



(51) International Patent Classification:

B60L 8/00 (2006.01) H02S 30/10 (2014.01)

B29C 65/54 (2006.01) B29C 65/50 (2006.01)

H02S 10/40 (2014.01)

(21) International Application Number:

PCT/SG2019/050322

(22) International Filing Date:

28 June 2019 (28.06.2019)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

10201805636P 29 June 2018 (29.06.2018) SG

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: FULLY SOLAR POWERED MULTI-COPTER AND ENABLING METHODS AND STRUCTURES

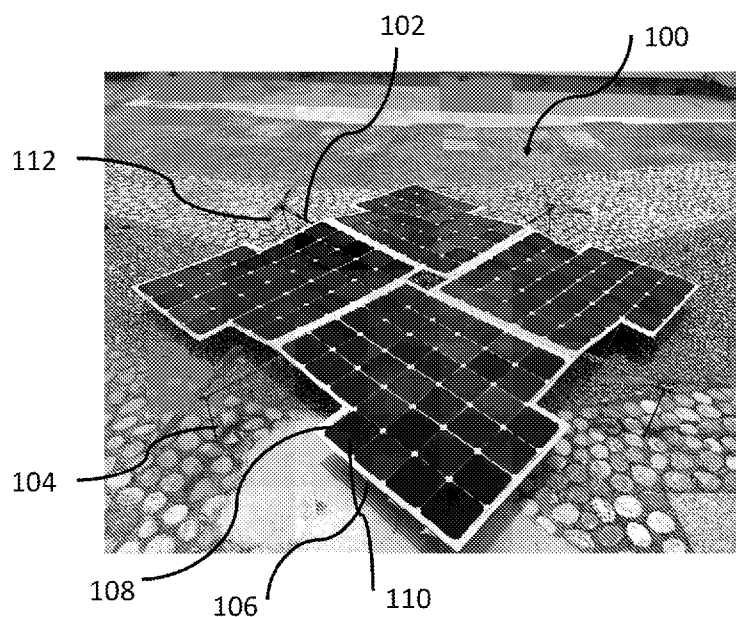


Figure 1a)

(57) Abstract: A fully solar powered multi-copter, a method of fabricating a multi-copter, and a method of interconnecting carbon fiber members.



UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

FULLY SOLAR POWERED MULTI-COPTER AND ENABLING METHODS AND STRUCTURES

FIELD OF INVENTION

- 5 The present invention relates broadly to a fully solar powered multi-copter, in particular to a quadcopter, to a method of fabricating a multi-copter, and to a method of interconnecting carbon fiber members.

BACKGROUND

- 10 Typical Multi-copters (such as quadcopter drones) have a limited flight time of 30 minutes or so, and need to return to a base station and charge their batteries. On the other hand, while structures using interconnected carbon fiber members, such as carbon fiber rods, are desirable, in particular for lightweight applications, existing interconnect fabrication methods typically suffer either in terms of strength or added weight.
- 15 Embodiments of the present invention seek to address at least one of the above problems.

SUMMARY

- In accordance with a first aspect of the present invention, there is provided a multi-copter capable of solar powered operation in solar radiation exposed conditions without requiring an on-board energy storage device.
- 20

A frame structure of the multi-copter may comprise carbon fiber rods interconnected in a screw-less manner.

The frame structure may comprise glued interconnections. The glued interconnections may comprise epoxy resin. The epoxy resin may be carbon nanotube infused.

- 25 In one embodiment, the carbon fiber rods are interconnected via a carbon fiber center mount. The center mount may be 3D printed. The center mount may comprise a plurality of slots for receiving respective ones of the carbon fiber rods.

- In one embodiment, the carbon fiber rods are interconnected via angled carbon rod-to-carbon rod joints to form a carbon fiber truss structure. The joints may comprise glue soaked carbon fiber fabric wrapped around a bond point of each joint.
- 30

The frame structure may comprise a plurality of support arms for supporting solar cells. The support arms may be tilted upwards relative to an in-flight orientation of the multi-copter from a center of the frame structure such that the support arms, under a load exerted by the solar cells, provide a substantially horizontal support plane for the solar cells.

The frame structure may comprise a plurality of motor arms for mounting of motors of the multi-copter. The motors may be mounted to the motor arms by way of respective motor mounts. The motor mounts may be configured to be glued to the motor arms. The motor arms may comprise carbon fiber adaptors coupled between the motor mounts and carbon fiber rods of the motor arm. The motor mounts may be configured to be coupled to landing gear of the multi-copter. The motor mounts may be configured to be coupled to the landing gear via interference fit.

The multi-copter may comprise electrical wiring made from aluminum wire. The aluminum wire may be encapsulated or coated with an electrically insulating substance or material for insulation.

The multi-copter may comprise a board coupled to the frame structure for supporting the solar cells. The board may be made from foam. The board may comprise holes for receiving the solar cells. The holes, primarily for saving weight, may be through-holes for exposing the backsides of the solar cells for improved airflow and heat dissipation. The solar cells may comprise back-contact solar cells.

The multi-copter may comprise low KV outrunner motors. The low KV outrunner motors may be coupled to propellers, wherein the size of the airfoils of the propellers is chosen based on the torque of the low KV outrunner motors.

The multi-copter may comprise an on-board energy storage device for enabling operation in non-solar exposed conditions.

The multi-copter may comprise a quadcopter.

In accordance with a second aspect of the present invention, there is provided a method of fabricating the multi-copter of the first aspect.

The method may comprise forming glued interconnections. The glued interconnections may comprise epoxy resin. The epoxy resin may be carbon nanotube infused.

In one embodiment, the carbon fiber rods are interconnected via a carbon fiber center mount. The center mount may be 3D printed. The method may comprise receiving respective ones of the carbon fiber rods in a plurality of slots of the center mount.

In one embodiment, the carbon fiber rods are interconnected via angled carbon rod-to-carbon rod joints to form a carbon fiber truss structure. The mechanism for interconnection may comprise wrapping glue soaked carbon fiber fabric around a bond point of each joint.

The method may comprise forming a plurality of support arms for supporting solar cells. The support arms may be tilted upwards relative to an in-flight orientation of the multi-copter from a center of the frame structure such that the support arms, under a load exerted by the solar cells, provide a substantially horizontal support plane for the solar cells.

The method may comprise forming a plurality of motor arms for mounting of motors of the multi-copter. The motors may be mounted to the motor arms by way of respective motor

mounts. The motor mounts may be glued to the motor arms. Carbon fiber adaptors may be coupled between the motor mounts and carbon fiber rods of the motor arm. The motor mounts may be coupled to landing gear of the multi-copter. The motor mounts may be coupled to the landing gear via interference fit.

- 5 The method may comprise providing electrical wiring for the multi-copter made from aluminum wire. The aluminum wire may be encapsulated or coated with an electrical insulating substance or material for insulation.

- 10 The method may comprise coupling a board to the frame structure for supporting the solar cells. The board may be made from foam. The method may comprise forming holes in the board for receiving the solar cells. The holes, primarily for saving weight, may be through-holes for exposing the backsides of the solar cells for improved airflow and heat dissipation. The solar cells may comprise back-contact solar cells.

