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(54) **Title:** AERIAL VEHICLE

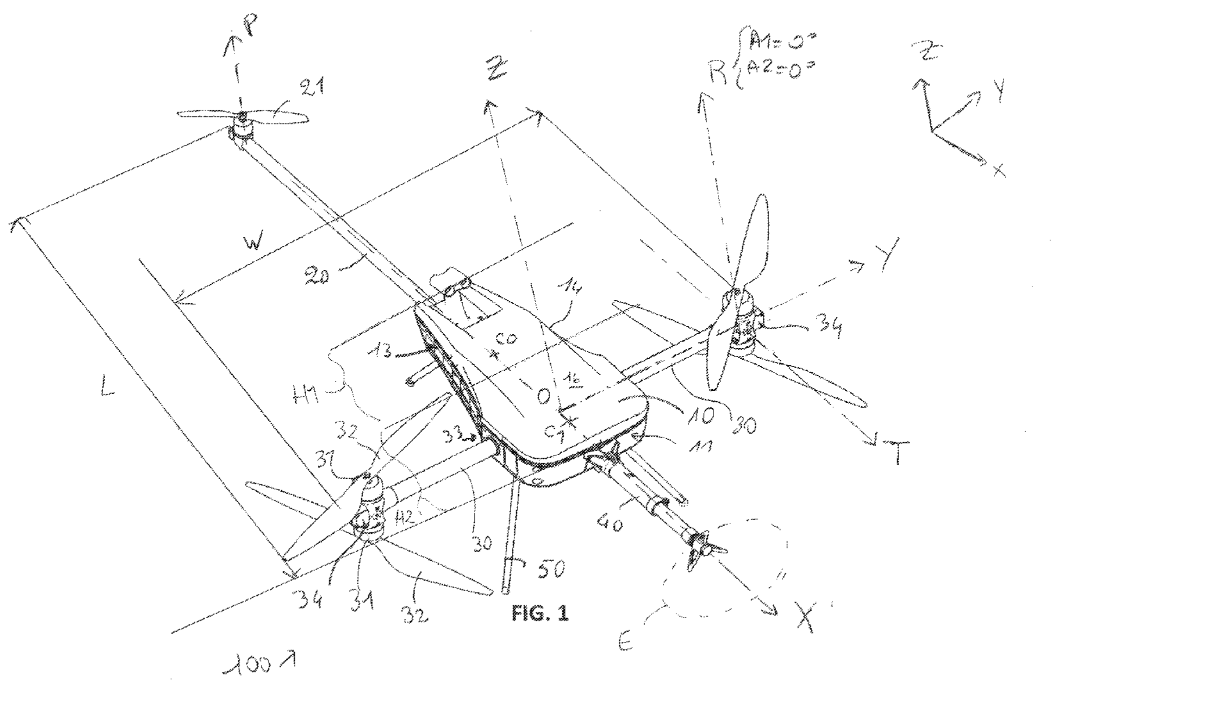

FIG. 1

(57) **Abstract:** The invention concerns an aerial vehicle (100) comprising: - a central frame (10), - a tail extending from the central frame (10) along a first axis (X), - at least two arms (30) extending from the central frame (10) and able to rotate around at least one second axis (Y), the angular position of the arm (30) with respect to the second axis (Y) defining an arm rotation angle (A1), * wherein said tail (20) is equipped with a tail rotor (21) spinning around a tail rotor axis (P), said tail rotor axis (P) being parallel to a third (Z) axis which is orthogonal to both first axis (X) and second axis (Y), *wherein the free end of each arm (30)is equipped with two thrust motors (31) controlling the spinning in opposite direction of two coaxial rotors (32), and * wherein the two coaxial rotors (32) define a double rotor axis (R) and can tilt together with respect to another tilting axis (T), said tilting axis (T) being perpendicular to the second axis (Y), the angular position of the double rotor (32) with respect to the double rotor axis (R) defining a double rotor tilting angle (A 2).

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Aerial vehicle

[0001] The present invention concerns an aerial vehicle, and in particular an unmanned aerial vehicle (UAV), and in particular a Micro Aerial Vehicle (MAVs) commonly known as a drone, which is an aircraft without a human pilot aboard.

[0002] While they originated mostly in military applications, the use of unmanned aerial vehicle has rapidly expanded to commercial, scientific, recreational, agricultural, and other applications, such as for instance policing, peacekeeping, and surveillance, but also product deliveries, aerial photography, agriculture, and drone racing.

[0003] Also, in the recent times, have been developed omnidirectional drones for physical interaction. A normal drone will need to be tilted to exert forces on the environment the environment, which is an unstable configuration. A small wind gust or any disturbance could rapidly lead to a crash of a normal drone. Therefore, current use for MAVs is most of the time limited to remote sensing tasks.

[0004] The main problem lies in the fact that currently existing MAVs cannot be robustly controlled when in physical contact with the environment. In recent years, fully actuated MAVs have started to gain attention as promising platforms for reliable aerial physical interaction. Equipped with an aerial manipulator, these platforms have the potential to achieve a high degree of versatility, robustness and stability.

[0005] Notably, there is a need not yet correctly fulfilled for omnidirectional drones or omnidirectional aerial vehicles that can interact with the environment, including applying force, while also staying in a stable position. Such type of omnidirectional aerial vehicles could be used for instance to do inspections of infrastructures, or to do painting or cleaning on high-rise buildings or any other difficult to reach places. Physical interaction with drones would be also useful for many other applications, notably industrial applications, such as non-destructive testing of bridges, tunnels, silos, or pipes, or other concrete structures, also for inspection of storage tanks or cavities .....that can further more be implemented by the human being remotely from the inspection site.

Description of related art

[0006] Document US2018120196A1 presents a non-destructive inspection ("NDI") system that includes an unmanned aerial vehicle ("UAV") comprising a body structure. The body structure comprises one or more support structures with a releasable end structure; and one or more non-destructive inspection sensors integrated to a respective releasable end structure. This system also includes a location tracking system. A manipulator arm that can comprises a gripper allows implementation of specific tasks. The propulsion system is not detailed.

[0007] Document US2017015412A1 concerns a rotor-based remote flying vehicle platform which comprises a central frame with a control center that is configured to control motors mounted to the vehicle platform. Four arms are connected to the central frame and extend outward. A unique motor is mounted on the distal end of each arm and is controlled by a tilt actuator capable of tilting the motor according to different configurations. This configuration becomes highly inefficient when interacting with environnement.

[0008] Document ES2614994 relates to an aircraft with a stationary flight capability comprising a contact device. More precisely, in this arrangement, there is a central section to which are attached two segments rigidly joined to each other, with a counterweight and a gripper. For propulsion, eight engines are used, equipped with propellers that are fixedly mounted with a predetermined inclination at an angle of between 0 ° and 45 ° on the horizontal plane.This configuration requires additional actuators to orient an end-effector in any orientation because it cannot tilt its body completely. Furthermore, it is not agile in changing the applied force and moment and requires a high thrust to weight ratio for stable control.

[0009] Document US2016325829 concerns a multi-rotor type unmanned aerial vehicle includes: a main body including the battery module and the control module; a plurality of frames (four main frames and four auxiliary frames) connected to a side surface of the main body and extending therefrom; a first motor connected to a distal end of each of the frames; and a drive unit connected to the first motor, wherein the drive unit includes a rotary frame and a stationary frame each having a circular shape and connected to each other in the form of a gyroscope, a second motor supported at the center of the rotatable frame, and a propeller connected to the second motor, and a vector of thrust generated by rotation of the propeller is variable according to rotation of the first and second motors. This arrangement having a lot of motors to be controlled, the driving of this aerial vehicle is quite complex and sensitive.

[0010] Document US2013105620 presents a system including a first coaxial rotor spaced from an aircraft body and a second coaxial rotor spaced from the aircraft body and opposite the first coaxial rotor; the first coaxial rotor having a first top propeller aligned with a first bottom propeller along a first rotational axis; the second coaxial rotor having a second top propeller aligned with a second bottom propeller along a second rotational axis. A gyroscopic moment to maintain pitch stability is controlled by modulating the first and second top propellers having a different angular speed or different torque from the first and second bottom propellers and tilting the first and second coaxial rotors towards the central axis with a common tilt angle and a common tilt rate.

[0011] One of the main problems lies in the unstable dynamics of aerial vehicles in contact with the environment and equipped with tools and sensors so as to perform as robots, which complicates the control performance.

[0012] In view of above considerations, there exist a need to propose an aerial vehicle that overcomes at least some of the drawbacks of the existing aerial vehicles.

[0013] There also exists a need to propose an improved aerial vehicle with respect of the existing aerial vehicles.

[0014] Also, some embodiments of the present invention aims to provide an aerial vehicle with advanced manipulation capabilities that can be employed in various tasks that require interaction with the environment, such as contact-based inspection, cleaning and lightweight maintenance.

Brief summary of the invention

[0015] According to the invention, these aims are achieved by means of an aerial vehicle comprising:

- a central frame
- a tail extending from the central frame along a first axis (X), ,
- at least two arms extending from the central frame and able to rotate around at least one second axis (Y), the angular position of the arm with respect to the second axis (Y) defining an arm rotation angle (A1),

* wherein said tail is equipped with a tail rotor spinning around a tail rotor axis, said tail rotor axis being parallel to a third (Z) axis which is orthogonal to both first axis (X) and second axis (Y),

*wherein each arm is equipped with two thrust motors controlling the spinning in opposite direction of two coaxial rotors, and

* wherein the two coaxial rotors define a double rotor axis and can tilt together with respect to another tilting axis, said tilting axis being perpendicular to the second axis, the angular position of the double rotor with respect to the double rotor axis defining a double rotor tilting angle.

