

UAV

DESCRIPTION

The invention relates to an unmanned aerial vehicle (UAV) attachable to an external target.

5 UAVs attachable to external targets can be used in a wide range of applications that require close interaction between the UAV and the external target.

For example, UAVs attachable to external targets can be used in inspection or manipulation applications, wherein the external target is a structure to be inspected or manipulated.

10 Among the structures that are routinely inspected and manipulated, there are certain which pose significant challenges, such as cargo holds, bridges, dams, offshore platforms, oil refineries, power plants, chemical processing plants, high rise buildings, just to name a few.

In-person human-based inspection and manipulation of such structures can be time consuming, expensive, complicated and often dangerous for an individual to perform. Thus, a need exists in the industry to address such a problem.

WO2023/079523A1 discloses a UAV for non-destructive testing (NDT) of structures, the UAV comprising an outer protective cage, a propulsion system mounted inside the outer protective cage, an arm comprising a first end attached to the outer protective cage, and an NDT sensor mounted at a second end of the arm. The arm extends outward from the outer protective cage, thereby facilitating measurements in hard-to-reach locations.

WO2023/079523A1 further discloses that, on the second end of the arm, there may be defined a structure-engaging surface configured to engage with a target surface on the structure to be tested. In particular, the second end may comprise means for securing the structure-engaging surface to the structure surface. This provision ensures that the NDT sensor remains on the target surface throughout the measurement.

The downside of this solution is that the engagement between the arm and the target surface creates a constraint on the propulsion system that disturbs flight stability.

This problem is felt especially in the situation where the engagement between the arm and the target surface produces a hinge at the bottom of the outer protective cage. In such a situation, the flight controller needs to fight against the torque generated by the hinge, which is not desirable.

Furthermore, standard flight controllers are typically unable to maintain stable flight in the presence of torque applied to the propulsion system. Therefore, a need exists in the industry to provide a UAV capable of attaching to an external target without causing the failure of the flight controller.

5 WO2019/232217A1 discloses a drone that may be flown into proximity of a structure to measure one or more parameters of the structure. An electromagnet of the drone may be activated to electromagnetically attach the drone to the structure for inspection. A probe may be activated to inspect the structure by measuring one or more parameters of the structure.

10 US2021/339845A1 discloses a UAV comprising an outer protective cage, a propulsion system mounted inside the outer protective cage, a sensor support system fixed on the outer protective cage and a sensor system coupled to the sensor support system. The sensor system is coupled to the sensor support system via a load-limiting coupling mechanism that comprises a spring coupling exerting an
15 elastic bias against the sensor system towards a normal operating position, the sensor system being retractable into the outer protective cage against the elastic bias of the spring coupling upon collision with an external object.

WO2022/251956A1 discloses a UAV system including a UAV, a payload deployment system, and a payload. The payload deployment system includes a payload
20 attachment system, a payload decoupling system, and, optionally, a payload detachment system. The payload attachment system is configured to attach the payload at a landing site such that the payload is at least partially supported at the landing site. The payload decoupling system is configured to decouple the payload from the UAV such that the UAV can move within a range of motions while the
25 payload remains attached at the landing site.

The technical problem addressed by the present invention is to provide a UAV that is structurally and functionally configured to at least partially overcome one or more of the disadvantages set out with reference to the prior art cited above.

Within this problem, a first objective of the invention is to provide a UAV capable of
30 aiming at an external target with precision.

A second objective of the invention is to provide a UAV able to maintain stable contact with an external target.

Another objective of the invention is to provide a UAV that is reliable, in particular for inspection and/or manipulation applications.

35 It is also an objective of the invention to provide a versatile UAV suitable for

inspecting and/or manipulating a wide range of structures.

This problem is solved, and these objectives are reached, at least in part, by providing a UAV attachable to an external target. The UAV comprises a propulsion system, in particular a flight propulsion system, and an arm which preferably
5 extends away from the propulsion system. The UAV may further comprise a releasable attachment element connected to the arm and configured to releasably attach to the external target.

In embodiments, the arm extends longitudinally between a first end which is connected to the propulsion system, and a second end which is opposite the
10 propulsion system. The attachment element may be connected to the second end of the arm.

Preferably, the propulsion system and the attachment element are coupled via a coupling mechanism. In embodiments, the coupling mechanism is interposed between the arm and the propulsion system or between the arm and the
15 attachment element. More particularly, the coupling mechanism may be interposed between the first end of the arm and the propulsion system or between the second end of the arm and the attachment element.

