system 150 may control the three motors 301, 302, and 303. After detecting the current orientation of the mounted object, via the sensor unit 101, the gimbal control system 150 may determine a preferred orientation along each of the three axes of rotation (e.g., yaw, pitch, and roll). The preferred orientation may be used by the gimbal control system 150 to compute a rotation for each motor in order to move the camera 120 to the preferred orientation or keep the camera 120 in the preferred orientation. In one embodiment, the gimbal control system 150 has a preferred orientation that is configured by the user. The user can input the preferred orientation of the camera 120 with a remote controller which sends the preferred orientation for the camera 120 to the aerial vehicle 110 through a

wireless network, which then provides the preferred orientation to the gimbal control logic 150. In some embodiments the preferred orientation can be defined relative to the ground, so that the yaw, pitch, and roll of the camera remain constant relative to the ground. In some embodiments, certain axes of rotation can be unfixed. That is, an unfixed axis of rotation is not corrected by the gimbal control system 150, but rather remains constant relative to the aerial vehicle 110. For example, the yaw of the camera 120 can be unfixed, while the roll and the pitch are fixed. In this case, if the yaw of the aerial vehicle 110 changes the yaw of the camera 120 will likewise change, but the roll and the pitch of the camera 120 will remain constant despite roll and pitch rotations of the aerial vehicle 110. In some embodiments, bounds of rotation can be defined which limit the rotation along certain axes relative to the connection between the gimbal 110 and the mount platform. For example, if the α_{max} and α_{min} are the relative maximum and minimum values for the yaw of the camera 120 relative to the mount platform, then if the aerial vehicle 110 is oriented at a yaw of α_{av} degrees then the preferred roll of the camera α_c can be chosen by the gimbal control system 150 so that the angle α_c is between the angles $(\alpha_{min} + \alpha_{av})$ and $(\alpha_{max} + \alpha_{av})$. Similar maximum and minimum values can be defined for the pitch and roll. The maximum and minimum for each of the relative angles can be defined such that the viewing angle of the camera 120 is not obstructed by the gimbal 100 and/or the mount platform at any angle within the valid bounds.

[0035] In some embodiments, the preferred orientation of the camera 120 is defined using a tracking algorithm. For example, if tracking is done via machine vision tracking, there may be a conversion from a machine vision camera reference frame (e.g., the camera that is used for machine vision), to host (e.g., the aerial vehicle) reference frame. The gimbal may be given a setpoint in the host reference frame such that the tracked point is in camera view (e.g., with respect to the camera used for video). Cameras can be the same or decoupled. If a user is carrying a GPS enabled tracker or similar localization device, the user location will most likely be in an earth (global) reference frame. The gimbal setpoint may be in a local (e.g., the aerial vehicle) reference frame. The aerial vehicle may have a navigation module that combines several sensors to calculate its own position in global reference frame. The aerial vehicle may convert user coordinates (e.g., global reference frame) into a gimbal setpoint (e.g., local reference frame) such that the object is in the view.

[0036] By way of another example, the camera 120 or the mount platform may detect a tracked object. The tracked object can be, for example, an audio source, a source radiating an electromagnetic signal, a device communicatively coupled with the mount platform, or an object identified by a machine vision system. The tracked object may be detected using appropriate sensors on either the camera 120 or the mount platform, and one or more processors on the camera 120 or the mount platform may calculate the position of the tracked object relative to the mount platform. Calculating the position of the tracked object relative to the mount platform may involve calculating the position of the tracked object relative to the camera 120 and converting the position to the reference of the mount platform. The position of the tracked object relative to the mount platform may be used by the gimbal control logic 150 to generate a setpoint (e.g., a preferred position) for the gimbal 100, defined so that the

camera 120 is oriented to face the tracked object. The position of the tracked object relative to the mount platform might be such that the camera 120 cannot be oriented to face the tracked object due to the mechanical limitations of the gimbal 100 or due to the gimbal 100 or the mount platform obstructing the view of the camera 120. In such a situation, a setpoint of the gimbal 100 can be set to a default orientation or the gimbal control logic 150 can define the setpoint so that the camera 120 is oriented at an orientation as close as possible to the ideal orientation.

[0037] In some embodiments, the user is able to define a tracked object which the camera 120 tracks via a machine vision object tracking algorithm. A video feed from the camera 120 or from a camera on the mount platform can be transmitted to, for example, a remote controller (dedicated controller with a display, smartphone, or tablet) for display to the user (e.g., on a screen of a remote controller which is communicatively coupled to the aerial vehicle 110 coupled to the gimbal 100). In addition, through the remote controller, the user can select an object (e.g., by tapping the object on a touchscreen) which selects the object as the tracked object. A machine vision system can recognize a plurality of objects in the video feed of the camera 120 using an object classifier (e.g., a facial recognition system or a classifier configured to recognize people) and display an indicator on the video feed which indicates to the user that the object is available for tracking. Once a tracked object is selected, a machine vision object tracking algorithm can be used to orient the camera 120 so that the tracked object is centered in the frame of the video. The machine vision algorithms used to identify and track objects can be performed by one or more processors on the camera 120, the mount platform, a remote controller device communicatively connected to a remote controlled vehicle to which the gimbal 100 is mounted, or a remote server connected to via the Internet. The gimbal 100 can also be configured to track an audio source, based on the directionality of the audio source. The camera 120 or mount platform can include a multiplicity of audio receivers (e.g., an acoustic-to-electric transducer or sensor) which can be used to record sound from an audio source and to estimate the directionality of the sound based on the relative delay between the spatially diverse audio receivers. The gimbal 100 can track any sound over a certain decibel level, or with a certain energy within a given frequency range, or that match an audio profile of a user which can be assessed using vocal recognition algorithms. In an example embodiment, an audio output device carried by a user can emit sound at an ultrasonic or infrasonic frequency (i.e., outside the threshold of human hearing), and this audio output device can be tracked by detecting the sound emitted by the audio output device. Additionally, the tracked object can be a GPS tracker that is communicatively coupled to the mount platform. The location device can detect its own coordinates via a GPS receiver and transmit the coordinates to the mount platform. The mount platform can then calculate the position of the GPS tracker relative to itself using a navigation module that also includes a GPS. In some embodiments, a handheld remote controller used to control the mount platform functions as the GPS tracker. Each of the aforementioned tracking schemes can allow the camera 120 to continuously track an object, such as a user, as the tracked object moves around and as the mount platform moves around and rotates. In some embodiments, multiple tracking systems can be combined to better track an

object. For example, a GPS tracker held by a user and a machine vision system configured to track the user can be used in conjunction to track the user more accurately than could be done with either tracking system in isolation.