[0016] The proposed aerial vehicle is able to exert forces and torques in all directions with high capability of the system to control position and orientation independently. It means the aerial vehicle can take any orientation (including for instance, level position, vertical position or inclined position of the central frame of the aerial vehicle), and stay stabilised in that orientation, with the possibility of moving in that orientation and have possibly contact with a surface, with or without exerting a force on that surface.

[0017] Therefore, the proposed aerial vehicle is capable for physical interaction with environment, including for instance contact-based inspection.

Brief Description of the Drawings

[0018]The invention will be better understood with the aid of the description of an embodiment given by way of example and illustrated by the figures, in which:

- Figure 1 shows a perspective view of an embodiment of an aerial vehicle according to the present invention, with the arm rotation angle and the double rotor tilting angle at 0°, that can be an initial or a reference position for the aerial vehicle,

- Figure 2 shows a projection view of the aerial vehicle in the reference position of Figure 1, from the front, namely from ahead the front face of the central frame,

- Figure 3 shows a projection view of the aerial vehicle in the reference position of Figure 1, from the rear, namely from behind the tail,

- Figure 4 shows a projection view of the aerial vehicle in the reference position of Figure 1, from the right side, namely from ahead of the end part of the right arm,

- Figure 5 shows a section view of the aerial vehicle in the reference position of Figure 1, according to the horizontal plane X, Y, along the line V-V of figure 4,

- Figures 6 and 7 are similar views respectively of figures 2 and 4 for the embodiment of the aerial vehicle of figures 1 to 5, in another position with the arm rotation angle at 30° and the double rotor tilting angle at 0°,

- Figures 8 and 9 are similar views respectively of figures 2 and 4 for the embodiment of the aerial vehicle of figures 1 to 5, in another position with the arm rotation angle at 90° and the double rotor tilting angle at 0°,

- Figure 10 is a similar view as figure 2 for the embodiment of the aerial vehicle of figures 1 to 5, in another position with the arm rotation angle at 0° and the double rotor tilting angle at 15°, and

- Figures 11 and 12 are perspective views of the tail rotor in two different positions, for a variant implementation of the tail rotor.

Detailed Description of possible embodiments of the Invention

The central frame 10 is a platform in the form of a flat box, elongated along and parallel to the first X axis, and parallel to the second axis Y. The central frame 10 contains on-board notably the electronical and control parts of the aerial vehicle 100. The central frame 10 defines a front face 11 for reversible attachment with equipment. The central frame 10 defines a rear face 12 from which extends a tail 20 equipped with a tail rotor 21. The central frame 10 also defines two lateral faces 13, 14 from each of which extends one arm 30 (as illustrated) or several arms (situation not shown). The central frame 10 also defines a top face 16 and a bottom face 17.Also, in a variant (not shown), the aerial vehicle 100 further comprises bumpers forming extension at the front part of the central frame 10

[0019] Unlike classic aerial vehicles where the arms 30 are fixed with respect to the frame, according to the invention, the arms are able to tilt or to rotate around at least one axis, which is named the second axis in the present text. Also, the angular position of the arm 30 around this second axis, with respect to the third axis Z, defines an arm rotation angle (A1) (see figure 1). In the illustrated embodiment, this second axis is coaxial with the arm's direction (Y axis) to that the orientation of the arms 30 with respect to the central frame 10 is fixed. The arm rotation angle A1 is controlled by a first actuator 33. In figure 5, this actuator 33 is visible within the central frame 10.

[0020] In figures 1 to 5, this arm rotation angle A1 is 0°; in figures 6 and 7, this arm rotation angle A1 is +30°; in figures 8 and 9, this arm rotation angle A1 is +90°.
Preferably, said arm rotation angle A1 is contained within the range -180° to + 180° so as to take any angular position around the second axis. In a possible embodiment, said arm rotation angle A1 can take any angular value in the 0° to 360° range, with a possible continuous rotation by using a slip ring that avoids the cable twisting.

[0021] Also, each arm 30 is equipped with two thrust motors 31 controlling the spinning in opposite direction of two coaxial rotors 32. In the illustrated embodiment, the free end of each arm 30 is equipped with said two thrust motors 31. In another possible arrangement, not shown, the two double rotors 32 are located at the end portion of the arm 30, which can be distant of the free end of said two arms 30. These thrust motors 31 allows the spinning of the double rotors 32 to generate lift force for the aerial vehicle 100.
Therefore, according to the invention, when considering each one of the two arms 30, his two rotors 32 (top rotor and bottom rotor of the same arm 30) are spinning in opposite directions.

[0022] Also, the two coaxial rotors 32 define a double rotor axis R. The thrust motors 31 rotate around this double rotor axis R, in opposite directions, which also make the two coaxial rotors 32 rotate around this double rotor axis R, in opposite directions. For each pair of rotors 32, the the respective angular position of the rotors 32 is not determined, and not defined (can be any relative rotate around this double rotor axis R, in opposite directions). The two coaxial rotors 32 can tilt together with

respect to another tilting axis T (see figure 1), . Said tilting axis T is perpendicular to the second axis (Y axis). The angular position of the double rotor 32 or double rotor axis R with respect to the plane orthogonal to the second axis, is defining a double rotor tilting angle A2. In the illustrated embodiment, this second axis is coaxial with the arm's direction (Y axis) so that the double rotor tilting angle A2 is measured with respect to the plane (Z, T). In figures 1 to 9, this double rotor tilting angle A2 is 0°; in Figure 10, , this double rotor tilting angle A2 is +15° for both double rotors 32 which double rotor tilting angle A2 are parallel. In other words, the two double rotors 32 tilt together the same amount with respect to the third axis Z, or more precisely with respect to a plane parallel to the third axis Z and secant with the tilting axis T..
Preferably, said double rotor tilting angle (A2) is contained within the range -25° to + 25°. In a possible embodiment, said double rotor tilting angle (A2) is contained within the range -15° to + 15°. The arm double rotor tilting angle A2 is controlled by a second actuator 34. In figures 1 and 5, this second actuator 34 is visible at the tip of the arm 30.

[0023] This way, changing the generated force direction or thrust vectoring, which provides omni-directionality, is possible notably through the tilting (rotation) of the arms 30 around at least one axis, named the second axis in the present text (Y axis in the figure), with respect to the central frame 10.

[0024] In the illustrated embodiment, said second axis (Y) is coaxial with the corresponding arm 30

[0025] In the illustrated embodiment, the aerial vehicle 100 comprises two coaxial arms 30, extending from opposite faces (two lateral faces 13 and 14) of said central frame, along said second axis (Y). Therefore, these two arms 30 are parallel and coaxial to each other.

[0026] In some other embodiments (not shown), the aerial vehicle 100 comprises more than two coaxial arms, namely four, six or eight arms, extending symmetrically from opposite faces of said central frame.

[0027] The tail 20 extends along the first axis X from the rear of the central frame 10, according to a relative long dimension, for instance 80 cm from the central point O. This long tail provides a good lever arm which is efficient for rapidly change the orientation of the aerial vehicle 100, namely to change the pitch angle of the central frame 10, notably when the rotor is decelerating or inversely accelerating. The tail 21 is equipped with a tail rotor 21 spinning around a tail rotor axis P, said tail rotor axis P being parallel to a third axis Z.

[0028] In a preferred embodiment, the direction of rotation of the tail rotor 21 can be inverted.

[0029] In that respect, the profile of the two airfoils of the tail rotor 21 is double symmetric, meaning symmetric with two planes of symmetry, a first plane of symmetry between the leading edge and the trailing edge of the foil, and a second plane of symmetry being the chord line. Such a geometry leads to a continuous identical section of the tail rotor 21 along the length of the foils: the upper camber being the same than the lower camber along the length of the two foils of the tail rotor 21, and the leading edge and the trailing edge having the same shape along the length of the two foils of the tail rotor. Thus, the tail rotor 21 has the same dynamics independent of the direction of rotation. In that configuration, the tail rotor 21 is in one piece, the two airfoils being not movable one with respect to the other.

[0030] In the illustrated embodiment, said arms 30 and said tail 20 define a main plane (X, Y) for said aerial vehicle 100, said central frame 10 being secant with said main plane (X, Y). Said main plane (X, Y) is also defined by the first axis (X) and the second axis (Y) which are orthogonal to each other. Also, these first axis (X) and the second axis (Y) are secant to a central point (O) which is contained within the central frame 10. A third axis Z defines with the first axis (X) and the second axis (Y) an orthogonal geometrical system (see figure 1). Said first axis (X), said second axis (y) and said third axis (Z) are therefore secant into said central point (O).

[0031] The control of the change of rotation direction for the tail rotor 21 with a double symmetric shape of the two airfoils of the tail rotor 21 provides in an efficient way the inversion of the lift direction for the aerial vehicle 100.

[0032] The decoupling of attitude and position makes it possible to control the position of any equipment mounted on the central frame 10 very precisely.

[0033] As can be seen in Figure 5, a clutch element 15 having a tube shape with a lateral opening at of its end for cable passage, connects the actuator 33 and the arm 30. As a possible embodiment, this clutch element 15 is designed (shape and material) so as to provide a relative mechanical flexibility : in that situation, the mechanical stress applied in the arm 30 is not transmitted to the actuator 35, except for the one rotation around the arm axis which is controlled by the actuator 35. In case of impact on the arm 30, such a flexible clutch element 15 prevents some serious damage of the arm 30, or at least of the actuator 33 while also making the rotation of the arm 30 possible. Such a clutch element 15 also compensates for small misalignment between actuator 35 axis and arm 30 axis. In that respect, the clutch element 15 can tolerate a radial, axial and angular misalignment between the actuator and the arm 30 but is relative stiff in torsion, which is important for precise control.