The coupling mechanism may comprise a releasable rigid coupling which advantageously provides a stable rigid positioning of the arm in a predefined
20 operating position. It will be appreciated that the stable rigid positioning of the arm in the predefined operating position allows for precisely aiming at the external target during flight. In embodiments, the predefined operating position of the arm may refer either to a predefined relative position of the arm with respect to the propulsion system (particularly if the coupling mechanism is interposed between
25 the propulsion system and the arm) or to a predefined relative position of the arm with respect to the attachment element (particularly if the coupling mechanism is interposed between the arm and the attachment element).

Preferably, the rigid coupling is releasable upon exercise of a force or torque greater than a predetermined threshold upon attachment of the UAV to the external
30 target. Advantageously, the predetermined threshold is selected so as to keep the arm in the predefined operating position while aiming at the external target and to release the rigid coupling upon attachment to the external target. It will be appreciated that the release of the rigid coupling frees the propulsion system from the hinge constraint produced by the attachment of the arm to the external target.
35 Therefore, the release of the rigid coupling protects the propulsion system from the

transmission of external torque and allows the propulsion system to tilt around its centre of gravity, thereby improving flight stability. Furthermore, the release of the rigid coupling allows the propulsion system to adjust its position, such as compensating for crosswinds during hovering flight, without the attachment
5 element losing contact with the external target. As used herein, the term "torque" refers preferably to a force that produces or tends to produce unwanted rotation of the propulsion system, the force being transmitted in particular by the arm to the propulsion system upon contact with the external target.

10 The coupling mechanism may further comprise an elastic coupling which preferably exerts an elastic bias urging the arm toward the predefined operating position. In this manner, the arm can return to the predefined operating position upon detachment of the UAV from the external target.

15 More particularly, the elastic coupling is configured to allow the propulsion system to move relative to the attachment element against the elastic bias upon release of the rigid coupling and, preferably, further configured to restore the rigid coupling upon detachment of the UAV from the external target. This allows for attaching the UAV multiple times in the same flight with no need to manually restore the predefined operating position of the arm.

20 The external target might be a structure to be inspected and/or manipulated. As used herein, the term "structure" is to be understood in a broad sense not only in reference to buildings but also other types of structures, such as aircraft structures, cargo holds, fuel tanks, sewers, electrical power grids, just to name a few.

The present invention may also have one or more of the following preferred features in addition to those previously mentioned.

25 In embodiments, the UAV comprises a device mounted on the arm, in particular on the second end of the arm. The device is advantageously configured to inspect and/or manipulate the external target upon attachment of the arm to the external target. It is therefore preferred that the device is an inspection and/or manipulation device. Further preferred is that the device comprises an inspection and/or
30 manipulation tool. It will be appreciated that the stable rigid positioning of the arm in the predefined operating position allows for precisely positioning the device with respect to the external target. Furthermore, the attachment element connected to the arm can ensure stable contact with the external target for the inspection/manipulation to be performed.

35 As used herein, the term "inspect" refers preferably to measuring a property of the

external target (such as the thickness of a wall), sensing a flaw in the external target (such as cracks, corrosion, deformation, and the like), capturing an image of the external target, and/or sampling the external target. Accordingly, the inspection device may comprise a sensor, preferably a non-destructive testing (NDT) sensor, further preferably an ultrasonic sensor. In a preferred embodiment, the device also comprises a couplant dispensing nozzle for delivering a couplant. Alternatively, or additionally, the device may comprise an Eddy current sensor, a video camera for capturing moving or still images, a sampler, and the like.

As used herein, the term "manipulate" refers preferably to performing an action on the external target that results in some change on the external target. For instance, manipulating the external target may comprise cleaning, brushing, welding, drilling, marking, painting, and/or printing on the external target. Accordingly, the manipulation device may comprise, for example, a cleaning tool (such as a brush or a cleaning pad), a welder, a drill, a marker, a painting tool, and/or a printer for printing on the external target.

In embodiments, the device is configured to contact the external target during the inspection/manipulation. For this reason, it is preferred that the device and the attachment element are arranged on the arm so that the device contacts the external target upon attachment of the attachment element to the external target.

Preferably, the coupling mechanism is interposed between the propulsion system and the arm, more particularly between the propulsion system and the first end of the arm. It will be appreciated that this arrangement allows for minimizing the distance between the propulsion system and the coupling mechanism, thereby reducing the lever arm of the torque transferred to the propulsion system before the release of the rigid coupling upon attachment of the arm to the external target.

In embodiments, the UAV further comprises a flexible coupling interposed between the arm (in particular, the second end of the arm) and the attachment element. More particularly, the coupling mechanism is interposed between the propulsion system and the first end of the arm, while the flexible coupling is interposed between the second end of the arm and the attachment element. It will be appreciated that the presence of both the coupling mechanism and the flexible coupling provides two points of decoupling between the propulsion system and the external target. The provision of two points of decoupling allows for rotation of the propulsion system about the centre of gravity of the UAV. Since the centre of gravity is typically at the origin of the UAV's roll, pitch and yaw axes, this provision

allows for more stable control of the propulsion system.