[0038] The axis to which each motor corresponds can depend on the platform to which the gimbal is attached. For example, when attached to the aerial vehicle 110, the first motor 301 can rotate the mounted object about the roll axis, the second motor 302 rotates corresponding to rotation in yaw and the third motor 303 corresponds to rotation in pitch. However, when the same gimbal 100 is attached to a handheld grip, the motors may correspond to different axis: for example, the first motor 301 corresponds to yaw, and the second motor 302 corresponds to roll, while the third motor 303 still corresponds to pitch.

[0039] In one embodiment, each of the three motors 301, 302, 303 is associated with an orthogonal axis of rotation. However, in some embodiments, such as the embodiment depicted in FIG. 3A and FIG. 3B the motors 301, 302, 303 of the gimbal 100 are not orthogonal. A gimbal 100 in which the motors are not orthogonal may have at least one motor that rotates the mounted object about an axis which is not orthogonal to the axis of rotation of the other motors. In a gimbal 100 in which the motors are not orthogonal, operation of one motor of the gimbal 100 can cause the angle of the camera 120 to shift on the axis of another motor. In the example embodiment shown in FIG. 3A and FIG. 3B, the first motor 301 and the third motor 303 have axes of rotation that are orthogonal to each other, and the second motor 302 and the third motor 303 are orthogonal, but the first motor 301 and second motor 302 are not orthogonal. Because of this configuration, when the gimbal 100 is coupled to the aerial vehicle 110 and the aerial vehicle 110 is level, operation of the first motor 301 may adjust only the roll of the camera 120 and the third motor 303 adjusts only the pitch of the camera 120. The second motor 302 may adjust the yaw primarily, but also may adjust the pitch and roll of the camera 120. Suppose for the purpose of example, the gimbal 100 is attached to the aerial vehicle 110 and the camera 120 is initially oriented at a pitch, yaw, and roll of 0° and that the axis of the second motor 302 is orthogonal to the axis of the third motor 303 and forms an angle of 0 degrees with the vertical axis, as depicted in FIG. 3A and FIG. 3B. In FIG. 3B, the angle θ is measured clockwise, and is about 16°. A rotation of ϕ degrees (where $-180^\circ \leq \phi \leq 180^\circ$) by the second motor 302 may also change the pitch, p , of the camera 120 to $p = (|\phi| * \theta) / 90^\circ$ where a pitch greater than 0 corresponds to the camera being oriented beneath the horizontal plane (i.e., facing down). The rotation of the second motor 302 by ϕ degrees may also change the roll, r , of the camera 120 to $r = \theta * (1 - |\phi - 90^\circ| / 90^\circ)$ in the case where $-90^\circ \leq \phi \leq 180^\circ$ and the roll will change to $r = -(\theta * \phi / 90^\circ - \theta)$ in the case where $-180^\circ < \phi < -90^\circ$. The change in the yaw, y , of the camera 120 will be equivalent to the change in angle of the second motor 120 (i.e., $y = \phi$).

[0040] A non-orthogonal motor configuration of the gimbal 100 can allow for a larger range of unobstructed viewing angles for the camera 120. For example, in the embodiment shown in FIG. 3A and FIG. 3B, the pitch of the camera 120 relative to the connection of the gimbal 100 to the mount platform (e.g., aerial vehicle 110) can be about 16° higher without the camera's frame being obstructed (i.e., without the motor appearing in the image captured by the camera) than it could with an orthogonal motor configuration. In

some embodiments, the second motor **302** is not identical to the other two motors **301**, **303**. The second motor **302** can be capable of producing a higher torque than the other two motors **301**, **303**.

[0041] A larger value of θ (the angle between the second motor **302** and the axis orthogonal to the rotational axes of the other two motors) in a non-orthogonal motor configuration can provide a larger range of viewing angles for the mounted camera **120**, but a larger θ may involve a higher maximum torque than a comparable orthogonal motor configuration. Thus, embodiments in which the motors are not orthogonal may implement a value of θ in which the two design considerations of a large viewing angle for the camera **120** and the torque required from the motors are optimized. Consequently, the choice of θ may depend on many factors, such as the targeted price point of the gimbal **100**, the type of cameras supported, the desired use cases of the gimbal, the available motor technology, among other things. Roughly, θ can be between $0^\circ \leq \theta \leq 30^\circ$ in one embodiment.

[0042] The gimbal **100** can support a plurality of different cameras with different mass distributions. Each camera can have a corresponding detachable camera frame (e.g., camera **120** corresponds to the detachable camera frame **130**), which secures the camera. A detachable camera frame **130** may have a connector, or a multiplicity of connectors, which couple to the gimbal **100** and a connector, or a multiplicity of connectors, which couple to the camera **102**. Thus, the detachable camera frame **130** includes a bus for sending signals from the camera to the gimbal **100**, which can, in some cases, be routed to the mount platform. In some embodiments, each detachable camera frame has the same types of connectors for coupling to the gimbal **100**, but the type of connector that connects to the camera is specific to the type of camera. In another embodiment, the detachable camera frame **130** provides no electronic connection between the camera **120** and the gimbal **100**, and the camera **120** and gimbal **100** are directly connected. In some embodiments, the gimbal **100** does not contain a bus and the camera **120** and the mount platform communicate via a wireless connection (e.g., Bluetooth or Wi-Fi).

[0043] In some embodiments, the gimbal **100** has a mount connector **304** (shown in FIG. 3B, but not in FIG. 3A) which allows the gimbal **100** to electronically couple to the mount platform (e.g., the aerial vehicle **110**). The mount connector **304** can include a power connection which provides power to the gimbal **100** and the camera **120**. The mount connector **304** can also allow communication between the sensor unit **101** and control logic unit **102** on the gimbal **100** and the control logic unit on the mount platform. In some embodiments, the mount connector **304** connects to the camera **120** via busses (e.g., a camera control connection **140** and a camera output connection **141**) which allow communication between the mount platform and the camera **120**.