[0034] In a variant implementation for the tail rotor 21', which is shown on figures 11 and 12, the two airfoils or blades 22' of the tail rotor 21' have opposite inclination, which means opposite angle of attack and are moveable with respect to each other. Among the possible positions for the orientation of the two blades 22' which have a continuous motion, can be defined the following extreme or remarkable positions:
* in a neutral angular position (not shown), the two blades 22' have an horizontal orientation (angle of attack =0°) and are parallel to each other;
* in a first extreme position visible on figure 11, a first one of the two blades (right side of the figure 11) is orientated with an angle $+\alpha$ with respect to the horizontal plane (X, Y) and the second one of the two blades

(left side of the figure 11) is orientated with an angle -α with respect to the horizontal plane (X, Y); and

* in a second extreme position visible on figure 12, the first one of the two blades 22' (right side of the figure 12) is orientated with an angle -α with respect to the horizontal plane (X, Y) and the second one of the two blades (left side of the figure 12) is orientated with an angle +α with respect to the horizontal plane (X, Y). Also, in that variant implementation of the tail rotor 21, there is one unique direction of rotation for the tail rotor 21. In that situation, the change of orientation of the blades 22', provides the inversion of the lift direction for the aerial vehicle 100.

[0035] An elongated member 40 is visible on the figures 1 to 10, at the front face 11 of the central frame. In this illustrated embodiment, the elongated member 40 is telescopic and can receive some piece of equipment through its end fixing part. Preferably, this elongated member 40 is compliant.

[0036] In another embodiment, not shown, the front face 11 of the central frame 10 has no elongated member but the central frame 10 is directly equipped with supporting means for removably attaching an equipment.

[0037] A lot of possible equipment can be mounted onto the front face 11 of the central frame 10. Among the possibilities, the following pieces of equipement can be, taken alone or in combination, as follows : manipulator, sensor, nozzle....

As non-limiting examples of manipulator, there are gripper, spray nozzle, driller.......

As non-limiting examples of sensor, there are profometer (see below), Eddy current profometer, ultrasonic thickness measurement gauge, ground penetration radar, potential field mapping sensor, camera, thermal camera, ...

[0038] Within the central frame, among other things, there are the following pieces of gear, forming on-board sensors:

- in all cases, an Inertial Measurement Unit IMU: this electronic device measures and reports a body's specific force, angular rate, and the magnetic field surroundings the body, using a combination of accelerometers, gyroscopes, and magnetometers;
- preferably, a Laser scanner (such as a 3D LiDar), namely a sensor that combines controlled steering of laser beams with a laser rangefinder. By taking a distance measurement at every direction the scanner rapidly captures the surface shape of the environment, buildings and structures. The sensor is used to create 3D map of the surrounding environment with a good accuracy (±3cm error);
- preferably, Cameras: Up to 10 cameras can be installed on the drone to create a 360 degree field of view coverage;
- preferably, a GNSS (Global Navigation Satellite System): An electronic device forming a GPS system that uses satellites to provide autonomous geo-spatial positioning. It allows small electronic receivers to determine their location (longitude, latitude, and altitude/elevation) to high precision (within a few metres) using time signals transmitted along a line of sight by radio from satellites; and
- (in some case) a barometer, namely an electronic device that measures the air pressure, in order to help controlling the altitude (the height) of the aerial vehicle 100.

[0039] The aerial vehicle 100 can be powered with a battery or from power coming over a tether.

[0040] The sensor data can be synchronized in time, namely taking the measure at the same moment(s), which allows to collect the date in a more accurate way. In another data collection mode, the sensor data can also be measured and collected at different moments between them but with accurate known timing with respect to a “wall clock”. Data from these sensors are fused using sensor fusion algorithms running on the onboard computer. The onboard computer placed also within the central frame generate actuators command signals to control the drone behavior.

[0041] Preferably, as visible on Figure 1, when the aerial vehicle 100 has no equipment, the center of mass C0 of the aerial vehicle 100 is placed within the central frame 10, and on particular within the half portion of the central frame 10 which is the closest to the tail 20 (Rear half portion H1 of the central frame).

[0042] Also, when the aerial vehicle 100 has an equipment (shown on figure 1 with zone E), the center of mass C1 is placed preferably within the central frame 10 or in front of the central frame 10, and in particular within the half portion H2 (shown on figure 1) of the central frame 10 which contains the front face 11 of the central frame 10 (Front half portion H2 of the central frame).
For instance the equipment is attached to the central frame 10 through supporting means that can removeably attach the equipment to the central frame 10. On figures 1 to 10, this supporting means is the telescopic elongated member 40. On Figure 1, the equipment is represented only by a identified zone E at the tip of the elongated member 40.

[0043] Also, preferably, as visible on Figure 1, the distance between the tail rotor 21 up to the front face 11 of the central frame (Length L) is larger than or equal to the distance between the two double rotors 32 (width W). This general geometrical relation provides a long tail 20 with respect of the size of the aerial vehicle 100, which gives rise to an efficient lever arm effect for the tail when changing the pitch by inverting the rotation direction of the tail rotor 21. In a possible embodiment, the length L is about 80cm. the width W is about 70 cm, while using a tail rotor of about 20 cm and main propellers of the double rotors 32 of the arms 30 of about 40 cm. In other possible configurations, not shown, the distance between the tail rotor 21 up to the front face 11 of the central frame 10 (Length L) is larger than or equal to the distance between the two double rotors 32 (width W).

[0044] In some embodiments, including the embodiment shown in figures 1 to 12, the aerial vehicle 100 comprises only one tail 20 extending from the central frame 10, this sole tail 20 being equipped with the only and sole tail rotor 21. Also, such an aerial vehicle 100 comprises only and exactly two arms 30, the latter being each able to tilt or to rotate with respect to the central frame 10, being aligned and being each equipped with said two rotors. Consequently, in this configuration the aerial vehicle 100 forms a aerial vehicle having a general T-shape, where the leg of the T is formed by the tail and the two branches of the upper part of the T are formed by the two arms 30. It means that the tail 20 is orthogonal to the two arms 30. Also, in this configuration, according to a possible variant corresponding to the aerial vehicle 100 shown in figures 1 to 12, the tail 20 and the two arms 30 are coplanar.

[0045] As an example of possible application of the aerial vehicle 100 of the invention, is now presented the non-destructive inspection of the reinforcement bars embedded in concrete. For such analysis, a profometer is mounted at the front face of the central frame as the only one element of equipment or one of the pieces of equipment of the aerial vehicle 100. Such a profometer is an instrument for detecting location, size of reinforcement in concrete cover also with thickness of concrete cover. This instrument is also known as rebar locator or a cover meter This is a small, versatile, portable and handy instrument which is normally used to locate the reinforcement via a display, notably an LCD display. In that case, the guiding or controlled navigation, including a possible predefined route, of the aerial vehicle 100 allows to have a contact point between the profometer and the surface of the structure to be controlled. This contact point (with or without application of a force applied by the profometer onto the surface) is moreover maintained while moving the aerial vehicle 100 and /or for each contact points formed by inspection predefined points where the control and/or measurement is to be implemented.

[0046] More generally, inspection of infrastructure, which is a continuous process, can be facilitated with the use of such an aerial vehicle 100. Moreover, sometimes, visual inspection isn't enough and an in-depth inspection is required where sensor placement on the structure is needed . In some situation, an internal structure of the pipe needs to be checked using scaffoldings, having people hanging on ropes or using cranes, which is risky and expensive. With the solution of the present invention, are provided omnidirectional drones that can interact with the environment. In an embodiment, the aerial vehicle 100 is equipped with a manipulator and can extend its front elongated member, place a sensor in front of or against (in contact with) the wall and get the measurements needed from the sensor and thus be helpful for inspection tasks. In that application of the aerial vehicle 100, this will help do away with temporary structure of scaffolding and having workers hanging on from ropes or using cranes.

[0047] As another example of possible application of the aerial vehicle 100 of the invention, for painting surfaces including drawing patterns on both planar and 3D surfaces. In that example, not shown on the drawing, an arm (or an elongated element) plus a spray nozzle are mounted at the front face 11 of the central frame 10 as elements of equipment of the aerial vehicle 100. In one embodiment, the spray nozzle is connected to a first end of a pipe which other end is mounted on a paint reservoir equipped with an air compressor, so that compressed air pushes the paint along a pipe. Also, a valve is mounted next to the nozzle on the pipe to control the flow of paint. Furthermore, through a system of valves and pipes, mixing multiple colors is possible.
With such an equipment, the aerial vehicle 100 according to the present invention is capable of painting surfaces and can draw patterns on both planar and 3D surfaces.

[0048] According to some embodiments, the aerial vehicle 100 interact with a surface while flying with the central frame 10 being orientated with any orientation, namely vertically, or being orientated horizontally, or being inclined (orientation of the plane (X, Y) between horizontal and vertical orientation.