In embodiments, the flexible coupling comprises an elastic element (e.g. a spring, such as a coil spring, or a resilient material, such as an elastomer) exerting an elastic bias urging the attachment element toward a predefined attachment position.

Alternatively, or additionally, the flexible coupling may comprise a second coupling mechanism which may be similar to the coupling mechanism by which the first end of the arm is coupled to the propulsion system. More particularly, the second coupling mechanism may comprise a second releasable rigid coupling providing a stable rigid positioning of the attachment element in a predefined attachment position, and being releasable upon exercise of a force or torque greater than a respective predetermined threshold upon attachment of the UAV to the external target. The second coupling mechanism may further comprise a second elastic coupling exerting an elastic bias urging the attachment element toward the predefined attachment position and being configured to allow the arm to move relative to the attachment element against the elastic bias upon release of the second rigid coupling, and to restore the second rigid coupling upon detachment of the UAV from the external target. It is understood that the second coupling mechanism, the second releasable rigid coupling, and the second elastic coupling may also have one or more of the features disclosed in this document with reference to the coupling mechanism, the releasable rigid coupling, and the elastic coupling, respectively, as applicable.

Optionally, the propulsion system comprises an outer protective cage. In this manner, the propulsion system can withstand impacts with external objects such as, in particular, the external target.

Preferably, the arm (in particular, the first end of the arm) is connected to the outer protective cage and, further preferably, extends to the outside of the same. In this manner, the arm is better exposed to contact with the external target while the outer protective cage can be kept at a safe distance from the external target.

In embodiments, the coupling mechanism is interposed between the outer protective cage and the arm, more particularly between the outer protective cage and the first end of the arm. In this manner, the outer protective cage can be decoupled from the external target upon attachment of the arm to the external target.

In embodiments, the coupling mechanism comprises a first coupling end and a

second coupling end. One of the two coupling ends may be connected to an end of the arm, and the other coupling end may be connected to the propulsion system or the attachment element. The first and second coupling ends may be coupled to each other, preferably in a releasable manner, in particular through the releasable rigid coupling. Furthermore, the first and second coupling ends may be coupled to each other through the elastic coupling. Advantageously, the first and second coupling ends are configured to provide the arm in the predefined operating position when they are coupled together. Further advantageously, the first and second coupling ends are configured to decouple, in particular by forming an angle with each other, when they are subject to a torque greater than the predetermined threshold.

The releasable rigid coupling may comprise a magnetic coupling including for example two magnets, such as a magnet on the first coupling end and another magnet on the second coupling end. It is understood that, in embodiments, the magnetic coupling may include a magnet or ferromagnetic element on the first coupling end, and a complementary ferromagnetic element or magnet on the second coupling end. The ferromagnetic element may have a ferromagnetic material such as an iron alloy. In this manner, the magnetic coupling may ensure that the first and second coupling ends are positioned in a stable and correctly oriented position with respect to each other. Additionally, or alternatively, the releasable rigid coupling may comprise an electromagnetic coupling, a pneumatic coupling, an elastic snap-fit coupling, or a friction-based coupling to provide a stable operating position for the arm. The magnetic coupling is preferred because the magnetic field decreases with the square of the distance. This means that the magnetic field does not hinder the movement of the arm when the magnet and the complementary ferromagnetic element are sufficiently far from each other. However, when the magnet and the complementary ferromagnetic element are close to each other, the magnetic field exerts a magnetic bias urging the arm toward the predefined operating position, thereby supplementing the elastic bias exerted by the elastic coupling. This is particularly advantageous in case the elastic coupling is not pre-loaded.

Preferably, the elastic coupling comprises an elastic cap enclosing the releasable rigid coupling. This protects the releasable rigid coupling from dust.

In embodiments, the arm develops longitudinally along an axis. Preferably, the coupling mechanism comprises a shape coupling providing a stable positioning of

the arm in a predefined angular position about said axis. The shape coupling may be releasable upon release of the rigid coupling and configured to restore the predefined angular position of the arm upon engagement of the rigid coupling. It is understood that the shape coupling may also be configured to maintain the arm in the predefined angular position about its axis even upon release of the rigid coupling. This allows for a more precise positioning of the arm and of the device possibly mounted thereon. This is especially advantageous in situations requiring the device to keep a constant orientation with respect to the external target, such as in the case of an ultrasonic sensor performing a thickness measurement on a pipe. In this situation, the shape coupling allows the ultrasonic sensor to keep a constant orientation with respect to the pipe, thereby providing more reliable measurements.