- 15 The method may comprise coupling low KV outrunner motors to the frame structure. The low KV outrunner motors may be coupled to propellers, wherein a size of the airfoils of the propellers is chosen based on the torque of the low KV outrunner motors.

The method may comprise providing an on-board energy storage device for enabling operation in non-solar exposed conditions.

In accordance with a third aspect of the present invention, there is provided a method of interconnecting carbon fiber members, the method comprising

- 20 securing interconnecting surfaces of the carbon fiber members in a desired alignment; and providing an epoxy resin soaked carbon fiber fabric wrapped around portions of the carbon fiber members including the interconnecting surfaces.

The method may comprise providing the epoxy resin on the portions of the carbon fiber members and/or pre-soaking the carbon fiber fabric with the epoxy resin.

- 25 The epoxy resin may be infused with carbon nanotubes.

The carbon fiber members may comprise carbon fiber rods.

BRIEF DESCRIPTION OF THE DRAWINGS

- 30 Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1a) shows a photograph of a prototype solar drone according to an example embodiment.

Figure 1b) shows a photograph of the prototype solar drone in-flight/hovering at 1 meter above starting ground, demonstrating achievement of fully solar operation.

Figure 1c) shows a photograph of the prototype solar drone in-flight/hovering at 3 meters altitude above starting ground, demonstrating achievement of fully solar operation.

- 5 Figure 2 shows a schematic diagram of 3D printed carbon and nylon composite center hub for the prototype solar drone according to one embodiment.

Figure 3 shows a schematic diagram of motor mount for the prototype solar drone according to one embodiment.

- 10 Figure 4a) shows a photograph of a portion of a truss structure for the prototype solar drone according to one embodiment.

Figure 4b) shows a schematic diagram of a frame structure for the prototype solar drone according to one embodiment.

Figure 4c) shows a schematic diagram of a detail of the frame structure for the prototype solar drone according to one embodiment.

- 15 Figure 4d) shows a schematic diagram of another detail of the frame structure for the prototype solar drone according to one embodiment.

Figure 4e) shows a schematic diagram of another detail of the frame structure for the prototype solar drone according to one embodiment.

- 20 Figure 4f) shows a schematic diagram of another detail of the frame structure for the prototype solar drone according to one embodiment.

Figure 5 shows images of stator and rotor assembly for the prototype solar drone according to one embodiment.

Figure 6 shows a flow-chart illustrating a method of interconnecting carbon fiber members according to an example embodiment.

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DETAILED DESCRIPTION

- 30 Embodiments of the present invention provide a fully solar powered quadcopter that can fly out of the ground effect, a major feat in aviation, given that flight endurance is a key challenge in drones of all types. The construction of the quadcopter according to example embodiments provides innovations in lightweight carbon fiber frame fabrication methods, careful selection and mounting of solar cells and motors, and other design innovations to advantageously achieve fully solar powered flight. Figure 1a) shows a photograph of a prototype solar drone 100 according to an example embodiment.

Figure 1b) and 1c) show photographs of the prototype solar drone 100 in-flight/hovering at 1 meter and 3 meters altitude above starting ground, respectively, demonstrating achievement of fully solar operation.

3D printed center mount to secure the 8 arms of the quadcopter (4 for motor arms, 4 for solar supporting arms), according to an example embodiment

The chassis of the solar drone 100 according to an example embodiment is made up of circular carbon fiber hollowed rods e.g. 102 of different diameters, and they are connected to each other with custom 3D printed carbon fiber joints (hidden in Figure 1) printed using carbon and nylon composite 3D printing technology in an example embodiment. The rods e.g. 102 are joined in the center of the aircraft with a 3D printed carbon and nylon composite center hub 200 which has circular slots e.g. 202 for four 12mm main arm rods and for circular slots e.g. 204 four 7mm support arm rods according to one embodiment, as shown in Figure 2. The whole frame (i.e. center hub 200 and rods e.g. 102) is preferably built without any screws according to example embodiments, except for the ones used to secure the motors and propellers. This advantageously saves weight and is also strong. The center hub 200 is designed to allow mounting supporting arms (for the solar cells) at an upward tilting angle, for example 3-degrees in one example embodiment, which advantageously balances downward deflection due to the weight of the solar cells.

Main quadcopter arms according to an example embodiment: 12mm x 100cm + 10mm x 5cm

With reference to Figure 1, the main arms e.g. 102 of the quadcopter are 12mm rods of 100cm in length, with short 10mm rods around 5cm in length inserted at the ends of each rod to attach the motor mounts, according to an example embodiments.

Supporting arms for solar cells according to an example embodiment: 7mm x 100cm

Carbon fiber arms used to support the solar platform are tilted upwards to account for the downward deflection due to the weight of the solar cells according to example embodiments, specifically 3-degrees upwards in an example embodiment. This design allows the resulting supporting platform for the solar cells to be horizontal, advantageously maximizing the solar power output.

Motor mount according to an example embodiment

The motor mounts e.g. 300 shown in Figure 3 are designed to be secured to carbon fiber rods, received in slot 302, with epoxy. The use of glue according to an example embodiment advantageously removes the need for screws, which are added weight. The landing gear (of the quadcopter) is integrated in the motor mount by way of the underside of the motor mount 300 allowing a 6mm landing gear rod e.g. 104 (Figure 1) to be fitted into the same piece, specifically into slot 304. The landing gear rods e.g. 104 (Figure 1) have been designed to be interference fitted into slot 304 for easy replacement according to an example embodiment.

The motors are fitted to the motor mount with two M3 screws in an example embodiment, received in slots e.g. 306.

Optional features according to an example embodiment

- 5 Due to the fixed distance between the M3 screw mountings of the motors used in an example embodiment, it does not allow the design of a motor mount to be used directly with 12mm rods e.g. 102 (Figure 1). The motor mount is thus designed and secured with a 10mm rod to be received in the slot 302, and the 10mm rod is subsequently inserted into the 12mm rods e.g. 102 (Figure 1) and secured with epoxy.

Gluing procedure and materials according to an example embodiment

- 10 Carbon nanotube infused resin is advantageously used for securing of carbon and nylon composite printed parts according to an example embodiment. The addition of carbon nanotubes into a two part epoxy resin preferably helps to form a better bond between the two separate pieces.

Frame design and construction method according to an example embodiment – method of bonding carbon fibers according to an example embodiment

- 15

The terms epoxy, resin, epoxy resin, superglue, glue and adhesive are intended to be interchangeably and synonymously herein, because many types of epoxy/resin/epoxy resin/superglue/glue/adhesives can be used and the result would be similar.