[0049] According to some embodiments, the aerial vehicle 100 can fly 90 degrees vertically and tilt horizontal, and do also upside down flights. Such features are coming to the market for the first time. The ability to interact with the environment in unique

[0050] According to some embodiments, the aerial vehicle 100 can correct disturbance, be in a stable position and apply force on the environment. Also, the aerial vehicle 100 can have compliance to handle collisions and impacts

[0051] According to an embodiment, the aerial vehicle 100 further comprises at least three legs 50 allowing for support of the aerial vehicle 100 on any support such as the floor, said legs 50 forming in particular a tripod or a three-legged stand. In the embodiment shown in the figures (see figures 1 to 4 and 6 to 9), three legs 50 are mounted to the central frame 10, from the bottom face 17, with a compliant (flexible) mount 51, so as to be able to absorb harsh landings.

[0052] According to some embodiments of the invention, is therefore provided an aerial vehicle 100 that is capable of omnidirectional flight and that carries a manipulator which can exert forces and torques in all directions, including a compliant manipulator or even a passively compliant manipulator.

[0053] In some embodiments, the aerial vehicle 100 can furthermore continuously maintain a target within the sensor field of view or can follow a complex structure.

[0054] With an aerial vehicle 100 according to some embodiments of the invention, this improves the possibilities of control and planning for aerial robots and therefore elevates the versatility and relevance of aerial robots to many industrial and scientific applications.

[0055] In some cases of the prior art aerial vehicle, the presence of internal forces within the aerial vehicle reduces the efficiency of the aerial vehicle as a whole system. With an aerial vehicle 100 according to some embodiments of the invention, the configuration reduces or even deletes internal forces within the aerial vehicle.

[0056] One or several of the following flight mode is (are) possible with the aerial vehicle 100 according to the invention:
- Manual mode: The most basic flight mode of the system is manual control by a pilot. 3D force command, heading angle and pitch tilting angles are transmitted using radio controller by a pilot.
- Fixed distance to wall: In this flight mode, fixed distance to wall can be maintained while a pilot commands lateral and vertical translation along the wall. Onboard sensors are used to measure distance to wall and onboard computer algorithm generate actuator command signal to maintain the distance to wall.
- Autonomous mode: In this mode, the drone using onboard and/or offboard sensors and computers can execute a predefined mission navigating in the environment and avoiding obstacles. Example of missions can be: inspection of predefined points or spray painting a desired figure or pattern.

List of reference signs used in the figures

X	First axis
Y	Second axis
Z	Third axis
R	Double rotor axis
T	Tilting axis
P	Tail rotor axis
A1	Arm rotation angle
A2	Double rotor tilting angle
O	Central point
W	Width of the aerial vehicle
L	Length of the aerial vehicle
E	Zone for equipment
H1	Rear half portion of the central frame
H2	Front half portion of the central frame
C0	Center of mass of the aerial vehicle without equipment
C1	Center of mass of the aerial vehicle with equipment
100	Aerial vehicle
10	Central frame
11	Front face
12	rear face
13	Lateral face
14	Lateral face
15	Clutch element
16	Top face
17	Bottom face
20	Tail
21	Tail rotor
21’	Tail rotor (alternative)
22’	Symmetric blade
α	Orientation angle of the blade
30	Arm
31	Thrust motor
32	Rotor

33	First actuator
34	Second actuator
40	Elongated member
50	Leg
51	Compliant mount

Claims

1. Aerial vehicle (100) comprising:

- a central frame (10)
- a tail extending from the central frame (10) along a first axis (X), ,
- at least two arms (30) extending from the central frame (10) and able to rotate around at least one second axis (Y), the angular position of the arm (30) with respect to the second axis (Y) defining an arm rotation angle (A1),

* wherein said tail (20) is equipped with a tail rotor (21) spinning around a tail rotor axis (P), said tail rotor axis (P) being parallel to a third (Z) axis which is orthogonal to both first axis (X) and second axis (Y),
*wherein each arm (30)is equipped with two thrust motors (31) controlling the spinning in opposite direction of two coaxial rotors (32), and
* wherein the two coaxial rotors (32) define a double rotor axis (R) and can tilt together with respect to another tilting axis (T), said tilting axis (T) being perpendicular to the second axis (Y), the angular position of the double rotor (32) with respect to the double rotor axis (R) defining a double rotor tilting angle (A2).

2. Aerial vehicle (100) according to claim 1, wherein said second axis (Y) is coaxial with the corresponding arm (30).

3. Aerial vehicle (100) according to claim 1 or 2, wherein said arms (30) and said tail define a main plane (X, Y) for said aerial vehicle (100), said central frame being secant with said main plane (X, Y).

4. Aerial vehicle (100) according to any of claims 1 to 3, wherein aid first axis (X), said second axis (y) and said third axis (Z) are secant into a central point (O)

5. Aerial vehicle (100) according to preceding claim, wherein said central point (O) is contained within the central frame (10).

6. Aerial vehicle (100) according to any of claims 1 to 5, wherein wherein said vehicle comprises two coaxial arms (30), extending from opposite faces of said central frame, along said second axis (Y).

7. Aerial vehicle (100) according to any of claims 1 to 6, wherein said double rotor tilting angle (A2) is contained within the range -25° to + 25°.

8. Aerial vehicle (100) according to any of claims 1 to 7, wherein said arm rotation angle (A1) can take any value within the range -180° to +180° with respect to the third axis (Z)

9. Aerial vehicle (100) according to any of claims 1 to 8, wherein the direction of rotation of the tail rotor can be inverted.

10. Aerial vehicle (100) according to preceding claim, wherein the tail rotor has two symmetric airfoils.

11. Aerial vehicle (100) according to any of claims 1 to 10, wherein the airfoils of the tail rotor have opposite inclination and wherein the direction of rotation of the tail rotor is unique.

12. Aerial vehicle (100) according to any of claims 1 to 11, wherein the front face of the central frame is equipped with supporting means for removably attaching an equipment

13. Aerial vehicle (100) according to preceding claim, wherein said equipment comprising on of the following : manipulator, sensor, nozzle…

14. Aerial vehicle (100) according to any of claims 1 to 13, wherein the center of mass (C0) of the aerial vehicle (100) is placed within the central frame (10), and on particular within the half portion (H1) of the central frame (10) which is the closest to the tail (20).

15. Aerial vehicle (100) according to any of claims 1 to 14, wherein it further comprises an equipment mounted onto the front face (11) of the central frame (10) and wherein the center of mass (C1), of the aerial vehicle (100) with the equipment, is placed within the central frame (10) or in front of the central frame (10).

16. Aerial vehicle (100) according to claim 15, wherein the center of mass (C1), of the aerial vehicle (100) with the equipment, is placedr within the half portion (H2) of the central frame (10) which contains the front face (11) of the central frame (10).

17. Aerial vehicle (100) according to any of claims 1 to 16, wherein the distance (L) between the tail rotor (21) up to the front of the central frame (10) is larger than or equal to the distance (W) between the two double rotors (32).

18. Aerial vehicle (100) according to any of claims 1 to 17, wherein the two double rotors (32) are located at the end portion of said two arms (30)

19. Aerial vehicle (100) according to any of claims 1 to 18, further comprising bumpers forming extension at the front part (11) of the central frame (10).

20. Aerial vehicle (100) according to any of claims 1 to 19, further comprising at least three legs (50) allowing for support of the aerial vehicle (100) on any support such as the floor.