In embodiments, the attachment element comprises a magnet and/or a suction cup. The magnet is advantageous in case the external target is made from metal. The suction cup is advantageous in case the external target has a non-porous surface.

Further preferred aspects are also defined in the attached claims as well as by the following description.

The features and advantages of the invention will be better appreciated from the detailed description of a preferred embodiment thereof, which is illustrated by way of non-limiting example with reference to the appended drawings, in which:

- Figure 1 is a schematic representation of the UAV according to the invention;
- Figures 2 to 4 are schematic representations of different positions of the UAV of figure 1 further comprising an outer protective cage;
- Figures 5 to 7 are sectional views of a detail of the UAV of the preceding figures;
- Figure 8 is a side view of an embodiment of the UAV of figures 2 to 4.

Referring to the figures, a UAV (unmanned aerial vehicle) 1 according to embodiments of the invention comprises a propulsion system 2, in particular a flight propulsion system;

- Figure 9 is a graph illustrating a restoring torque versus angle of a coupling mechanism of a UAV according to embodiments of the invention.

The propulsion system 2 may comprise a frame 20 which preferably supports one or more rotors 21. The rotors may be controlled by a control system and may be powered by one or more batteries, which may be mounted on the frame 20. The rotors may comprise one or more propellers which are preferably driven by electric

motors. Within the scope of the invention, the propellers may however be driven by other types of motors, for instance combustion motors and the energy source provided in the form for instance of liquid fuel. In preferred embodiments, the propulsion system 2 may comprise three or four rotors 21, for instance in a rectangular configuration, the propellers being individually controlled, or controlled in pairs, to adjust the roll, yaw, and pitch angles of the UAV for flight and hovering of the UAV.

In embodiments, as shown in the examples of figures 2 to 4, the propulsion system 2 comprises an outer protective cage 11. The outer protective cage preferably defines two separate spaces, one inside and the other outside the outer protective cage. The frame 20 of the propulsion system is preferably mounted inside the outer protective cage. The outer protective cage may be fixed to the frame of the propulsion system, preferably in a rigid manner.

Advantageously, the outer protective cage 11 surrounds and protects the frame 20 and/or the rotors 21 from impacts with external objects. To better absorb impact energy, the outer protective cage may comprise a plurality of beams 22 connected to each other to form a grid of polygons or a geodesic structure, as shown in the example of figure 8. Moreover, the outer protective cage may have an at least partially rounded outer shape, for example an at least partially ellipsoidal, ovoid, spheroidal or spherical outer shape, such that the frame and/or the rotors are protected from all sides in case of a collision with an external object. In embodiments, the outer protective cage may be substantially flat at the bottom to facilitate a stable landing.

The beams 22 may be connected together to form cage modules 23. The cage modules may have an outer pentagon shape and may be reversibly fixed together, in particular at the corners of their outer pentagon shape, for example by connectors 24. The connectors 24 may be permanently attached to the longitudinal extremities of the beams, or in a preferred embodiment, the connectors may be configured to allow removable connection between cage modules 23 such that the outer protective cage can be assembled from cage modules and disassembled at least partially. The assembly and disassembly of the cage modules facilitate shipping the UAV by providing the outer protective cage in parts that may be connected together prior to use, and disconnected in two or more parts for packaging, storage, and transport. The disassembly of cage modules 23 may also facilitate maintenance, for example by replacing cage modules with broken beams,

or access to the frame 20 inside the outer protective cage.

The UAV may comprise a sensor system 17 coupled to the propulsion system 2. The sensor system 17 may comprise an image capture device, such as a video camera for capturing moving or still images, and may further comprise a lighting system, in particular for projecting infrared or visible light for the image capture device.

In embodiments, the sensor system 17 is coupled to the frame 20. If the outer protective cage 11 is present, it is preferred that the outer protective cage has an opening allowing the sensor system 17 to project therethrough so that the sensor system has an unhindered view over a wide angle of the environment around the UAV. Furthermore, the outer protective cage may be substantially flat in a region where the sensor system 17 projects through the outer protective cage 11 so that the view of the sensor system is broader.

Alternatively, or additionally, the sensor system 17 may be coupled to the outer protective cage 11 and may extend to the outside of the same. In embodiments, a sensor support system 18 is fixed on the outer protective cage 11 and the sensor system 17 may be coupled to the sensor support system 18.

It is preferred that the UAV comprises an arm 3. The arm 3 may be connected to the propulsion system 2, more particularly to the frame 20 or to the outer protective cage 11. Further preferred is that the arm 3 extends away from the propulsion system 2, more particularly away from the frame 20 and, if present, the outer protective cage 11. In embodiments, the outer protective cage 11 may have an opening allowing the arm 3 to project therethrough to the outside of the outer protective cage. However, it is preferred that the arm is arranged outside (in particular, completely outside) the outer protective cage.