- 20 In an example embodiment, a carbon fiber truss structure 400 is constructed with carbon fiber rods e.g. 402, 403 angled to each other and bonded by epoxy resin e.g. 404, as shown in Figure 4a). In one non-limiting embodiment, the frame design 410 may be as shown in Figures 4b) to 4f). Specifically, the frame design 410 comprises 4 carbon fiber truss arms e.g. 412 connected to a center mount 413 and supporting solar cell mounting boards e.g. 414. Motor mounts e.g. 416 are provided on each arm e.g. 412 for mounting and supporting respective motors (not shown).
- 25

- In one example, the joints between the carbon fiber rods e.g. 402, 403 are first secured, end-to-end/connecting surface-to-connecting surface, with superglue, and then reinforced with carbon fiber fabric soaked with resin e.g. 404, which can be carbon nanotube infused, according to an example embodiment. It is noted that the use of superglue is optional. The carbon fiber rods e.g. 402, 403 can be held in place with any method. It is also noted that, as mentioned the carbon fiber rods e.g. 402, 403 are joint end-to-end/connecting surface-to-connecting surface, rather than using mechanical interconnection structures (such as created via nesting or insertion for mechanical overlap). This greatly increases the versatility of forming the joints where desired and without the need for mechanical adaptation of the carbon fiber rods.
- 30

- 35 Preferably, carbon fiber fabric is wrapped around the joints to soak up the epoxy resin e.g. 404 and keep it concentrated at the joint area. It is noted that the epoxy resin e.g. 404 may be provided at the joint prior to the carbon fiber fabric being wound around the joint, and/or the carbon fiber fabric may additionally be soaked with epoxy resin e.g. 404 prior to being wound

around the joint.. This advantageously also maximizes the contact area of the epoxy-soaked fabric to the rods e.g. 402, 403 allowing better bond strength in theory. This is an important construction procedure according to such embodiments, since the bond point of carbon fiber members, specifically angled carbon fiber rods is usually weak structurally, and has prevented the use of truss structures in carbon-fiber drones in the past. The resulting structure is substantially strong and resistant to flexing.

In one non-limiting example embodiment, a weaved carbon fiber single-layer fabric was used, specifically a cross-weaved carbon fiber single-layer fabric, and it was wrapped one or more times around the joint, while soaked in epoxy resin, specifically cyanoacrylate.

Until now, there has not been an easy construction method to join carbon fiber rods together, especially at unusual angles like those needed for trusses. Accordingly, the carbon fiber member bonding method to form a carbon fiber structure, such as truss structure 400, may thus find application outside the area of drones.

Compared to existing methods such as securing carbon fiber with joints, which add weight, the method according to example embodiments has the advantage that much less weight is required, enabling lightweight structures, such as lightweight aircraft and specifically solar aircraft.

The combination of having the joints wrapped with epoxy or adhesive-soaked carbon fiber fabric advantageously give the joints their strength, providing substantial weight savings without sacrificing strength.

Figure 6 shows a flow-chart 600 illustrating a method of interconnecting carbon fiber members, according to an example embodiment. At step 602, interconnecting surfaces of the carbon fiber members are secured in a desired alignment. At step 604, an epoxy resin soaked carbon fiber fabric wrapped around portions of the carbon fiber members including the interconnecting surfaces is provided.

The method may comprise providing the epoxy resin on the portions of the carbon fiber members and/or pre-soaking the carbon fiber fabric with the epoxy resin.

The epoxy resin may be infused with carbon nanotubes.

The carbon fiber members may comprise carbon fiber rods.

Electrical and wiring according to example embodiments

Solar cell selection according to an example embodiment

Monocrystalline solar cells are selected for high efficiency in an example embodiment. Back-contact cells that have the bus wires on the non-sunlight absorbent surface are preferred to conventional cells that have the bus wires on the sunlight absorbent surface so as to maximize the area of sunlight absorbent surface.

Wiring selection according to an example embodiment

Aluminum wires are used in an example embodiment over conventional copper wires for the power distribution lines of the multi-copter, for good ratio of conductivity to weight. The aluminum wires that are used in an example embodiment have a thin polymer coating as insulation which is much lighter than the silicone coating used to insulate most copper wires.

Solar platform design according to an example embodiment

With reference to Figure 1, foam boards e.g. 106 are used as the supporting platform for solar cells in an example embodiment due to their lightweight properties.

The foam boards e.g. 106 have holes e.g. 108 cut into them by having material strategically removed through laser cutting, with the solar cells e.g. 110 positioned in the holes e.g. 108 on the foam boards e.g. 106. The holes e.g. 108 are cut into the foam boards e.g. 106 to reduce the weight of the quadcopter 100, while providing adequate support for the solar cells e.g. 110. The holes e.g. 108 also serve to expose the underside of the solar cells e.g. 110 to facilitate heat dissipation by air, hence improving the electrical properties by reducing the temperature of the solar cells e.g. 110. Each solar cell e.g. 110 is positioned over a hole e.g. 108 and secured to the foam board e.g. 106 with the use of adhesive tape on the underside of the foam board e.g. 106, in an example embodiment.

Motor Selection according to an example embodiment

Low KV outrunner motors 500 shown in Figure 5 and coupled with large carbon-fiber propellers e.g. 112 (Figure 1) for high thrust to power ratio are used in an example embodiment. The wider motors 500, as compared to high KV motors as will be appreciated by a person skilled in the art, are able to produce a greater torque and the distance from the shaft 502 to the rotor magnets 504 is increased. This torque is advantageous to reduce the electrical power required to spin a larger propeller e.g. 112 (Figure 1) in an example embodiment.

In turn, larger propellers e.g. 112 (Figure 1) are able to produce more thrust due to the increased size of the airfoils, but they are also heavier, and hence a motor with sufficient torque to overcome the airfoils higher inertia is used in an example embodiment.

The lower the KV rating of a motor, the slower it spins. This is advantageous as a motor that spins very fast is usually less efficient due to the energy lost to the air resistance of the propeller against the surrounding air, and friction in the ball bearings 506.

Advantageous of a Solar Quadcopter according to an example embodiment

The solar quadcopter 100 (Figure 1) according to an example embodiment can solve a key problem that all drones face today: endurance. Typical Multi-copters (such as quadcopter drones) have a limited flight time of 30 minutes or so. The prototype quadcopter 100 shows that unlimited flight time is available to drones with use of solar power. In fact, the solar quadcopter 100 can fly as long as the sun is shining, be it minutes, or even hours. During bits of cloudy weather, the solar quadcopter 100 can simply land on any flat surface and wait for

the sun. Alternatively, a battery could hypothetically be carried on board and charged during sunny flight for use during cloudy weather or night, according to an example embodiment. With the use of solar power for a multi-copter, a multi-copter according to an example embodiment is able to achieve flight whenever there is sun. This extended range extends both the flight time, and flight range of the multi-copter. Addition of battery allows a multi-copter according to an example embodiment to be charged in full sunlight and still achieve flight for a certain period of time with lower light levels or darkness.

The solar quadcopter 100 according to an example embodiment also solves another key challenge facing all drones today: the need to return to a base station and charge their batteries.

The quadcopter 100 can theoretically fly across oceans and continents, and can fly above the cloud cover as well.

Conventional motor mounts used in typical multi-copters, even though being typically modular, weigh a lot due to the weight of screws. In an example embodiment, the motor mount is a motor mount and landing gear integrated without the use of screws, except the screws required to secure the motor to the mount itself.