21. Aerial vehicle (100) according to claim 20, wherein said legs form a tripod or a three-legged stand.

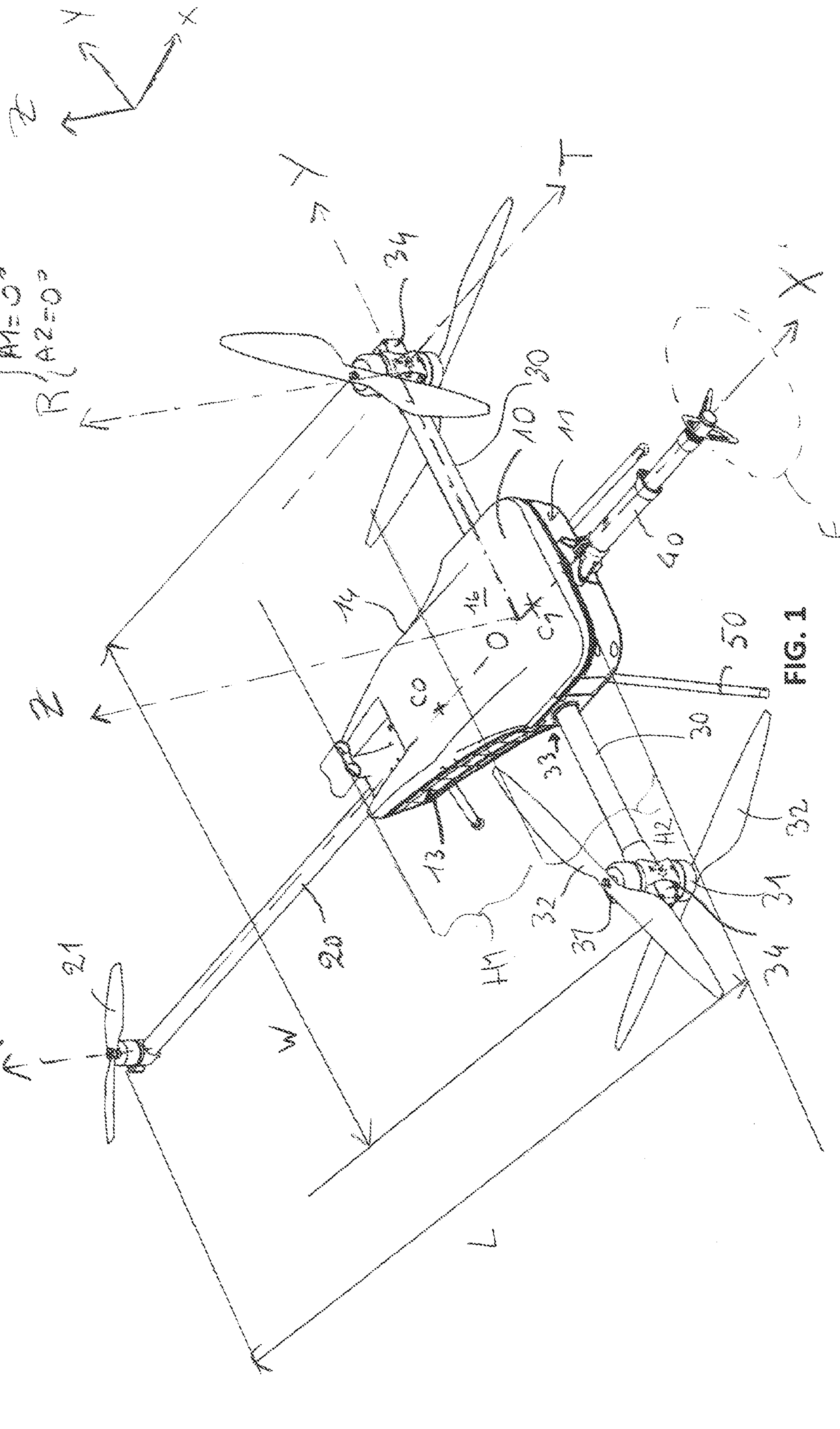

FIG. 1

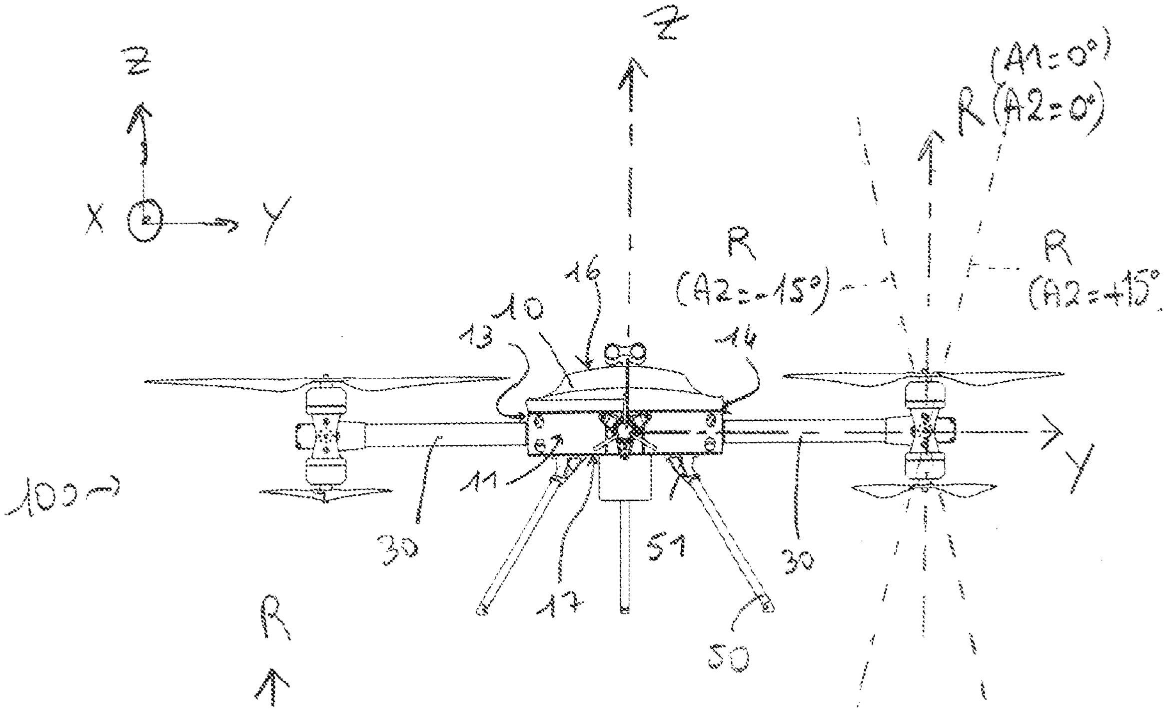
Z
X
Y
Z
R (A1=0°)
(A2=0°)
R
(A2=-15°)
R
(A2=+15°)
16
10
13
14
Y
100
11
30
51
30
17
50

FIG. 2

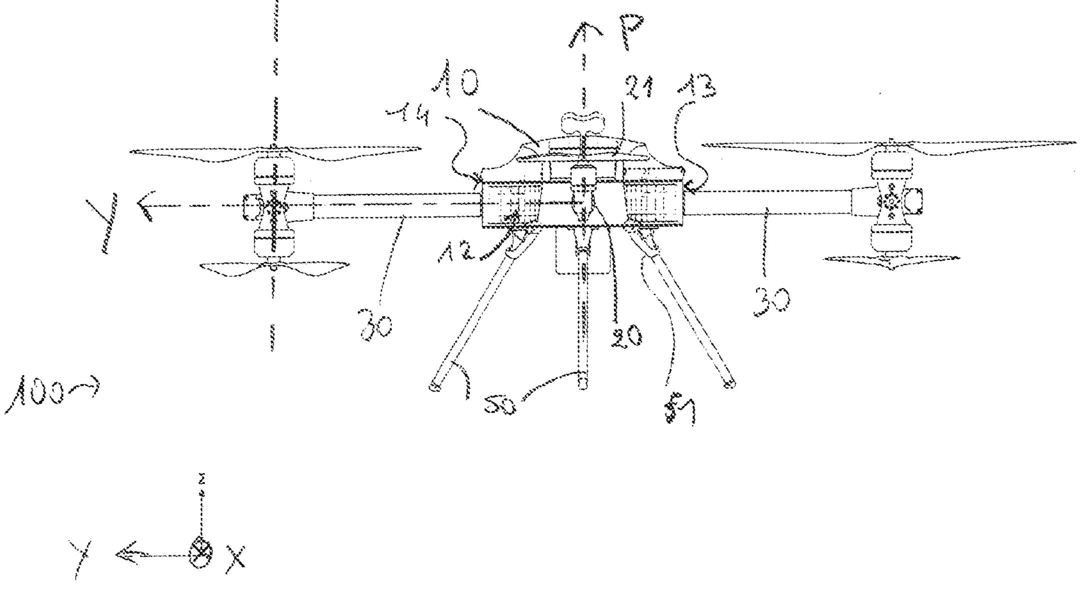
R
P
10
21
13
14
Y
12
30
30
20
100
50
51
Z
Y
X