In embodiments, the arm 3 extends longitudinally, in particular along an axis X, from a first end 31 of the arm, which may be connected to the propulsion system, to a second end 32 of the arm, which is preferably opposite the propulsion system. The position of the arm 3 may be defined by the orientation of the axis X. The longitudinal development of the arm along the axis X is preferably straight but may alternatively be at least partially curved or adjustable through, for example, one or more adjustable joints. In other words, the arm may be articulated along its longitudinal development through one or more adjustable joints. The adjustable joints advantageously allow a user to adjust the orientation or arrangement of the arm relative to the propulsion system to best suit the orientation of the surface of the external target or to bypass any obstacles between the UAV and the external

target, thereby facilitating attachment in hard-to-reach locations.

Preferably, the second end 32 of the arm is arranged at a distal end of the arm outside the outer protective cage 11, in such a manner that the second end 32 of the arm is advantageously exposed to contact with the external target while the
5 outer protective cage 11 can advantageously be kept at a distance from the external target. The external target may be, for example, the wall of a structure to be inspected and/or manipulated with the arm 3.

The UAV may further comprise a releasable attachment element 4 connected to the arm 3 (in particular, to the second end 32 of the arm) and configured to releasably
10 attach to the external target. For example, the attachment element 4 may have an engagement surface configured to engage with the external target. In embodiments, the attachment element 4 comprises one or more magnets 15, such as permanent magnets (particularly neodymium magnets) or electromagnets, which are preferably arranged flush with the engagement surface. Additionally, or
15 alternatively, the attachment element 4 may comprise a suction cup 16 configured to use the negative fluid pressure of air to adhere to the surface of the external target, creating a partial vacuum.

Advantageously, the propulsion system 2 and the attachment element 4 are coupled via a coupling mechanism 5. The coupling mechanism 5 is preferably
20 interposed between the first end 31 of the arm and the propulsion system 2, more particularly between the first end 31 and either the frame 20 or the outer protective cage 11. Alternatively, the coupling mechanism 5 may be interposed between the second end 32 of the arm and the attachment element 4.

As shown in the examples of figures 5 and 6, the coupling mechanism 5 preferably
25 comprises a releasable rigid coupling 6. Advantageously, the releasable rigid coupling 6 provides a stable rigid positioning of the arm 3 in a predefined operating position Pos1. Further advantageously, the releasable rigid coupling 6 is releasable upon exercise of a torque T greater than a predetermined threshold T_1 upon attachment of the UAV to the external target. The releasable rigid coupling 6 may
30 be based on various coupling mechanisms, including magnetic, electromagnetic, pneumatic, elastic snap-fit, or friction based, to provide a stable operating position for the arm 3. The release of the rigid coupling 6 may allow movement of the attachment element 4 relative to the propulsion system 2 according to at least two or three degrees of freedom.

35 Preferably, the coupling mechanism 5 further comprises an elastic coupling 7

exerting an elastic bias urging the arm 3 toward the predefined operating position Pos1 and being configured to allow the propulsion system 2 to move relative to the attachment element 4 against the elastic bias upon release of the rigid coupling 6, and to restore the rigid coupling upon detachment of the UAV from the external target. The elastic coupling 7 may have various configurations depending on the embodiment. For example, it may comprise one or more rubber joints, elastic bands (e.g. rubber bands), and/or springs (e.g. traction springs, compression springs, torsion springs, or constant force springs).

In embodiments, the coupling mechanism 5 comprises a first coupling end 51 and a second coupling end 52 which may have a flanged shape. The first and second coupling ends 51, 52 may be releasably coupled to each other to advantageously provide the stable rigid positioning of the arm 3 in the predefined operating position Pos1. When the first and second coupling ends 51, 52 are coupled to each other, they are preferably aligned along the axis X. The first and second coupling ends 51, 52 may be releasable upon exercise of a torque T greater than the predetermined threshold T1. In a preferred embodiment, the first coupling end 51 is connected to the propulsion system 2, while the second coupling end 52 is connected to the arm 3 and preferably coincides with the first end 31 of the arm. Alternatively, the first coupling end 51 may be connected to the arm 3 and may coincide with the second end 32 of the arm, while the second coupling end 52 may be connected to the attachment element 4.

In embodiments, the releasable rigid coupling 6 comprises a magnetic coupling 12. The magnetic coupling 12 may comprise a pair of magnets 19, in particular permanent magnets, such as neodymium magnets. Preferably, one magnet is fixed to the first coupling end 51 and the other magnet is fixed to the second coupling end 52. It is understood that, in embodiments, a ferromagnetic element having a ferromagnetic material such as an iron alloy may be used in lieu of one of the two magnets. The magnetic coupling 12 can be easily scaled to different loads and behave rigidly within a threshold given by the magnetic force of the magnets 19. When the threshold is exceeded, the elastic coupling 7 can undergo large deformations without failure due to overloading. Advantageously, the elastic bias exerted by the elastic coupling 7 increases linearly with the deformation of the elastic coupling.