Conventional center mounts used in typical quadcopters only have four extended arms for the motors. Such a design requires additional supporting structures to support the solar cells on a platform. With an added eight-arm center mount according to an example embodiment, the four additional arms can provide adequate support for the solar platform with minimal weight. While most existing quadcopters have carbon fiber rod arms attached to each other in the center via the use of aluminum clamps and screws, which add considerable weight, the multi-copter design according to an example embodiment uses only carbon fiber.

A Carbon fiber truss frame used in an example embodiment will further reduce the total weight of the quadcopter, compared to designs that utilize carbon fiber rods.

Even though copper wires are more conductive, they weigh much more than aluminum. It was found by the inventors that the added weight of copper is not worth its improved conductivity. Therefore, aluminum was chosen as the conductor for the quadcopter according to an example embodiment. It is noted that this is likely true for any quadcopter design, not just those which are solar powered.

Industrial applications of example embodiments can include aerial imagery at a fraction of the cost of satellite imaging.

The main benefit of a solar quadcopter according to an example embodiment would be its extended flight time, which is beneficial in essentially all applications of current drone technology:

- 3D façade mapping of buildings, and other surveillance.
- Carrying and delivery of small packages over a much greater range than traditional drones.

- Construction work progress monitoring since construction work is often carried out in the day when the sun is abundant.

- Use in disaster relief. In disaster stricken zones where electricity supply is unavailable or scarce, the quadcopter can serve as a portable and mobile solar power plant that can fly itself to whichever region requires electrical power the most.

The aircraft according to an example embodiment does not need to return to a base station. Having the ability to recharge an onboard battery with solar panels in an example embodiment, the aircraft can fly, land, recharge, and then fly again, potentially giving it unlimited flight range, which could be used for low-cost international or trans-atlantic package delivery services.

Modifications according to other example embodiments

The current prototype described herein is relatively large. This is primarily because silicon solar cells were used due to cost. In different embodiments, different solar cells such as high efficiency triple junction cells can be used, which can reduce the size of the aircraft to the size of an ordinary quadcopter drone. With the use of the more efficient carbon fiber truss structure according to another example embodiment, the size of the solar quadcopter can be reduced further.

Also, with an added supercapacitor or small battery in another example embodiment, extra power can be supplemented whenever required and for emergency landing purposes.

As another example, while fixed motor mounts and arms are used in the example embodiment described herein, a modular center mount can be designed in a different example embodiment to enable the changing of individual arms.

Another modification according to different embodiments of the present invention is that, rather than truss arms extending from a centre mount, the entire platform for the multi-copter can be of the type of a space truss constructed of carbon fiber rods joined using the method described above. Furthermore, in such embodiments, instead of resting on foam, the solar cells may rest on the space truss.

Embodiments of the present invention can have one or more of the following features and associated benefits:

1. The use of all carbon fiber hubs to join the carbon fiber rods together, which is much stronger and lighter than the use of screws.
2. The method of joining carbon fiber rods into a truss structure with the epoxy-and-tape method.
3. The use of aluminum instead of copper electrical wiring in drones.
4. The use of laser-cut holes in the foam/backing of the solar cells to save weight.

The above description of illustrated embodiments of the systems and methods is not intended to be exhaustive or to limit the systems and methods to the precise forms disclosed. While specific embodiments of, and examples for, the systems components and methods are described
5 herein for illustrative purposes, various equivalent modifications are possible within the scope of the systems, components and methods, as those skilled in the relevant art will recognize. The teachings of the systems and methods provided herein can be applied to other processing systems and methods, not only for the systems and methods described above.

The elements and acts of the various embodiments described above can be combined to provide
10 further embodiments. These and other changes can be made to the systems and methods in light of the above detailed description.

In general, in the following claims, the terms used should not be construed to limit the systems and methods to the specific embodiments disclosed in the specification and the claims, but should be construed to include all processing systems that operate under the claims.
15 Accordingly, the systems and methods are not limited by the disclosure, but instead the scope of the systems and methods is to be determined entirely by the claims.

Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in a sense of "including, but not
20 limited to." Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words "herein," "hereunder," "above," "below," and words of similar import refer to this application as a whole and not to any particular portions of this application. When the word "or" is used in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of
25 the items in the list and any combination of the items in the list.

CLAIMS

1. A multi-copter capable of solar powered operation in solar radiation exposed conditions without requiring an on-board energy storage device.
2. The multi-copter of claim 1, wherein a frame structure of the multi-copter comprises carbon fiber rods interconnected in a screw-less manner.
3. The multi-copter of claim 2, wherein the frame structure comprise glued interconnections.
4. The multi-copter of claim 3, wherein the glued interconnections comprise epoxy resin.
5. The multi-copter of claim 4, wherein the epoxy resin is carbon nanotube infused.
6. The multi-copter of any one of claims 2 to 5, wherein the carbon fiber rods are interconnected via a carbon fiber center mount.
7. The multi-copter of claim 6, wherein the center mount is 3D printed.
8. The multi-copter of claims 6 or 7, wherein the center mount comprises a plurality of slots for receiving respective ones of the carbon fiber rods.
9. The multi-copter of any one of claims 2 to 8, wherein the carbon fiber rods are interconnected via angled carbon rod-to-carbon rod joints to form a carbon fiber truss structure.
10. The multi-copter of claim 9, wherein the joints comprise glue soaked carbon fiber fabric wrapped around a bond point of each joint.
11. The multi-copter of any one of claims 2 to 10, wherein the frame structure comprises a plurality of support arms for supporting solar cells.
12. The multi-copter of claim 11, wherein the support arms are tilted upwards relative to an in-flight orientation of the multi-copter from a center of the frame structure such that the support arms, under a load exerted by the solar cells, provide a substantially horizontal support plane for the solar cells.
13. The multi-copter of any one of claims 2 to 12, wherein the frame structure comprises a plurality of motor arms for mounting of motors of the multi-copter.
14. The multi-copter of claim 13, wherein the motors are mounted to the motor arms by way of respective motor mounts.
15. The multi-copter of claim 14, wherein the motor mounts are configured to be glued to the motor arms.
16. The multi-copter of claims 14 or 15, wherein the motor arms comprise carbon fiber adaptors coupled between the motor mounts and carbon fiber rods of the motor arm.