FIG. 3

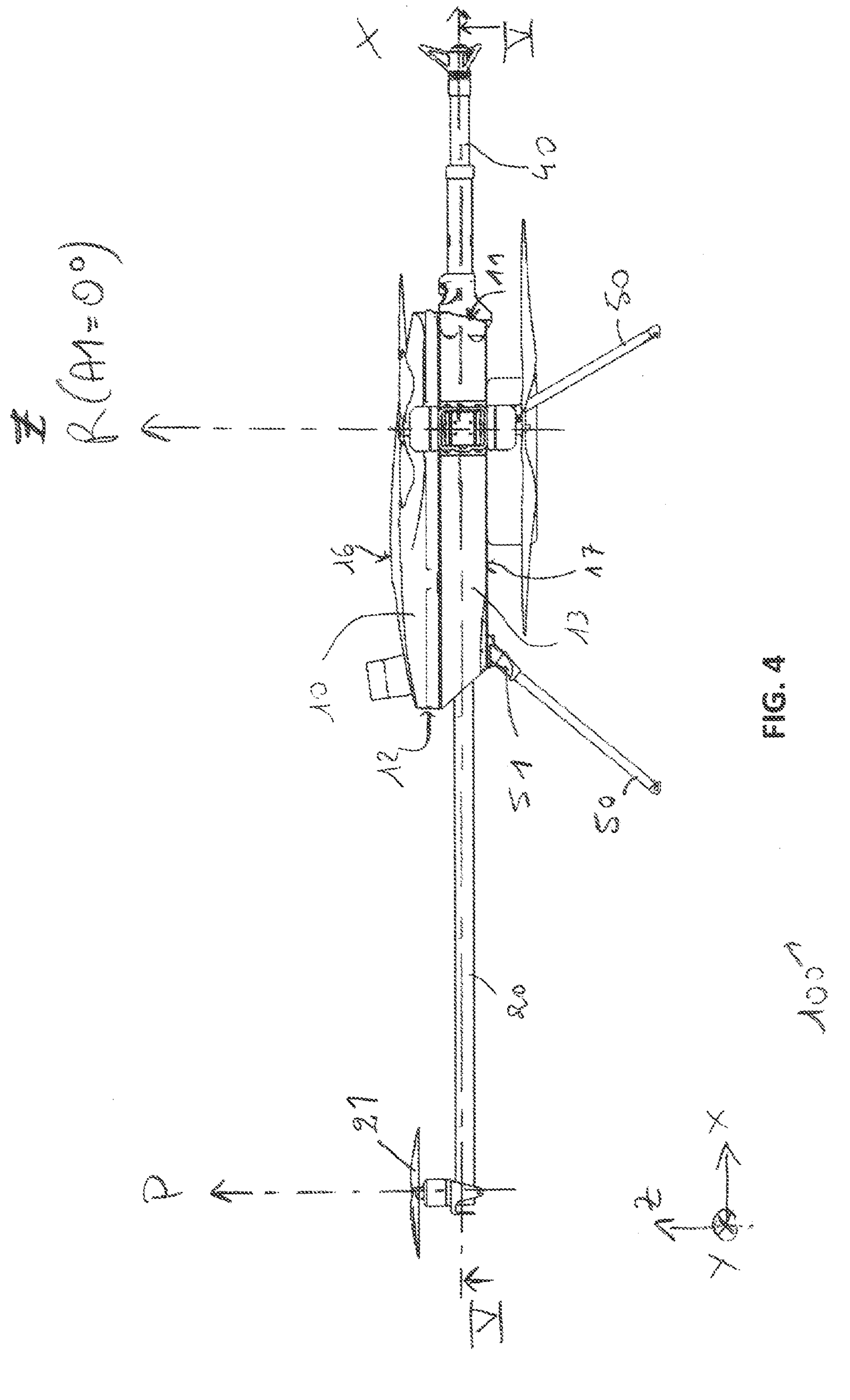

FIG. 4

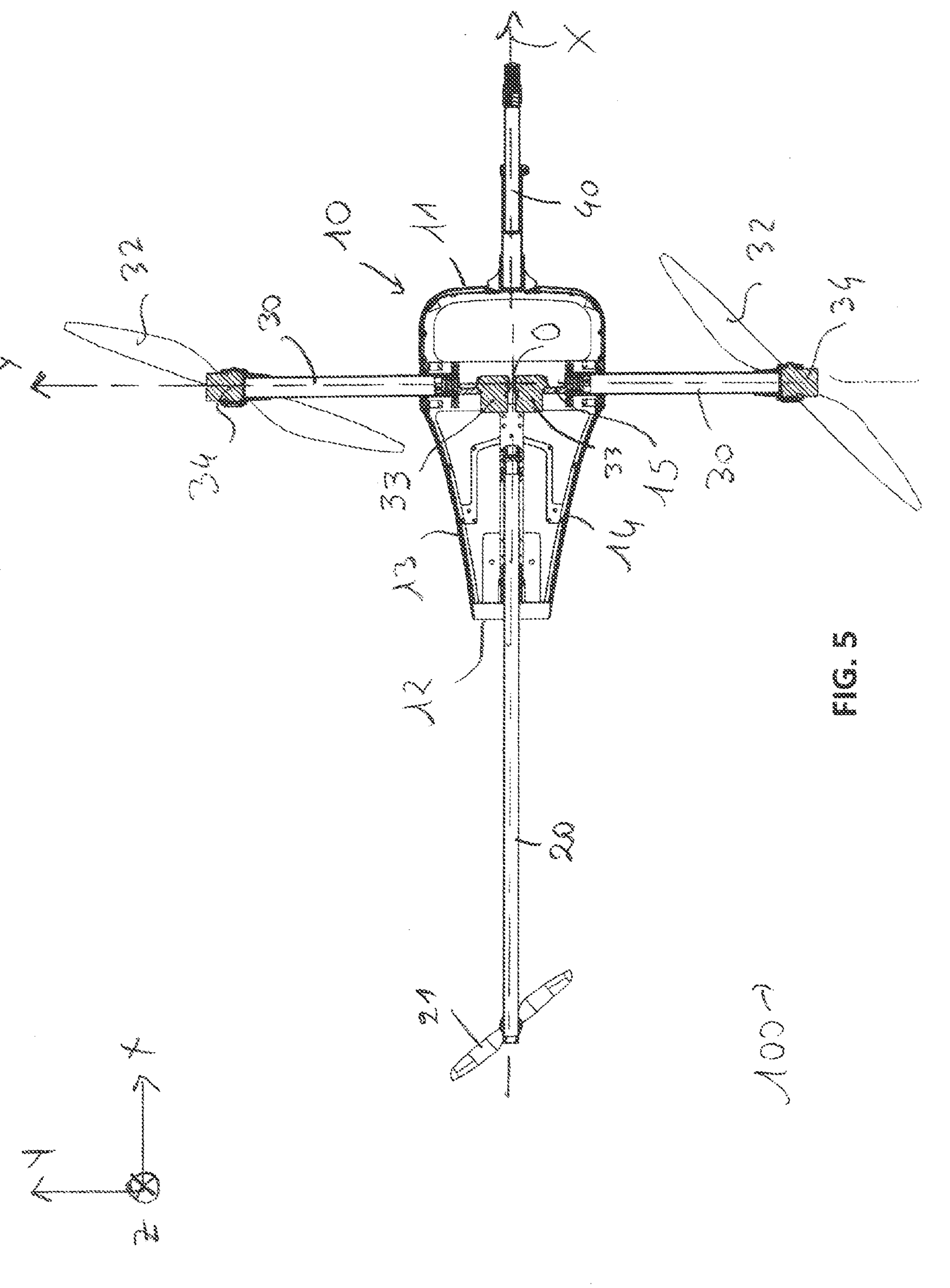

FIG. 5

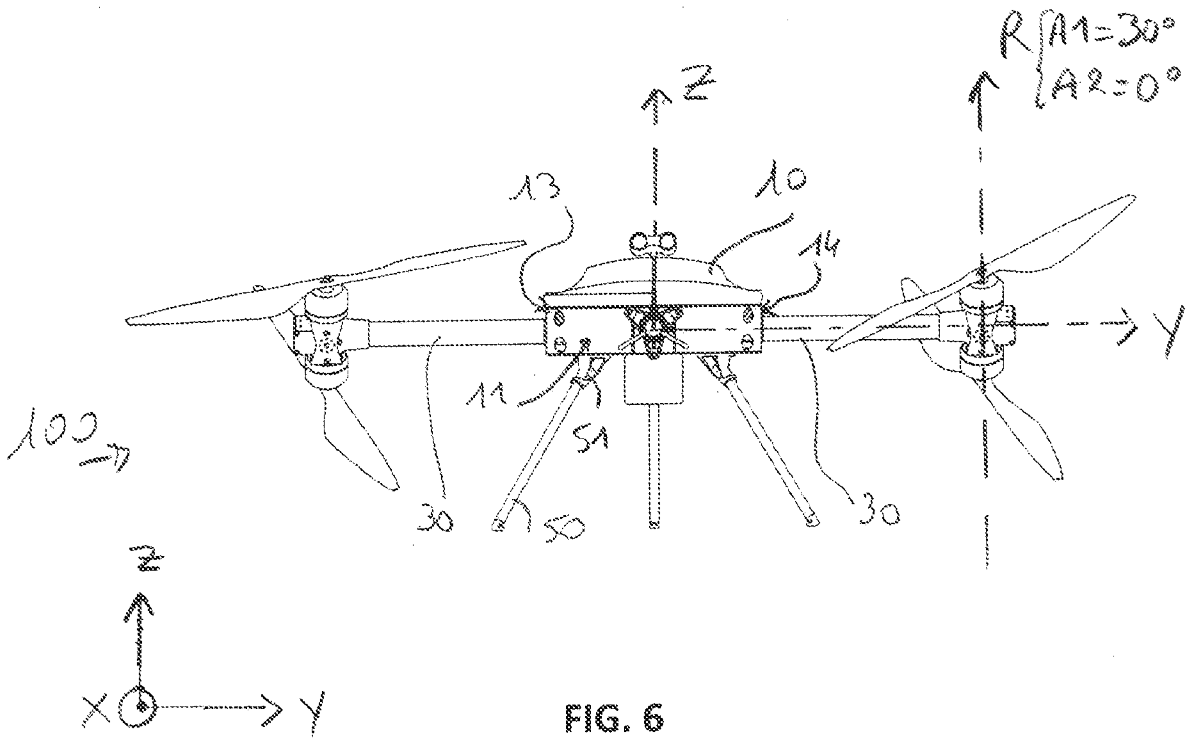
R A1=30° A2=0°
Z
13
10
14
Y
11
51
100
30
50
30
Z
X
Y

FIG. 6

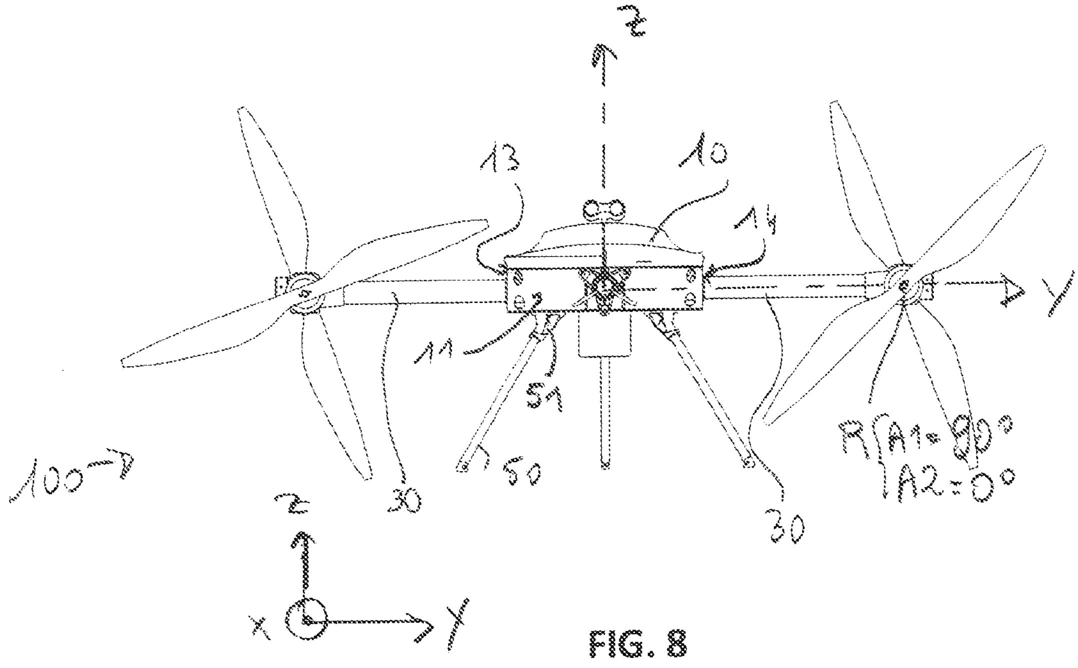
Z
13
10
14
Y
11
51
R A1=90° A2=0°
100
30
50
30
Z
X
Y