[0044] The gimbal **100** also can couple mechanically to a mount platform via a mechanical attachment portion **350**. The mechanical attachment portion **350** can be part of the base arm **310**. The mechanical attachment portion **350** can include a mechanical locking mechanism to securely attach a reciprocal component on a mount platform (e.g., an aerial vehicle, a ground vehicle, an underwater vehicle, or a handheld grip). The example mechanical locking mechanism shown in FIGS. 3A and 3B includes a groove with a channel in which a key (e.g., a tapered pin or block) on a

reciprocal component on a mount platform can fit. The gimbal **100** can be locked with the mount platform in a first position and unlocked in a second position, allowing for detachment of the gimbal **100** from the mount platform. The mechanical attachment portion **350** may connect to a reciprocal component on a mount platform in which the mechanical attachment portion **350** is configured as a female portion of a sleeve coupling, where the mount platform is configured as a male portion of a sleeve coupling. The coupling between the mount platform and the gimbal **100** can be held together by a frictional force. The coupling between the mount platform and the gimbal **100** can also be held together by a clamping mechanism on the mount platform.

[0045] If the gimbal **100** supports multiple different cameras of differing mass distributions, the differences in mass and moments of inertia between cameras might cause the gimbal **100** to perform sub-optimally. A variety of techniques are suggested herein for allowing a single gimbal **100** to be used with cameras of different mass distributions. The detachable camera frame **130** can hold the camera **120** in such a way that the detachable frame **130** and camera **120** act as a single rigid body. In some embodiments, each camera which can be coupled to the gimbal **100** has a corresponding detachable frame, and each pair of camera and frame have masses and moments of inertia which are approximately the same. For example, if m_{ca} and m_{fa} are the masses of a first camera and its corresponding detachable frame, respectively, and if m_{cb} and m_{fb} are the masses of a second camera and its corresponding detachable frame, then, $m_{ca} + m_{fa} \approx m_{cb} + m_{fb}$. Also, I_{cb} and I_{fb} are the matrices representing the moments of inertia for the axes around about which the first camera rotates for the first camera and the corresponding detachable frame, respectively. In addition, I_{cb} and I_{fb} are the corresponding matrices for the second camera and the corresponding detachable frame, respectively. Thereafter, $I_{ca} + I_{fa} \approx I_{cb} + I_{fb}$, where “+” denotes the matrix addition operator. Since the mounted object which is being rotated by the gimbal is the rigid body of the camera and detachable camera frame pair, the mass profile of the mounted object may not vary although the mass profile of the camera itself does. Thus, by employing detachable camera frames with specific mass profiles a single gimbal **100** can couple to a multiplicity of cameras with different mass profiles.

[0046] In alternate embodiments, the mass profile of the camera and detachable frame pair is different for each different type of camera, but control parameters used in the control algorithms, implemented by the gimbal control system **150**, which control the motors, are changed to compensate for the different mass profiles of each pair camera and detachable camera frame. These control parameters can specify the acceleration of a motor, a maximum or minimum for the velocity of a motor, a torque exerted by a motor, a current draw of a motor, and a voltage of a motor. In one embodiment, the camera **120** and/or the camera frame **130** is communicatively coupled to either the gimbal **100** or the mount platform, and upon connection of a camera **120** to the gimbal **100** information is sent from the camera **120** to the gimbal control system **150** which initiates the update of control parameters used to control the motors of the gimbal **100**. The information can be the control parameters used by the gimbal control system **150**, information about the mass profile (e.g., mass or moment of inertia) of the camera **120** and/or detachable camera mount **130**, or an identifier for the camera **120** or the camera mount **130**. If the information sent

to the gimbal control system **150** is a mass profile, then the gimbal control system **150** can calculate control parameters from the mass profile. If the information is an identifier for the camera **120** or the detachable camera frame **130**, then the gimbal control system **150** can access a non-volatile memory which stores sets of control parameters mapped to identifiers in order to obtain the correct set of control parameters for a given identifier.

Example Camera Architecture

[0047] FIG. 4 illustrates a block diagram of an example camera architecture. The camera architecture **405** corresponds to an architecture for the camera, e.g., **120**. In one embodiment, the camera **120** is capable of capturing spherical or substantially spherical content. As used herein, spherical content may include still images or video having spherical or substantially spherical field of view. For example, in one embodiment, the camera **120** captures video having a 360° field of view in the horizontal plane and a 180° field of view in the vertical plane. Alternatively, the camera **120** may capture substantially spherical images or video having less than 360° in the horizontal direction and less than 180° in the vertical direction (e.g., within 10% of the field of view associated with fully spherical content). In other embodiments, the camera **120** may capture images or video having a non-spherical wide angle field of view.

[0048] As described in greater detail below, the camera **120** can include sensors **440** to capture metadata associated with video data, such as timing data, motion data, speed data, acceleration data, altitude data, GPS data, and the like. In a particular embodiment, location and/or time centric metadata (geographic location, time, speed, etc.) can be incorporated into a media file together with the captured content in order to track the location of the camera **120** over time. This metadata may be captured by the camera **120** itself or by another device (e.g., a mobile phone or the aerial vehicle **110**) proximate to the camera **120**. In one embodiment, the metadata may be incorporated with the content stream by the camera **120** as the content is being captured. In another embodiment, a metadata file separate from the video file may be captured (by the same capture device or a different capture device) and the two separate files can be combined or otherwise processed together in post-processing. These sensors **440** can be in addition to sensors in a telemetric subsystem of the aerial vehicle **110**. In embodiments in which the camera **120** is integrated with the aerial vehicle **110**, the camera need not have separate individual sensors, but rather could rely upon the sensors integrated with the aerial vehicle **110**.

[0049] In the embodiment illustrated in FIG. 4, the camera **120** comprises a camera core **410** comprising a lens **412**, an image sensor **414**, and an image processor **416**. The camera **120** additionally includes a system controller **420** (e.g., a microcontroller or microprocessor) that controls the operation and functionality of the camera **120** and system memory **430** configured to store executable computer instructions that, when executed by the system controller **420** and/or the image processors **416**, perform the camera functionalities described herein. In some embodiments, a camera **120** may include multiple camera cores **410** to capture fields of view in different directions which may then be stitched together to form a cohesive image. For example, in an embodiment of a spherical camera system, the camera **120** may include two camera cores **410** each having a hemispherical or hyper

hemispherical lens that each captures a hemispherical or hyper hemispherical field of view which are stitched together in post-processing to form a spherical image.