17. The multi-copter of any one of claims 14 to 16, wherein the motor mounts are configured to be coupled to landing gear of the multi-copter.
18. The multi-copter of claim 17, wherein the motor mounts may be configured to be coupled to the landing gear via interference fit.
- 5 19. The multi-copter of any one of claims 1 to 18, wherein the multi-copter comprises electrical wiring made from aluminum wire.
20. The multi-copter of claim 19, wherein the aluminum wire is encapsulated or coated with an electrically insulating substance or material for insulation.
21. The multi-copter of any one of claims 1 to 20, wherein the multi-copter comprises a
10 board coupled to the frame structure for supporting the solar cells.
22. The multi-copter of claim 21, wherein the board is made from foam.
23. The multi-copter of claims 21 or 22, wherein the board comprises holes for receiving the solar cells.
24. The multi-copter of claim 23, wherein the holes are through-holes for exposing the
15 backsides of the solar cells for improved airflow and heat dissipation.
25. The multi-copter of any one of claims 1 to 24, wherein the solar cells comprise back-contact solar cells.
26. The multi-copter of any one of claims 1 to 25, wherein the multi-copter comprises low KV outrunner motors.
- 20 27. The multi-copter of claim 26, wherein the low KV outrunner motors is coupled to propellers, wherein the size of the airfoils of the propellers is chosen based on the torque of the low KV outrunner motors.
28. The multi-copter of any one of claims 1 to 27, wherein the multi-copter comprises an on-board energy storage device for enabling operation in non-solar exposed conditions.
- 25 29. The multi-copter of any one of claims 1 to 28, wherein the multi-copter comprises a quadcopter.
30. The multi-copter of any one of claims 1 to 28, wherein the frame structure comprises a space truss structure.
31. A method of fabricating the multi-copter of any one of claims 1 to 30.
- 30 32. The method of claim 31, comprising forming glued interconnections of carbon fiber rods for a frame structure of the multi-copter.
33. The method of claim 32, wherein the glued interconnections comprise epoxy resin.
34. The method of claim 33, wherein the epoxy resin is carbon nanotube infused.

35. The method of any one of claims 32 to 34, wherein the carbon fiber rods are interconnected via a carbon fiber center mount.
36. The method of claim 35, wherein the center mount is 3D printed.
37. The method of claims 35 or 36, comprising receiving respective ones of the carbon fiber rods in a plurality of slots of the center mount.
38. The method of any one of claims claim 32 to 37, wherein the carbon fiber rods are interconnected via angled carbon rod-to-carbon rod joints to form a carbon fiber truss structure.
39. The method of claim 38, wherein the mechanism for interconnection comprises wrapping glue soaked carbon fiber fabric around a bond point of each joint.
40. The method of any one of claims 31 to 39, comprising forming a plurality of support arms for supporting solar cells.
41. The method of claim 40, wherein the support arms are tilted upwards relative to an in-flight orientation of the multi-copter from a center of the frame structure such that the support arms, under a load exerted by the solar cells, provide a substantially horizontal support plane for the solar cells.
42. The method of any one of claims 31 to 41, comprising forming a plurality of motor arms for mounting of motors of the multi-copter.
43. The method of claim 42, wherein the motors are mounted to the motor arms by way of respective motor mounts.
44. The method of claims 42 or 43, wherein the motor mounts are glued to the motor arms.
45. The method of any one of claims 42 to 44, wherein carbon fiber adaptors are coupled between the motor mounts and carbon fiber rods of the motor arm.
46. The method of any one of claims 42 to 44, wherein the motor mounts are coupled to landing gear of the multi-copter.
47. The method of claim 46, wherein the motor mounts are coupled to the landing gear via interference fit.
48. The method of any one of claims 31 to 47, comprising providing electrical wiring for the multi-copter made from aluminum wire.
49. The method of claim 48, wherein the aluminum wire is encapsulated or coated with an electrical insulating substance or material for insulation.
50. The method of any one of claims 31 to 49, comprising coupling a board to the frame structure for supporting the solar cells. The board may be made from foam.

51. The method of claim 50, comprising forming holes in the board for receiving the solar cells.
52. The method of claim 51, wherein the holes are through-holes for exposing the backsides of the solar cells for improved airflow and heat dissipation.
- 5 53. The method of claim 52, wherein the solar cells comprise back-contact solar cells.
54. The method of any one of claims 31 to 53, comprising coupling low KV outrunner motors to the frame structure.
55. The method of claim 54, wherein the low KV outrunner motors are coupled to propellers, wherein a size of the airfoils of the propellers is chosen based on the torque of the
10 low KV outrunner motors.
56. The method of any one of claims 31 to 55, comprising providing an on-board energy storage device for enabling operation in non-solar exposed conditions.
57. The method of any one of claims 31 to 56, wherein the frame structure comprises a space truss structure.
- 15 58. A method of interconnecting carbon fiber members, the method comprising
securing interconnecting surfaces of the carbon fiber members in a desired alignment; and
providing an epoxy resin soaked carbon fiber fabric wrapped around portions of the carbon fiber members including the interconnecting surfaces.
59. The method of claim 58, comprising providing the epoxy resin on the portions of the
20 carbon fiber members and/or pre-soaking the carbon fiber fabric with the epoxy resin.
60. The method of claims 58 or 59, wherein the epoxy resin is infused with carbon nanotubes.
61. The method of any one of claims 58 to 60, wherein the carbon fiber members comprise carbon fiber rods.

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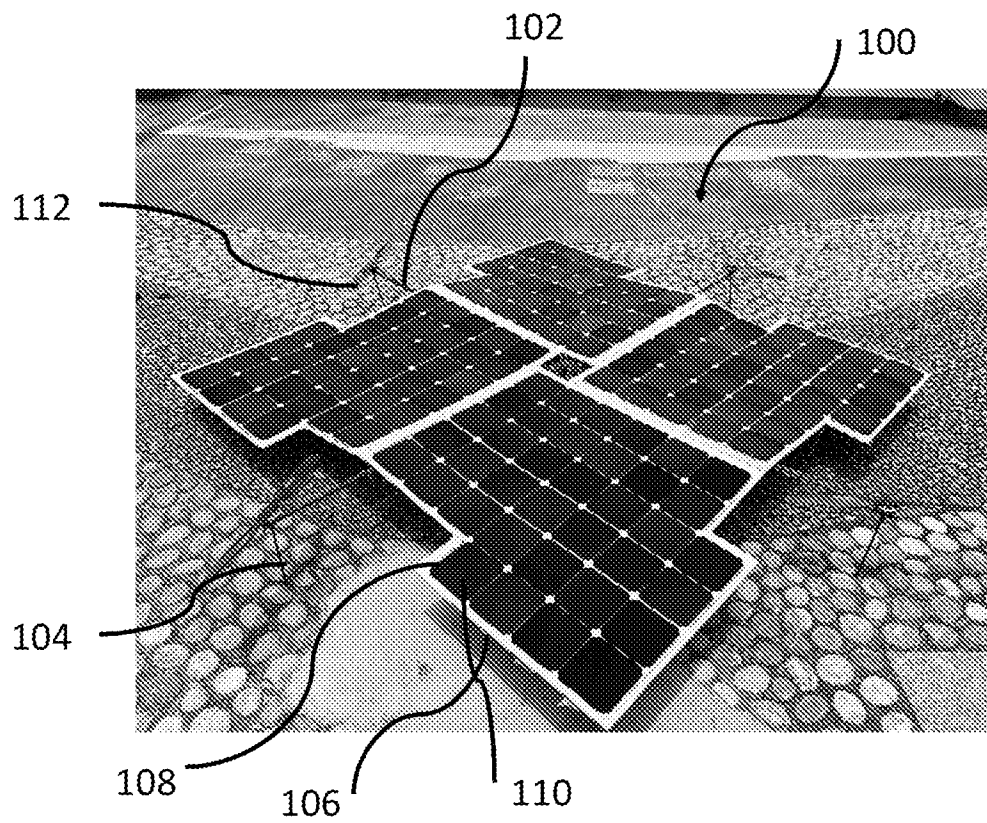