FIG. 8

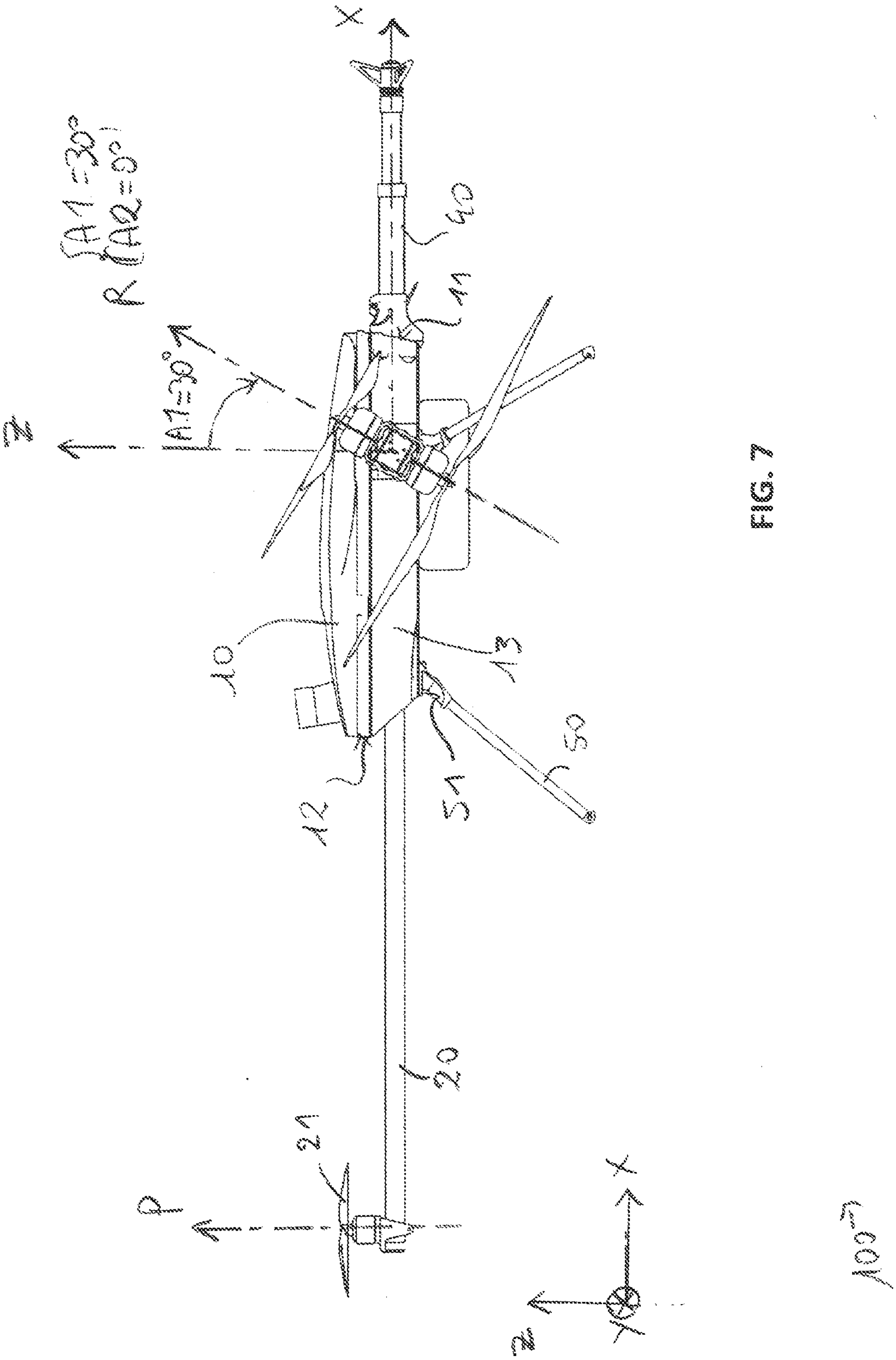

FIG. 7

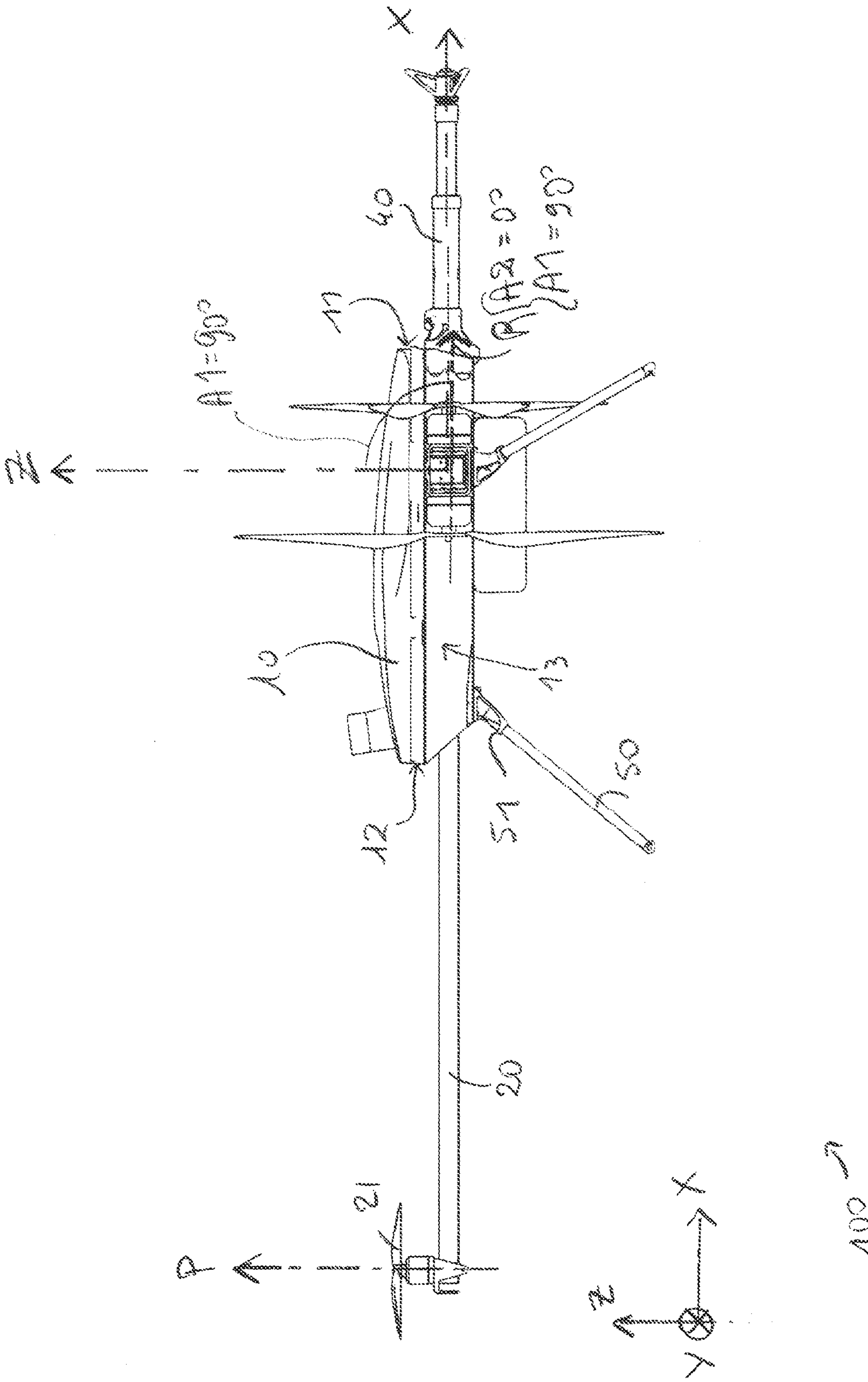

FIG. 9

VOLIRO-1-CH

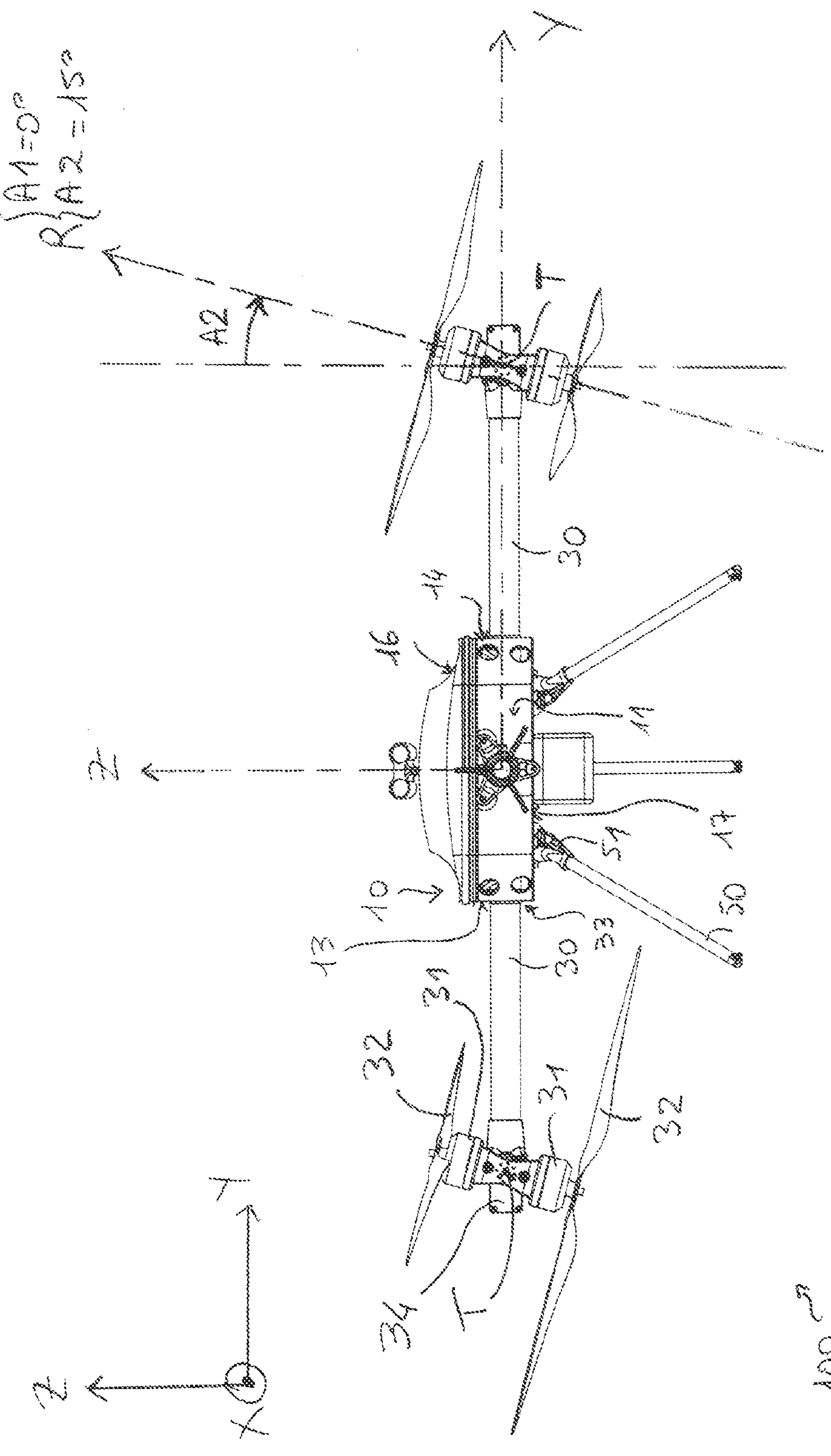

FIG. 10

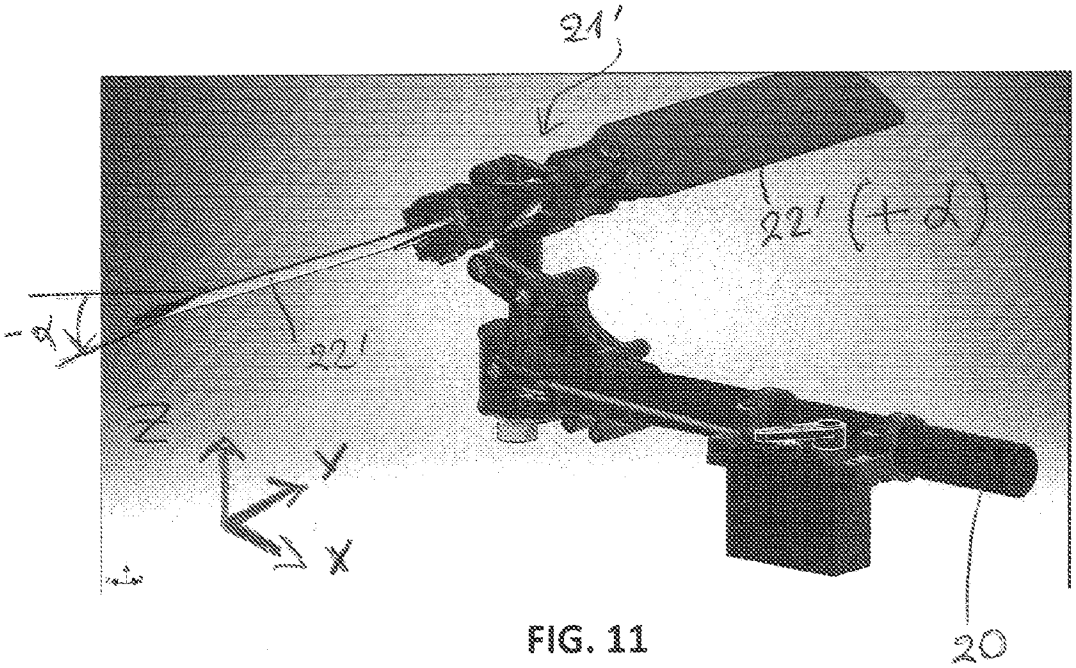

FIG. 11

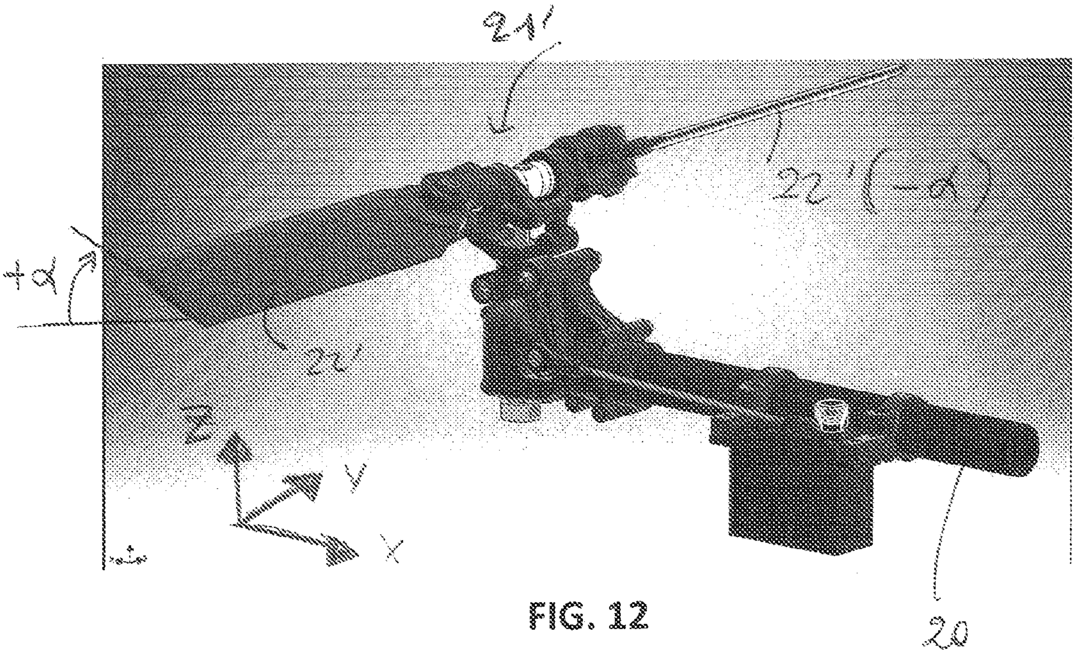

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/050857

A. CLASSIFICATION OF SUBJECT MATTER
INV. B64C29/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B64C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2013/105620 A1 (ABDE QADER ALZU BI HAMZEH MAHMOUD [JO] ET AL) 2 May 2013 (2013-05-02) paragraphs [0021], [0023], [0025] figures 1-3	1-8, 11-21 9,10
Y A	CN 107 639 984 A (UNIV DALIAN TECH) 30 January 2018 (2018-01-30) figures 1-3	1-8, 11-21 9,10
A	US 2016/325829 A1 (AHN HYO SUNG [KR] ET AL) 10 November 2016 (2016-11-10) figures Fig. 1-3	1-21
A	WO 2018/106137 A2 (LIVIU GRIGORIAN GIURCA [RO]) 14 June 2018 (2018-06-14) the whole document	1-21

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 March 2020	27/03/2020

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
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Authorized officer
Duval, Yann

2

International application No
PCT/IB2020/050857

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 105 539 829 A (LIU HAITAO) 4 May 2016 (2016-05-04) the whole document -----	1-21
A	CN 207 191 416 U (UNIV FUZHOU) 6 April 2018 (2018-04-06) the whole document -----	1-21
A	KR 2017 0114097 A (ITDAALL CO LTD [KR]) 13 October 2017 (2017-10-13) the whole document -----	1-21

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2020/050857

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013105620 A1	02-05-2013	NONE	
CN 107639984 A	30-01-2018	NONE	
US 2016325829 A1	10-11-2016	CN 106114851 A KR 20160131631 A US 2016325829 A1	16-11-2016 16-11-2016 10-11-2016
WO 2018106137 A2	14-06-2018	RO 132565 A2 WO 2018106137 A2	30-05-2018 14-06-2018
CN 105539829 A	04-05-2016	NONE	
CN 207191416 U	06-04-2018	NONE	
KR 20170114097 A	13-10-2017	NONE	