In embodiments, the elastic coupling 7 comprises an elastic cap 13 which preferably encloses the releasable rigid coupling 6. The elastic cap 13 may be made

from an elastomer, such as a polymeric elastomer or rubber material. The elastic cap 13 may have a tubular shape which preferably comprises a middle section 33 interposed between two opposite end sections 34. In embodiments, the tubular shape is tapered from the middle section 33 toward the end sections 34. The end sections 34 of the elastic cap may be attached respectively to the first and second coupling ends 51, 52 through, for example, zip-ties 35. The releasable rigid coupling 6 may be arranged in the region of the middle section 33 of the elastic cap. The middle section 33 may be configured to elastically deform upon release of the rigid coupling 6, as shown in the example of figure 6.

As shown in the example of figure 6, the arm 3 is preferably configured to form an angle A with respect to its predefined operating position Pos1 upon release of the rigid coupling 6. In particular, the angle A may refer to the angular displacement of the axis X of the arm from its predefined operating position Pos1 around the coupling mechanism 5. Accordingly, the coupling mechanism 6 is preferably configured to exercise a torque T which tends to restore the rigid coupling 6 or, in other words, which tends to restore the predefined operating position Pos1.

It is preferred that the restoring torque T varies in accordance with the angle A, as explained in the following examples with reference to the curves shown in figure 9.

In embodiments, the restoring torque T has two components: a magnetic restoring torque, due in particular to the magnetic coupling 12, and an elastic restoring torque, due in particular to the elastic coupling 7. As a result, the total restoring torque T may be given by the sum of the magnetic and the elastic restoring torque components. Advantageously, the magnetic restoring torque is maximal in the predefined operating position Pos1 and may decrease as the angle A increases. Conversely, the elastic restoring torque is advantageously minimal in the predefined operating position Pos1 and may increase as the angle A increases. In embodiments, the elastic restoring torque is substantially zero in the predefined operating position Pos1. Alternatively, the elastic coupling 7 may be pre-loaded, thereby providing some elastic restoring torque even in the predefined operating position Pos1.

In the predefined operating position Pos1, the coupling mechanism 5 may exercise a restoring torque T having a predetermined threshold T1. In embodiments, possibly depending on the pre-load of the elastic coupling 7, the predetermined threshold T1 is given only or prevailing by the magnetic restoring torque component. Upon release of the rigid coupling 6 or, in other words, upon

displacement of the arm 3 away from the predefined operating position Pos1, the angle A may increase and the restoring torque T may decrease accordingly up to a second threshold T2 lower than the predetermined threshold T1. In such a situation, if the angle A continues to increase, the restoring torque T may then
5 increase above the second threshold T2, due to the increase of the elastic restoring torque component.

Advantageously, the propulsion system 2 has enough authority to overcome the predetermined threshold T1 or, in other words, the propulsion system 2 is configured to be able to exercise a propulsion torque greater than the
10 predetermined threshold T1. This allows for releasing the rigid coupling 6 upon attachment of the attachment element 4 to the external target.

Further advantageously, the second threshold T2 is higher than the torque applied to the coupling mechanism 5 by the weight of the components supported by the coupling mechanism 5 (e.g., the weight of the arm 3, attachment element 4, device
15 8, etc.) when the attachment element 4 is detached from the external target. This allows the coupling mechanism 5 to be able to exercise enough torque for restoring the predefined operating position Pos1 upon detachment from the external target.

Advantageously, the predefined operating position Pos1 of the arm allows the arm to aim at the external target while keeping the propulsion system 2 at a safe
20 distance from the external target. The predefined operating position Pos1 of the arm may be selected based on the position and orientation of the external target that needs to be reached with the arm. For example, the arm 3 in the predefined operating position Pos1 may extend upward/forward of the propulsion system 2 as shown in the example of figure 1, or downward from the propulsion system 2 as
25 shown in the example of figure 2. In embodiments, the arm 3 may be coupled to a portion of the outer protective cage 11 which is located below the frame 20 as shown in the examples of figures 2 and 3, or above the frame 20 as shown in the example of figure 3. It will be appreciated that each one of these configurations facilitates attachment to a different type of external target including vertical walls,
30 downward-facing surfaces (e.g. ceilings), or upward-facing surfaces (e.g. floors).