Figure 1a)

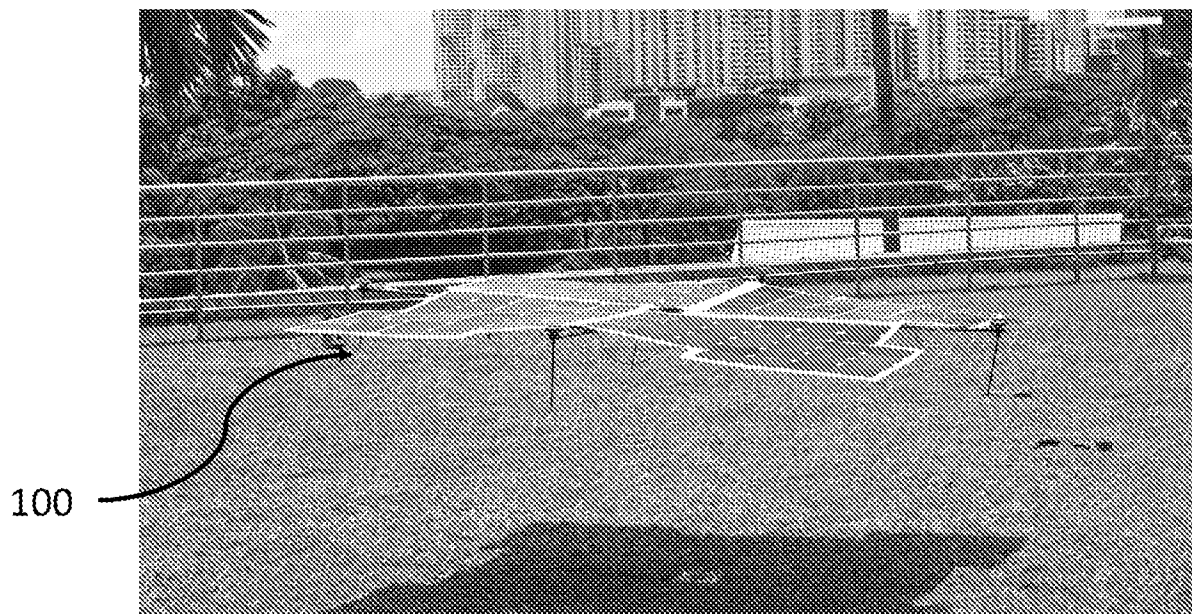


Figure 1b)

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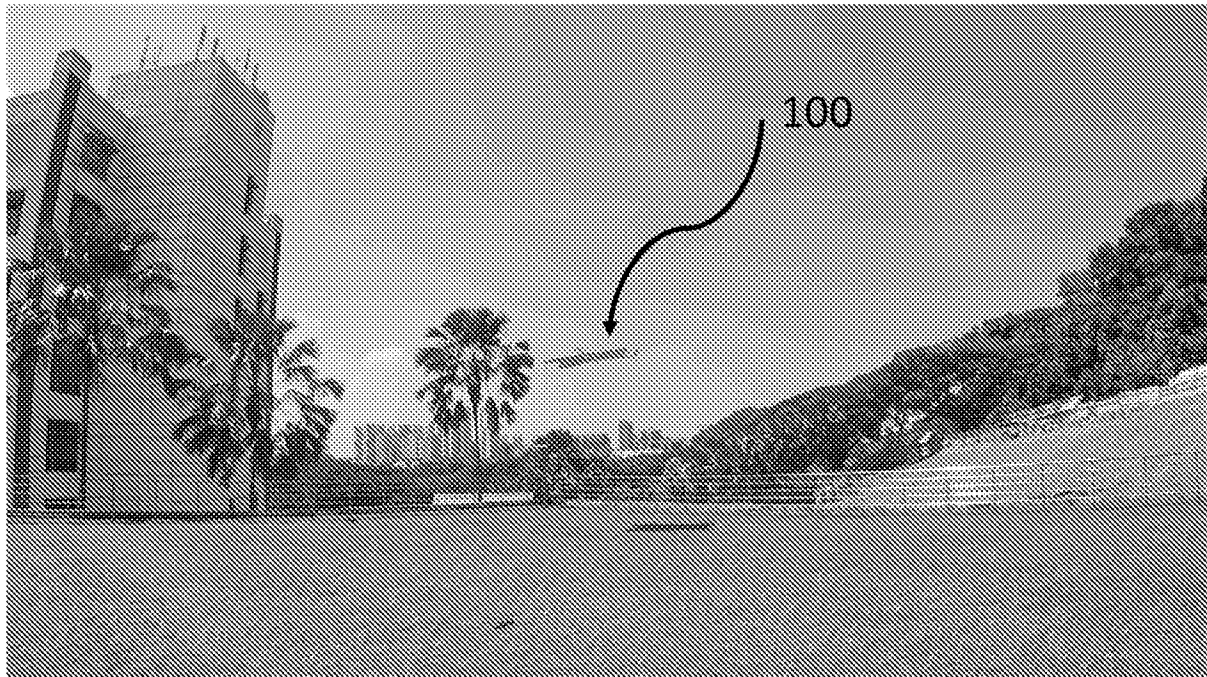


Figure 1c)