[0050] The lens **412** can be, for example, a wide angle lens, hemispherical, or hyper hemispherical lens that focuses light entering the lens to the image sensor **414** which captures images and/or video frames. The image sensor **414** may capture high-definition images having a resolution of, for example, 720p, 1080p, 4k, or higher. In one embodiment, spherical video is captured in a resolution of 5760 pixels by 2880 pixels with a 360° horizontal field of view and a 180° vertical field of view. For video, the image sensor **414** may capture video at frame rates of, for example, 30 frames per second, 60 frames per second, or higher. The image processor **416** performs one or more image processing functions of the captured images or video. For example, the image processor **416** may perform a Bayer transformation, demosaicing, noise reduction, image sharpening, image stabilization, rolling shutter artifact reduction, color space conversion, compression, or other in-camera processing functions. Processed images and video may be temporarily or persistently stored to system memory **430** and/or to a non-volatile storage, which may be in the form of internal storage or an external memory card.

[0051] An input/output (I/O) interface **460** may transmit and receive data from various external devices. For example, the I/O interface **460** may facilitate the receiving or transmitting video or audio information through an I/O port. Examples of I/O ports or interfaces include USB ports, HDMI ports, Ethernet ports, audio ports, and the like. Furthermore, embodiments of the I/O interface **460** may include wireless ports that can accommodate wireless connections. Examples of wireless ports include Bluetooth, Wireless USB, Near Field Communication (NFC), and the like. The I/O interface **460** may also include an interface to synchronize the camera **120** with other cameras or with other external devices, such as a remote control, a second camera, a smartphone, a client device, or a video server.

[0052] A control/display subsystem **470** may include various control and display components associated with operation of the camera **120** including, for example, LED lights, a display, buttons, microphones, speakers, and the like. The audio subsystem **450** may include, for example, one or more microphones and one or more audio processors to capture and process audio data correlated with video capture. In one embodiment, the audio subsystem **450** may include a microphone array having two or microphones arranged to obtain directional audio signals.

[0053] Sensors **440** may capture various metadata concurrently with, or separately from, video capture. For example, the sensors **440** may capture time-stamped location information based on a global positioning system (GPS) sensor, and/or an altimeter. Other sensors **440** may be used to detect and capture orientation of the camera **120** including, for example, an orientation sensor, an accelerometer, a gyroscope, or a magnetometer. Sensor data captured from the various sensors **440** may be processed to generate other types of metadata. For example, sensor data from the accelerometer may be used to generate motion metadata, comprising velocity and/or acceleration vectors representative of motion of the camera **120**. Furthermore, sensor data from the aerial vehicle **110** and/or the gimbal **100** may be used to generate orientation metadata describing the orientation of the camera **120**. Sensor data from a GPS sensor can

provide GPS coordinates identifying the location of the camera 120, and the altimeter can measure the altitude of the camera 120. In one embodiment, the sensors 440 are rigidly coupled to the camera 120 such that any motion, orientation or change in location experienced by the camera 120 is also experienced by the sensors 440. The sensors 440 furthermore may associate a time stamp representing when the data was captured by each sensor. In one embodiment, the sensors 440 automatically begin collecting sensor metadata when the camera 120 begins recording a video.

[0054] The camera 120 can be enclosed or mounted to a detachable camera frame 130, such as the one depicted in FIG. 5. The detachable camera frame 130 can include electronic connectors which can couple with the corresponding camera (not shown). The detachable camera frame 130 depicted in FIG. 5 includes a micro USB connector 500, which can provide power to the camera and can allow the mount platform (e.g., an aerial vehicle 110) to send executable instructions to the camera 120, such as a command to change the frame rate of a video, or take a picture. The HDMI connector 510 depicted in FIG. 5 may allow the camera to transmit captured video, audio, and images to the mount platform. The detachable camera frame 130 can include any set of connectors and utilize any communication protocols to transmit data to and from the mount platform. The detachable camera frame 130 can include a set of connectors (not shown) which connect to the gimbal 100, so that the gimbal 100 can act as a bus for transmitting data or power between the mount platform 130 and the camera 120, and vice versa.

Mount Platform Examples

[0055] FIG. 6 illustrates an example embodiment of a mount platform that can removably couple with the gimbal 100. In this example, the mount platform is the handheld grip 600 that electronically and mechanically couples with the gimbal 100. The handheld grip 600 can include a plurality of buttons 605, 610, 615, 620, 625 which can be used by a user to control the camera 120 and/or the gimbal 100. The handheld grip 600 contains a battery from which it can provide power to the gimbal 100 and may also be used to power and/or charge the camera 120 in addition to operating any electronic functions on the handheld grip 600 itself.

[0056] The handheld grip 600 can be communicatively coupled to the camera 120 via a connection provided by the gimbal 100. The camera 120 can provide captured video content and images to the handheld grip 600. In one embodiment, the handheld grip can store the provided video content and images in storage media, such as a flash storage, which can be removably coupled to the handheld grip 600 (e.g., a secure digital memory card (SD card) or a micro SD card) or integrated into the handheld grip 600 itself. In an alternate embodiment, the handheld grip 600 has a port which can be used to connect to another device, such as a personal computer. This port can allow the connected device to request and receive video content and images from the camera 120. Thus, the connected device, would receive content from the camera 120 via a connection running through the detachable camera frame 130, the gimbal 100, and the handheld grip 600. In some embodiments, the port on the handheld grip 600 provides a USB connection. The handheld grip can also transmit executable instructions to the camera 120. These instructions can take the form of

commands which are sent to the camera 120 responsive to a user pressing a button on the handheld grip 600.

[0057] In some embodiments, the handheld grip includes a plurality of buttons 605, 610, 615, 620, 625. An instruction can be sent from the handheld grip 600 to the camera 120 responsive to pressing a button. In one embodiment, a first button 605 takes a picture or a burst of pictures. The first button 605 can also begin recording a video or terminate the recording of a video if it is currently recording. In some embodiments, the camera 120 can be in a picture mode, in which it takes pictures or bursts of pictures, or a video mode, in which it records video. The result of pressing the first button 605 can be determined by whether the camera 120 is in video mode or camera mode. A second button 610 can toggle the mode of the camera 120 between the video mode and picture mode. A third button 615 can toggle the power of the camera 120. A fourth button 620 can change the mode of the camera 120 so that it takes bursts of pictures rather than a single picture responsive to pressing the first button 605. A fifth button 625 can change the frame rate at which the camera 120 records videos. In some embodiments, a button on the handheld grip can also change the resolution or compression rate at which pictures or videos are recorded. The handheld grip 600 can include light emitting diodes (LEDs) or other visual indicators which can indicate the mode that the camera is operating in. For example, an LED of a first color can be turned on in order to indicate that the camera 120 is in picture mode and an LED of a second color can be turned on to indicate that the camera 120 is in video mode. In some embodiments, the handheld grip 600 can include an audio output device, such as an electroacoustic transducer, which plays a sound responsive to pressing a button. The sound played by the audio output device can vary depending on the mode of the camera. By way of example, the sound that is played when a video recording is initiated is different than the sound that is played when a picture is taken. As will be known to one skilled in the art, additional buttons with additional functions can be added to the handheld grip 600 and some or all of the aforementioned buttons can be omitted. In one embodiment, the handheld grip 600 has only two buttons: a first button 605 which operates as a shutter button, and a second button 610 which instructs the camera 120 to include a metadata tag in a recorded video, where the metadata tag can specify the time at which the second button 610 was pressed.