Upon release of the rigid coupling 6, the arm 3 can move away from the predefined operating position Pos1 such that the propulsion system 2 is free to move to another position Pos2 relative to the arm, as shown in the examples of figures 2 and 3.

35 Another advantage provided by the coupling mechanism 5 is the ability to

overcome an obstacle by reversibly reducing the bulk of the arm upon impact with the obstacle. As shown in the example of figure 4, the UAV may have to fly through a manhole having a size which is smaller than the overall dimensions of the UAV including the arm in the predefined operating position Pos1. However, upon impact
5 of the arm against the edge of the manhole, the coupling mechanism 5 allows the arm to move away from the predefined operating position Pos1 toward another position Pos2 which is closer to the propulsion system. This allows the UAV to fly through the manhole. Once the obstacle has been overcome, the coupling mechanism 5 automatically restores the predefined operating position Pos1 of the
10 arm. It will be appreciated that this ability facilitates navigation in cluttered environments. Furthermore, this ability allows for fitting the UAV in a compact case for shipment.

Another advantage provided by the coupling mechanism 5 is the ability for the UAV to take off and land more stably thanks to the ability to reversibly move the arm 3
15 away from the predefined operating position Pos1 in situations where the arm is exposed to contact with the landing ground, such as in the situation where the arm is coupled to a portion of the outer protective cage 11 which is located below the frame 20.

In embodiments, as shown in the example of figure 7, the coupling mechanism 5
20 comprises a shape coupling 14 (such as a Hirth coupling) configured to keep the arm 3 in a predefined angular position about the axis X. The shape coupling 14 may comprise conjugated toothed profiles obtained respectively on the first and second coupling ends 51, 52. The conjugated toothed profiles may comprise respective
25 teeth extended along the axis X and configured to engage with each other to prevent relative rotation of the first and second coupling ends about the axis X of the arm. The shape coupling 14 may be configured to keep the arm 3 in a predefined angular position about the axis X at least when the releasable rigid coupling 6 is engaged and, preferably, even upon release of the rigid coupling. To
30 this aim, one of the coupling ends may comprise an outer rim 53 which projects around the other coupling end so as to keep the two coupling ends centered with respect to each other.

The UAV may further comprise a device 8 mounted on the arm 3 and configured to inspect and/or manipulate the external target upon attachment of the arm to the external target. The device 8 may be operatively connected to the propulsion
35 system 2, for example through a cable, for power and/or signal transmission.

Unwanted twisting of the cable around the arm 3 may be avoided thanks to the shape coupling 14.

In embodiments, the device 8 comprises a sensor 9, preferably a non-destructive testing (NDT) sensor, in particular for performing non-destructive testing of structures. For example, the sensor 9 may be adapted for measuring a thickness or sensing a flaw in a structure to be tested. The sensor 9 may be configured to emit measurement signals and receive return signals in response thereto. The emitted measurement signals may be affected by the material of the structure being tested to provide return signals which are representative of the physical conditions of the structure.

In embodiments, the sensor 9 has an operating surface configured to contact the surface of the external target to perform a measurement thereon. In a preferred embodiment, the sensor 9 comprises an ultrasonic sensor, such as a contact ultrasonic sensor, particularly for measuring thickness. As used herein, the term "contact ultrasonic sensor" refers preferably to a sensor capable of performing ultrasonic testing only by making direct or indirect contact between the sensor and the structure being tested. Additionally, or alternatively, the sensor 9 may comprise an Eddy current sensor, an electromagnetic acoustic transducer, or an NDT scanner.

In embodiments, the device 8 may further comprise a cleaning tool for cleaning a portion of the structure to be tested with the sensor 9 and particularly with the ultrasonic sensor. This allows for more accurate measurements. The cleaning tool may comprise, for example, a rotating brush, such as a steel or abrasive brush, or a cleaning pad, such as an abrasive cleaning pad.

In embodiments, as shown in the example of figure 8, the device 8 may further comprise a couplant dispensing nozzle 81 for delivering a couplant onto the sensor 9. This is particularly advantageous where the sensor comprises an ultrasonic sensor. The UAV may further comprise a couplant dispensing system 82 mounted inside the outer protective cage 11 and a tubing system 83 for fluidly connecting the couplant dispensing system 82 to the couplant dispensing nozzle 81. The tubing system may be flexible to allow for movement of the arm 3. Unwanted twisting of the tubing system 83 around the arm may be avoided thanks to the shape coupling 14. The couplant dispensing system 82 may include a couplant reservoir and a pump fluidly connected thereto for delivering the couplant from the couplant reservoir to the couplant dispensing nozzle 81. As used herein, the term "couplant"

refers preferably to a fluid medium that facilitates sound transmission between the sensor 9 and the external target to be inspected.