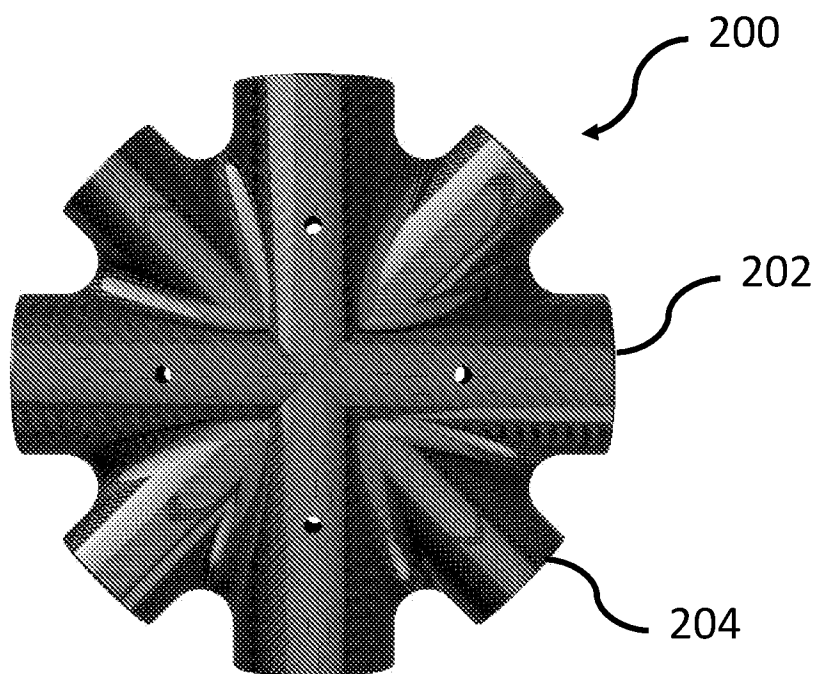


Figure 2

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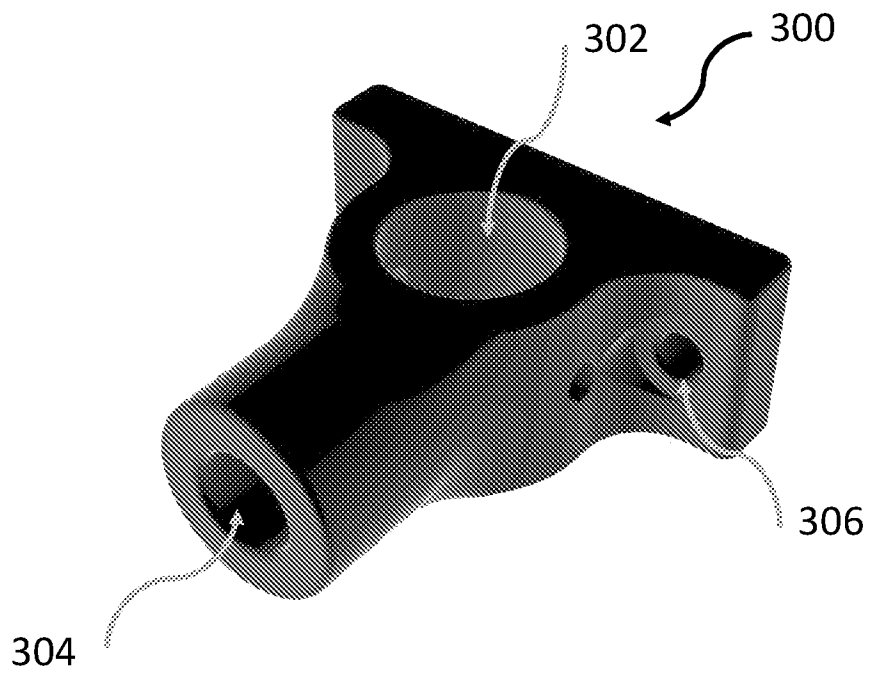


Figure 3

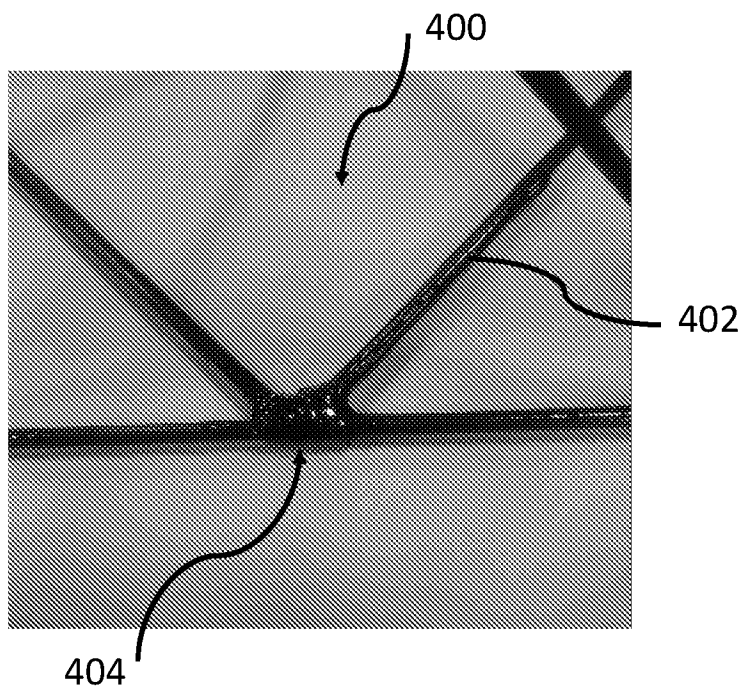


Figure 4a)

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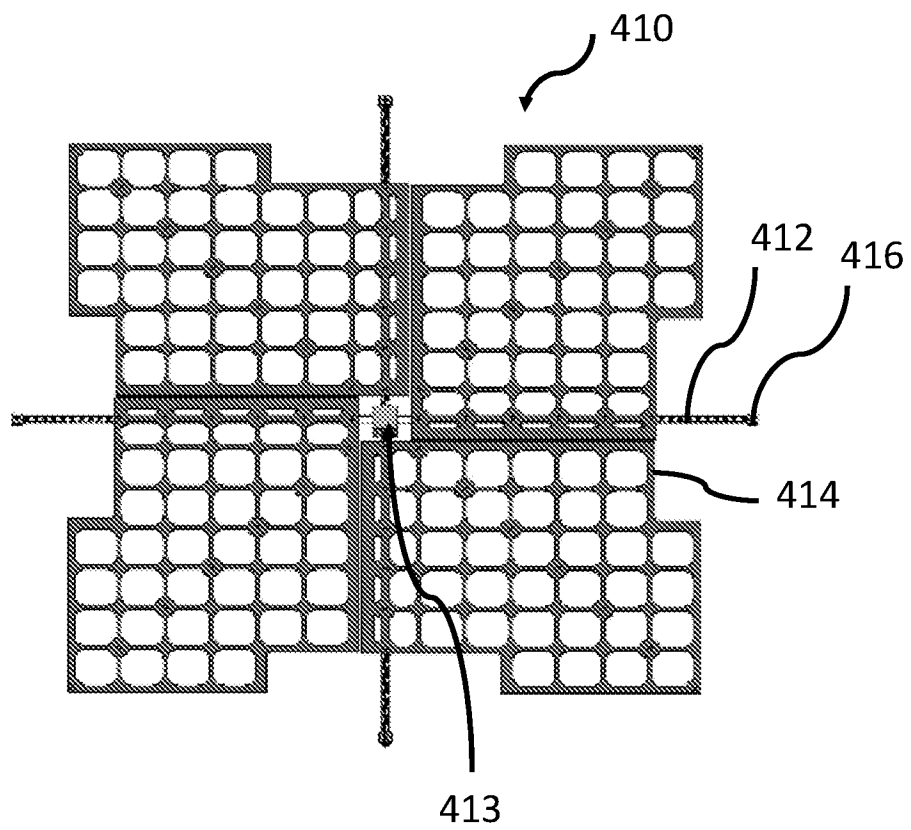


Figure 4b)

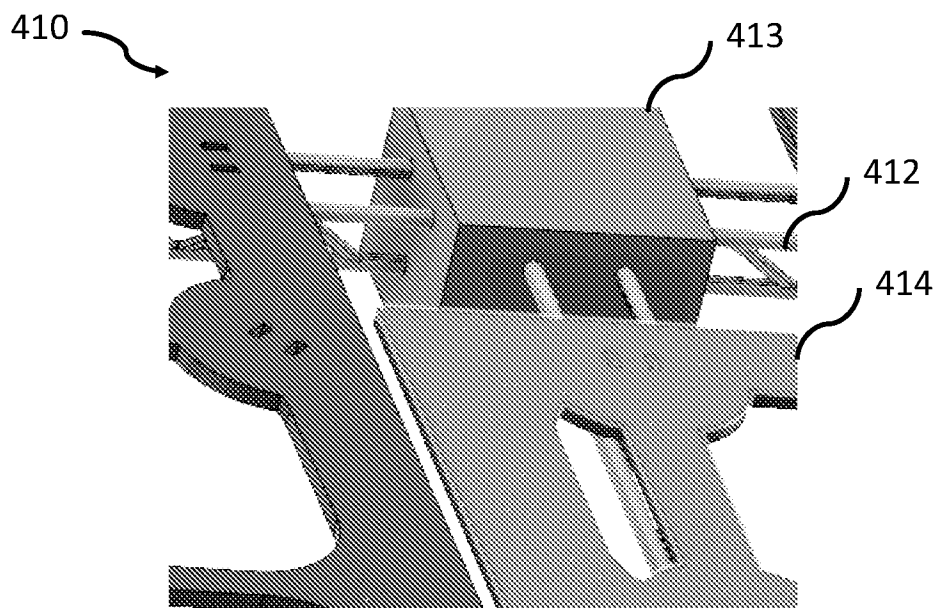


Figure 4c)