[0058] In some embodiments, the rotational angle of the camera 120 to which each motor corresponds can vary depending on the mount platform to which the gimbal is attached. In the embodiment shown in FIG. 6, the first motor 301 controls the yaw of the camera 120, the second motor 302 (not shown in FIG. 6) controls the roll of the camera 120, and the third motor 303 controls the pitch of the camera 120. This is in contrast to FIG. 3A and FIG. 3B which depict the motors controlling the roll, yaw, and pitch, respectively. In some embodiments, the same gimbal 100 can operate in both configurations, responsive to the mount platform to which it is connected. For example, when connected to the handheld grip 600 the gimbal's motors can operate as yaw, roll, and pitch motors, respectively, and when connected to the aerial vehicle 110 the gimbal's motors can operate as roll, yaw, and pitch motors.

[0059] In some embodiments, the camera's rotation for each axis of rotation can be fixed or unfixed. When the camera's rotation is fixed on an axis, then the camera will

maintain that same orientation, relative to the ground, on that axis despite the movement of the handheld grip. Conversely, when the rotation of the camera 120 is unfixed on an axis, then the camera's rotation on that axis can change when the handheld grip 600 is rotated. For example, if the yaw of the camera 120 is unfixed then a change in the yaw of the handheld grip 600 by ϕ degrees can correspond to a change in the yaw of the camera 120 by ϕ or $-\phi$ degrees (depending on the point of reference for which the yaw is considered). If all three of the camera's axes are unfixed, then the motors 301, 302, 303 of the gimbal 100 will remain fixed (i.e., they will not turn) when the handheld grip 600 changes orientation. The gimbal control system 150 can have a fixed yaw mode and an unfixed yaw mode which dictates that the yaw of the camera 120 should remain fixed or unfixed, respectively. Similarly the gimbal control system 150 can have a fixed and unfixed mode for the roll and the pitch. The user can set the mode to unfixed for a certain axis and reorient the camera 120 to the desired angle along that axis, then set the mode for the axis to fixed so the camera 120 will remain at that angle. This will allow a user to easily set the preferred angle of the camera relative to the ground. The gimbal control system 150 can still stabilize the rotation along an axis, while in unfixed mode. In one embodiment, a second button 610 toggles the yaw mode between fixed and unfixed, the third button 615 toggles the pitch mode between fixed and unfixed, and the fourth button 620 toggles the roll mode between fixed and unfixed. The axes of the gimbal 100 can be in a fixed mode or unfixed mode while connected to the aerial vehicle 110, as well. In one embodiment, the yaw is unfixed and the pitch and roll are fixed by default. In this embodiment, the yaw will be roughly fixed in the same direction relative to the mount device and the pitch and roll will remain fixed relative to a horizontal plane (e.g., the ground).

[0060] FIG. 7 illustrates a gimbal 100 attached to a remote controlled aerial vehicle 110, which communicates with a remote controller 720 via a wireless network 725. The remote controlled aerial vehicle 110 in this example is shown with a housing 230 and arms 235 of an arm assembly. In addition, this example embodiment shows a thrust motor 240 coupled with the end of each arm 130 of the arm assembly, a gimbal 100 and a camera mount 220. Each thrust motor 240 may be coupled to a propeller 710. The thrust motors 240 may spin the propellers 710 when the motors are operational.

[0061] The aerial vehicle 110 may communicate with the remote controller 720 through the wireless network 725. The remote controller 725 can be a dedicated remote controller or can be another computing device such as a laptop, smartphone, or tablet that is configured to wirelessly communicate with and control the aerial vehicle 110. In one embodiment, the wireless network 725 can be a long range Wi-Fi system. It also can include or be another wireless communication system, for example, one based on long term evolution (LTE), 3G, 4G, or 5G mobile communication standards. In place of a single wireless network 725, the a uni-directional RC channel can be used for communication of controls from the remote controller 720 to the aerial vehicle 110 and a separate unidirectional channel can be used for video downlink from the aerial vehicle 110 to the remote controller 720 (or to a video receiver where direct video connection may be desired).

[0062] The remote controller 720 in this example can include a first control panel 750 and a second control panel 755, an ignition button 760, a return button 765 and a display 770. A first control panel, e.g., 750, can be used to control "up-down" direction (e.g. lift and landing) of the aerial vehicle 110. A second control panel, e.g., 755, can be used to control "forward-reverse" direction of the aerial vehicle 110. Each control panel 750, 755 can be structurally configured as a joystick controller and/or touch pad controller. The ignition button 760 can be used to start the rotary assembly (e.g., start the propellers 710). The return button 765 can be used to override the controls of the remote controller 720 and transmit instructions to the aerial vehicle 110 to return to a predefined location as further described herein. The ignition button 760 and the return button 765 can be mechanical and/or solid state press sensitive buttons. In addition, each button may be illuminated with one or more light emitting diodes (LED) to provide additional details. For example the LED can switch from one visual state to another to indicate with respect to the ignition button 760 whether the aerial vehicle 110 is ready to fly (e.g., lit green) or not (e.g., lit red) or whether the aerial vehicle 110 is now in an override mode on return path (e.g., lit yellow) or not (e.g., lit red). The remote controller 720 can include other dedicated hardware buttons and switches and those buttons and switches may be solid state buttons and switches. The remote controller 720 can also include hardware buttons or other controls that control the gimbal 100. The remote control can allow its user to change the preferred orientation of the camera 120. In some embodiments, the preferred orientation of the camera 120 can be set relative to the angle of the aerial vehicle 110. In another embodiment, the preferred orientation of the camera 120 can be set relative to the ground.