In embodiments, the UAV comprises at least one mounting support 90 fastened to the outer protective cage 11 and advantageously configured to receive the first end 31 of the arm or the first coupling end 51 of the coupling mechanism. The at least one mounting support 90 may be reversibly fastened to the outer protective cage 11. The first end 31 or the first coupling end 51 may be reversibly attached to the at least one mounting support 90.

In embodiments, the arm 3 or the coupling mechanism 5 is connected to the at least one mounting support 90 in an articulated manner, for example about a pin interposed between the mounting support 90 and the first end 31 or the first coupling end 51. Such articulation advantageously allows the arm 3 to be oriented toward the surface of the external target, be it vertical, inclined or horizontal. In embodiments, the UAV may comprise an actuator, such as an electric motor, configured to adjust the orientation of the arm 3 about the articulation of the mounting support 90.

The UAV may comprise a plurality of mounting supports 90 fastened to the outer protective cage 11. Preferably, the mounting supports 90 are fastened to the outer protective cage 11 in respective spaced-apart fastening portions of the outer protective cage. Further preferably, the arm 3 or the coupling mechanism 5 is reversibly connected to a mounting support 90 freely selected or selectable from the plurality of mounting supports. The possibility of connecting the arm 3 or the coupling mechanism 5 to any one of the mounting supports 90 advantageously allows for arranging the arm 3 in the position that best suits the spatial orientation of the surface of the external target.

In embodiments, particularly if the coupling mechanism 5 is interposed between the propulsion system 2 and the arm 3, the UAV may further comprise a flexible coupling 10 interposed between the arm 3 and the attachment element 4. Preferably, the flexible coupling 10 extends along the longitudinal development of the arm 3. As shown in the example of figure 8, the flexible coupling 10 may comprise a spring coupling. Alternatively, or additionally, the flexible coupling 10 may comprise a second coupling mechanism which may have the same or similar features as the coupling mechanism 5 by which the arm 3 is coupled to the propulsion system 2. Advantageously, the flexible coupling 10 allows movement of the attachment element 4 relative to the arm 3 according to at least two or three

degrees of freedom. The degrees of freedom freed by the flexible coupling 10 add to those freed by the coupling mechanism 5 to allow the propulsion system 2 to tilt around its centre of gravity G, thus improving flight control upon attachment to the external target. Additionally, the flexible coupling 10 facilitates establishing a stable
5 contact between the attachment element and the external target when the UAV approaches the external target from any of a wide range of angles relative to the horizontal or vertical plane.

CLAIMS

1. UAV (1) attachable to an external target, the UAV comprising a propulsion system (2), an arm (3) extending away from the propulsion system, and a releasable attachment element (4) connected to the arm and configured to
5 releasably attach to the external target, wherein the propulsion system and the attachment element are coupled via a coupling mechanism (5) interposed between the arm and the propulsion system or between the arm and the attachment element, the coupling mechanism comprising:
 - a releasable rigid coupling (6) providing a stable rigid positioning of the arm
10 in a predefined operating position (Pos1), and being releasable upon exercise of a torque (T) greater than a predetermined threshold (T1) upon attachment of the UAV to the external target, and
 - an elastic coupling (7) exerting an elastic bias urging the arm toward the predefined operating position (Pos1) and being configured to allow the
15 propulsion system to move relative to the attachment element against the elastic bias upon release of the rigid coupling, and to restore the rigid coupling upon detachment of the UAV from the external target.
2. UAV according to claim 1, comprising a device (8) mounted on the arm and configured to inspect and/or manipulate the external target upon attachment of
20 the arm to the external target.
3. UAV according to claim 2, wherein the device comprises a sensor (9), preferably an ultrasonic sensor.
4. UAV according to any one of the preceding claims, wherein the coupling mechanism is interposed between the propulsion system and the arm, the UAV
25 further comprising a flexible coupling (10) interposed between the arm and the attachment element.
5. UAV according to any one of the preceding claims, wherein the propulsion system comprises an outer protective cage (11), the arm being connected to the outer protective cage and extending to the outside of the same.
- 30 6. UAV according to claim 5, wherein the coupling mechanism is interposed between the outer protective cage and the arm.
7. UAV according to any one of the preceding claims, wherein the releasable rigid coupling comprises a magnetic coupling (12).
8. UAV according to any one of the preceding claims, wherein the elastic coupling
35 comprises an elastic cap (13) enclosing the releasable rigid coupling.

9. UAV according to any one of the preceding claims, wherein the arm develops longitudinally along an axis (X), the coupling mechanism comprising a shape coupling (14) providing a stable positioning of the arm in a predefined angular position about said axis.
- 5 10. UAV according to any one of the preceding claims, wherein the attachment element comprises a magnet (15) and/or a suction cup (16).