[0063] The remote controller 720 also can include a screen (or display) 770 which provides for visual display. The screen 770 can be a touch sensitive screen. The screen 770 also can be, for example, a liquid crystal display (LCD), an LED display, an organic LED (OLED) display or a plasma screen. The screen 770 can allow for display of information related to the remote controller 720, such as menus for configuring the remote controller 720 or remotely configuring the aerial vehicle 110. The screen 770 also can display images or video captured from the camera 120 coupled with the aerial vehicle 110, wherein the images and video are transmitted via the wireless network 725. The video content displayed by on the screen 770 can be a live feed of the video or a portion of the video captured by the camera 120. For example, the video content displayed on the screen 770 may be presented within a short time (preferably fractions of a second) of being captured by the camera 120.

[0064] The video may be overlaid and/or augmented with other data from the aerial vehicle 110 such as the telemetric data from a telemetric subsystem of the aerial vehicle 110. The telemetric subsystem may include navigational components, such as a gyroscope, an accelerometer, a compass, a global positioning system (GPS) and/or a barometric sensor. In one example embodiment, the aerial vehicle 110 can incorporate the telemetric data with video that is transmitted back to the remote controller 720 in real time. The received telemetric data can be extracted from the video data stream and incorporate into predefined templates for display with the video on the screen 170 of the remote controller 120. The telemetric data also may be transmitted separate from the

video from the aerial vehicle **110** to the remote controller **120**. Synchronization methods such as time and/or location information can be used to synchronize the telemetric data with the video at the remote controller **120**. This example configuration allows a user, e.g., operator, of the remote controller **120** to see where the aerial vehicle **110** is flying along with corresponding telemetric data associated with the aerial vehicle **110** at that point in the flight. Further, if the user is not interested in telemetric data being displayed real-time, the data can still be received and later applied for playback with the templates applied to the video.

[0065] The predefined templates can correspond with “gauges” that provide a visual representation of speed, altitude, and charts, e.g., as a speedometer, altitude chart, and a terrain map. The populated templates, which may appear as gauges on a screen **170** of the remote controller **120**, can further be shared, e.g., via social media, and/or saved for later retrieval and use. For example, a user may share a gauge with another user by selecting a gauge (or a set of gauges) for export. Export can be initiated by clicking the appropriate export button, or a drag and drop of the gauge(s). A file with a predefined extension will be created at the desired location. The gauge to be selected and be structured with a runtime version of the gauge or can play the gauge back through software that can read the file extension.

Dampening Connection

[0066] FIGS. **8A** and **8B** show an example of a dampening connection, which can allow the connection between the gimbal **100** and the aerial vehicle **110** to have a small range of motion. The dampening connection can include a floating connection base **800**, a locking cylindrical shell **810**, four elastic pillars **820**, connection housing **830**, a four tapered locking blocks **840**, a fixed mount floor **850** with four slots **855**, and a fixed mount ceiling **860**. The locking cylindrical shell **810** can be attached to the connection housing **830**, and may be capable of being rotated, which can be used to lock the attachment portion **350** of the gimbal **100** into the connection housing **830**. The connection housing **830** is attached to the floating connection base **800**. The floating connection base **800** can be attached to the fixed mount ceiling **860** by the four elastic pillars **820**. The floating connection base **800** may have four tapered locking blocks **840** projecting out of it. Each of the four tapered locking blocks **840** may have a corresponding slot **855** into which it fits. The corresponding slots **855** may be bored into the fixed mount floor **850**.

[0067] Compared to a rigid mechanical connection, the dampening connection can help to dissipate high frequency vibrations in the gimbal **100** and to prevent, to some degree, the gimbal **100** from vibrating, for example, when the aerial vehicle **110** is operational. The dampening connection depicted in FIGS. **8A** and **8B** can be a mechanical connection between the gimbal **100** and the aerial vehicle **110**, but similar structures can be used to connect the gimbal **100** to other mount platforms, such as ground vehicle, an underwater vehicle, or a handheld grip. FIG. **8A** shows a vertical perspective (looking down) of the dampening connection, wherein the fixed mount ceiling **860** has been removed. FIG. **8A** shows a horizontal view of the dampening connection. Both FIG. **8A** and FIG. **8B** are simplified for illustrative purposes, and thus the shapes, relative sizes, and relative

positions of the components of the dampening connection are shown for ease of discussion purposes.

[0068] The dampening connection may comprise a floating connection base **800**, which is coupled to four elastic pillars **820**. The elastic pillars **820** may connect the floating connection base **800** to the connection ceiling **860**. Aside from the four elastic pillars **820**, the floating connection base **800** may not be rigidly connected to the other components of the aerial vehicle **110**, which allows it a small range of motion. The floating connection base **800** may be rigidly coupled to a connection housing **830**. The connection housing **830** may contain the mount connector **304** of the gimbal **100** and the electronic connector which connects the gimbal **100** and the aerial vehicle **110** may be enclosed in the connection housing **830**.

[0069] A locking cylindrical shell **810** may be connected to the connection housing **830**. The locking cylindrical shell **810** can rotate along its axis. The user can insert the end of the gimbal **100** into the connection housing **830** and turn the locking cylindrical shell **810** in order to lock the gimbal **100** to the connection housing **830**. When the gimbal **100** and the connection housing **830** are thus locked together, the gimbal **100**, the connection housing **830**, and the floating connection base **800** may all be rigidly connected together. A user can unlock the gimbal **100** from the connection housing **830** by twisting the locking cylindrical shell **810** in the opposite direction, which will allow the user to remove the gimbal **100** from the connection housing **830**.

[0070] When force is exerted on the gimbal **100** by the user in order to insert the mount connector **304** into the connection housing **830**, the floating connection base **800** may be pushed backwards (e.g., in FIGS. **8A** and **8B**, the force would be directed to the left). This may cause a deformation of the four elastic pillars **820** due to a shearing force, and the four tapered locking blocks **840** may be forced into the corresponding slots **855** on the fixed mount floor **850**. The elastic pillars **820** may be mechanically coupled to the floating connection base **800** and to the fixed mount ceiling **860**, and, in the absence of a shearing force, may hold the floating connection base **800** at an equilibrium position, relative to the fixed mount ceiling **860**, which may be rigidly mechanically coupled to the chassis of the aerial vehicle **110**. The fixed mount floor **820** may also be rigidly mechanically coupled to the chassis of the aerial vehicle **110**. In some embodiments, the fixed mount floor **820** and the fixed mount ceiling **860** are conjoined.

[0071] At equilibrium (e.g., when the user is not applying a force on the gimbal **100**), the four tapered locking blocks **840** may be held, by shear forces on the elastic pillars **820**, at a position that is not flush with the corresponding slots **855**. The gap between the tapered locking blocks **840** and their corresponding slots **855** can be small (e.g., 2-5 millimeters). In some embodiments, at equilibrium, the tapered locking blocks **840** rest outside the corresponding slots **855**. When a force pushes the tapered locking blocks **840** into the slots **855** on the fixed mount floor **850**, the floating connection base **830** may be locked in place, which may make it easier for the user to turn the locking cylindrical shell **810**. Once the user is no longer pushing on the gimbal **100**, the restoring shear force on the elastic pillars **820** may move the floating connection base **830** back into its equilibrium position. In this equilibrium position, the floating connection base **830** may have some freedom of movement, which may result in dampening oscillations on the gimbal **100** or the

aerial vehicle **110**. Thus, when connected to the aerial vehicle **110**, the gimbal **110** may “float” (e.g., is not rigidly coupled to the aerial vehicle **110**) during normal operation.

Additional Considerations

[0072] The disclosed configuration describes an electronic gimbal capable of being removably connected to multiple different mount platforms, such as aerial vehicles, ground vehicles, and handheld grips. The disclosed configuration further describes an electronic gimbal capable of removably connecting to multiple different cameras, and maintaining the orientation of a camera in space while the mount platform to which the gimbal is attached changes orientation. Moreover, the gimbal can contain an internal bus between the camera and the mount platform, which provides for communication. The gimbal can also be configured with motors that are not orthogonal which provides for a greater viewing angle for the camera.

[0073] Throughout this specification, plural instances may implement components, operations, or structures described as a single instance. Although individual operations of one or more methods are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated. Structures and functionality presented as separate components in example configurations may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single component may be implemented as separate components. These and other variations, modifications, additions, and improvements fall within the scope of the subject matter herein.

[0074] Certain embodiments are described herein as including logic or a number of components, modules, or mechanisms. Modules may constitute either software modules (e.g., code embodied on a machine-readable medium or in a transmission signal) or hardware modules. A hardware module is a tangible unit capable of performing certain operations and may be configured or arranged in a certain manner. In example embodiments, one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware modules of a computer system (e.g., a processor or a group of processors) may be configured by software (e.g., an application or application portion) as a hardware module that operates to perform certain operations as described herein.

[0075] In various embodiments, a hardware module may be implemented mechanically or electronically. For example, a hardware module may comprise dedicated circuitry or logic that is permanently configured (e.g., as a special-purpose processor, such as a field programmable gate array (FPGA) or an application-specific integrated circuit (ASIC)) to perform certain operations. A hardware module may also comprise programmable logic or circuitry (e.g., as encompassed within a general-purpose processor or other programmable processor) that is temporarily configured by software to perform certain operations. It will be appreciated that the decision to implement a hardware module mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) may be driven by cost and time considerations.

[0076] The various operations of example methods described herein may be performed, at least partially, by one

or more processors, that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented modules that operate to perform one or more operations or functions. The modules referred to herein may, in some example embodiments, comprise processor-implemented modules.

[0077] The one or more processors may also operate to support performance of the relevant operations in a “cloud computing” environment or as a “software as a service” (SaaS). For example, at least some of the operations may be performed by a group of computers (as examples of machines including processors), these operations being accessible via a network (e.g., the Internet) and via one or more appropriate interfaces (e.g., application program interfaces (APIs)).

[0078] The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the one or more processors or processor-implemented modules may be located in a single geographic location (e.g., within a home environment, an office environment, or a server farm). In other example embodiments, the one or more processors or processor-implemented modules may be distributed across a number of geographic locations.

[0079] Some portions of this specification are presented in terms of algorithms or symbolic representations of operations on data stored as bits or binary digital signals within a machine memory (e.g., a computer memory). These algorithms or symbolic representations are examples of techniques used by those of ordinary skill in the data processing arts to convey the substance of their work to others skilled in the art. As used herein, an “algorithm” is a self-consistent sequence of operations or similar processing leading to a desired result. In this context, algorithms and operations involve physical manipulation of physical quantities. Typically, but not necessarily, such quantities may take the form of electrical, magnetic, or optical signals capable of being stored, accessed, transferred, combined, compared, or otherwise manipulated by a machine. It is convenient at times, principally for reasons of common usage, to refer to such signals using words such as “data,” “content,” “bits,” “values,” “elements,” “symbols,” “characters,” “terms,” “numbers,” “numerals,” or the like. These words, however, are merely convenient labels and are to be associated with appropriate physical quantities.

[0080] Unless specifically stated otherwise, discussions herein using words such as “processing,” “computing,” “calculating,” “determining,” “presenting,” “displaying,” or the like may refer to actions or processes of a machine (e.g., a computer) that manipulates or transforms data represented as physical (e.g., electronic, magnetic, or optical) quantities within one or more memories (e.g., volatile memory, non-volatile memory, or a combination thereof), registers, or other machine components that receive, store, transmit, or display information.

[0081] As used herein any reference to “one embodiment” or “an embodiment” means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The

appearances of the phrase “in one embodiment” in various places in the specification are not necessarily all referring to the same embodiment.

[0082] Some embodiments may be described using the expression “coupled” and “connected” along with their derivatives. For example, some embodiments may be described using the term “coupled” to indicate that two or more elements are in direct physical or electrical contact. The term “coupled,” however, may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other. The embodiments are not limited in this context.

[0083] As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, “or” refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0084] In addition, use of the “a” or “an” are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

[0085] Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs for the disclosed gimbal and associated systems. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the disclosed embodiments are not limited to the precise construction and components disclosed herein. Various modifications, changes and variations, which will be apparent to those skilled in the art, may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope defined in the appended claims.

1. A stabilizing mounting system for a camera comprising:

- a handheld grip comprising:
 - a shaft;
 - a gimbal connection at an end of the shaft including a first securing mechanism and a first electrical interface;
 - a control button on the shaft, the control button when activated causing a control signal to be transmitted via the gimbal connection; and
- an electronic gimbal, comprising:
 - a grip connection including a second securing mechanism to removably secure to the first securing mechanism of the handheld grip and a second electrical interface to communicatively couple to the first electrical interface of the handheld grip;
 - a first motor connected to the grip connection, the first motor to apply a first torque to a first motor shaft to cause the first motor shaft to rotate about a first axis of rotation;

- a second motor connected to the first motor shaft, the second motor to apply a second torque to a second motor shaft to rotate the second motor shaft about a second axis of rotation;
 - a third motor connected to the second motor shaft, the third motor to apply a third torque to a third motor shaft to rotate the third motor about a third axis of rotation;
 - a camera connection including a third securing mechanism to removably secure a camera to the third motor shaft of the electronic gimbal, and the camera connection comprising a third electrical interface to communicatively couple the electronic gimbal to the camera; and
 - an internal data bus, wherein the bus communicatively connects the second electrical interface to the third electrical interface, the internal data bus to transfer the control signal from the handheld grip to the camera when the control button is activated to enable the control button on the handheld grip to control an action of the camera.
2. The stabilizing mounting system of claim 1, wherein the handheld grip further comprises:
- a battery to provide power to the handheld grip, the electronic gimbal, and the camera.
3. The stabilizing mounting system of claim 1, wherein the control signal when transmitted from the control button to the camera cause the camera to take a picture or begin recording video.
4. The stabilizing mount system of claim 1, wherein the handheld grip further comprises:
- a power button that when activated toggles a power state of the camera.
5. The stabilizing mount of claim 1, wherein the handheld grip further comprises:
- a light emitting diode to indicate a mode that the camera is operating in.
6. The stabilizing mount of claim 1, wherein at least one of the first motor, the second motor, and the third motor is configured as a fixed motor in a fixed motor mode and wherein at least one of the first motor, the second motor, and the third motor is configured as an unfixed motor in an unfixed motor mode, wherein the fixed motor operates to stabilize the camera at a fixed orientation about an axis of rotation corresponding to the fixed motor, and wherein the unfixed motor enables the camera to rotate about an axis of rotation corresponding to the unfixed motor in response to the movement of the handheld grip.
7. The stabilizing mount of claim 1, further comprising:
- a mode control button to switch a mode of at least one of the first motor, the second motor, and the third motor between the fixed motor mode and the unfixed motor mode.
8. The stabilizing mount of claim 1, wherein in a default operation mode, the first motor, the second motor, and the third motor are configured such that a motor corresponding to a yaw axis is in the unfixed mode, and motors corresponding to pitch and roll axes are in the fixed mode.
9. The stabilizing mount of claim 1, wherein,
- the first axis of rotation for the first motor shaft is orthogonal to the third axis of rotation of the second motor shaft; and

the second axis of rotation for the second motor shaft is orthogonal to the third axis of rotation of the third motor shaft.

10. The stabilizing mount of claim **9**, wherein the first axis of rotation for the first motor shaft is not orthogonal to the second axis of rotation of the second motor shaft.

11. The stabilizing mount of claim **10**, wherein the angle between the axis of rotation of the second motor shaft and an axis orthogonal to both the axis of rotation for the first motor shaft and the axis of rotation for the third motor shaft is less than 30 degrees.

12. The electronic gimbal of claim **1**, wherein the camera connection comprises:

a camera frame mount connected to the third motor shaft; and

a camera frame removably connected to the camera frame mount and the camera, wherein the camera frame includes an electronic connection between the camera and the electronic camera connection of the electronic gimbal.

13. The electronic gimbal of claim **1**, wherein the control signal when transmitted from the control button to the camera causes the camera to store a meta data tag in association with a current time in a video being recorded by the camera.

14. A stabilizing mounting system for a camera comprising:

a handheld grip comprising:

a shaft;

a gimbal connecting means for connecting to a gimbal, the gimbal connecting means comprising a first securing means for mechanically securing to the gimbal and a first electrical interfacing means for electrically interfacing to the gimbal;

a control means on the shaft for causing a control signal to be transmitted via the gimbal connecting means; and

an electronic gimbal, comprising:

a grip connecting means for connecting to the handheld grip, the grip connecting means including a second securing means for removably securing to the first securing means of the handheld grip and a second electrical interfacing means for communicatively interfacing to the first electrical interfacing means of the handheld grip;

a first rotating means connected to the grip connecting means, the first rotating means for applying a first torque to a first motor shaft to cause the first motor shaft to rotate about a first axis of rotation;

a second rotating means connected to the first motor shaft, the second rotating means for applying a second torque to a second motor shaft to rotate the second motor shaft about a second axis of rotation;

a third rotating means connected to the second motor shaft, the third rotating means for applying a third

torque to a third motor shaft to rotate the third motor about a third axis of rotation;

a camera connecting means for connecting to a camera, the camera connecting means including a third securing means to removably secure the camera to the third motor shaft, and the camera connecting means comprising a third electrical interfacing means for communicatively coupling the electronic gimbal to the camera; and

a data transfer means for communicatively connecting the second electrical interfacing means to the third electrical interfacing means, the data transfer means for transferring the control signal from the handheld grip to the camera when the control means is activated to enable the control means on the handheld grip to control an action of the camera.

15. The stabilizing mounting system of claim **14**, wherein the handheld grip further comprises:

a power power for providing power to the handheld grip, the electronic gimbal, and the camera.

16. The stabilizing mounting system of claim **14**, wherein the control signal when transmitted from the control means to the camera cause the camera to take a picture or begin recording video.

17. The stabilizing mount system of claim **14**, wherein the handheld grip further comprises:

a power control means for toggling a power state of the camera when activated.

18. The stabilizing mount of claim **14**, wherein the handheld grip further comprises:

a light emitting means for indicating a mode that the camera is operating in.

19. The stabilizing mount of claim **14**, wherein at least one of the first rotating means, the second rotating means, and the third rotating means is configured as a fixed rotating means in a fixed mode and wherein at least one of the first rotating means, the second rotating means, and the third rotating means is configured as an unfixed rotating means in an unfixed mode, wherein the fixed rotating means operates to stabilize the camera at a fixed orientation about an axis of rotation corresponding to the fixed rotating means, and wherein the unfixed rotating means enables the camera to rotate about an axis of rotation corresponding to the unfixed rotating means in response to the movement of the handheld grip.

20. The stabilizing mount of claim **14**, further comprising: a mode control means for switching a mode of at least one of the first rotating means, the second rotating means, and the third rotating means between the fixed mode and the unfixed mode.

21. The stabilizing mount of claim **14**, wherein in a default operation mode, the first rotating means, the second rotating means, and the third rotating means are configured such that a rotating means corresponding to a yaw axis is in the unfixed mode, and rotating means corresponding to pitch and roll axes are in the fixed mode.

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