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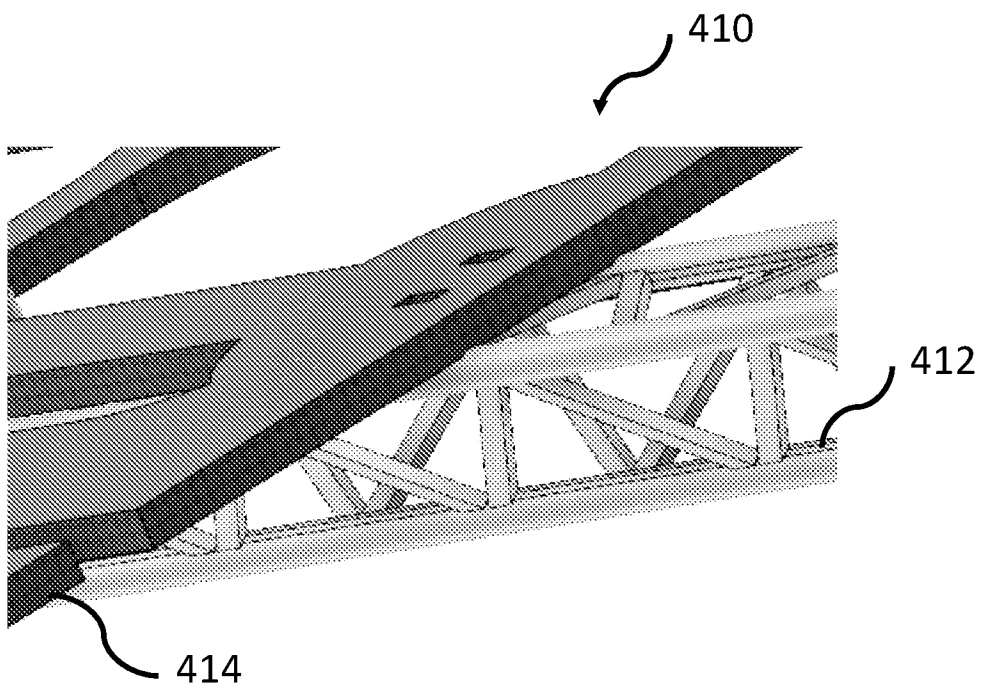


Figure 4d)

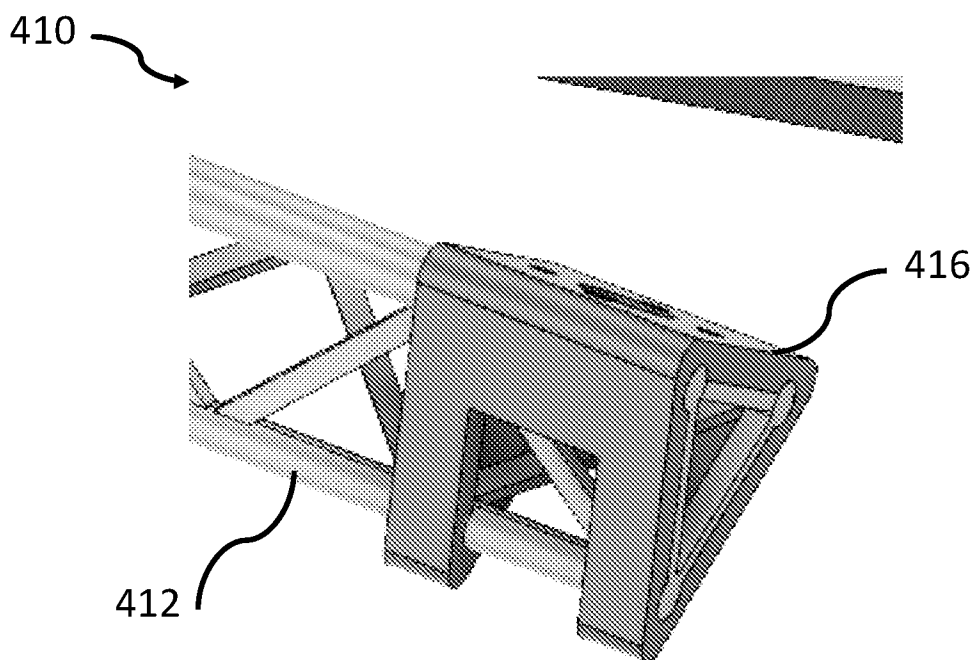


Figure 4e)

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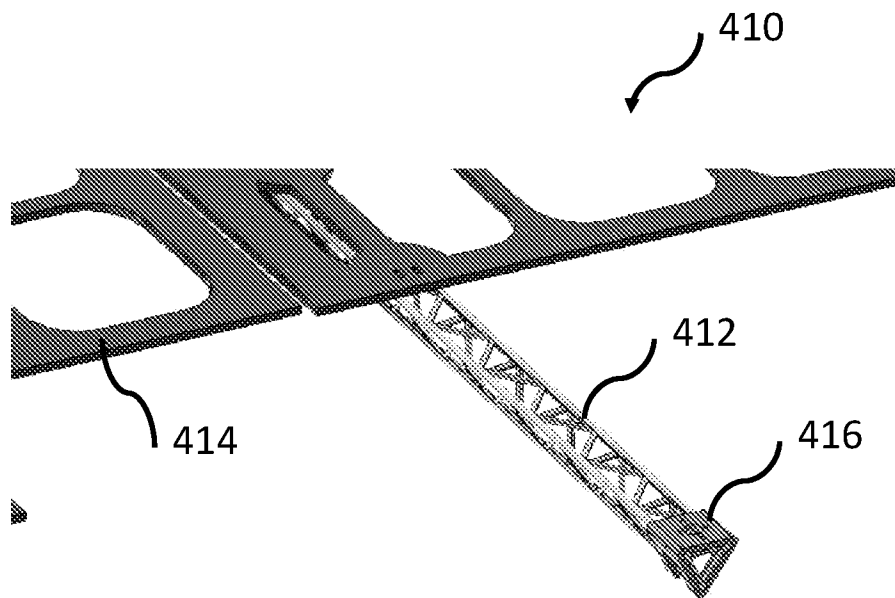


Figure 4f)

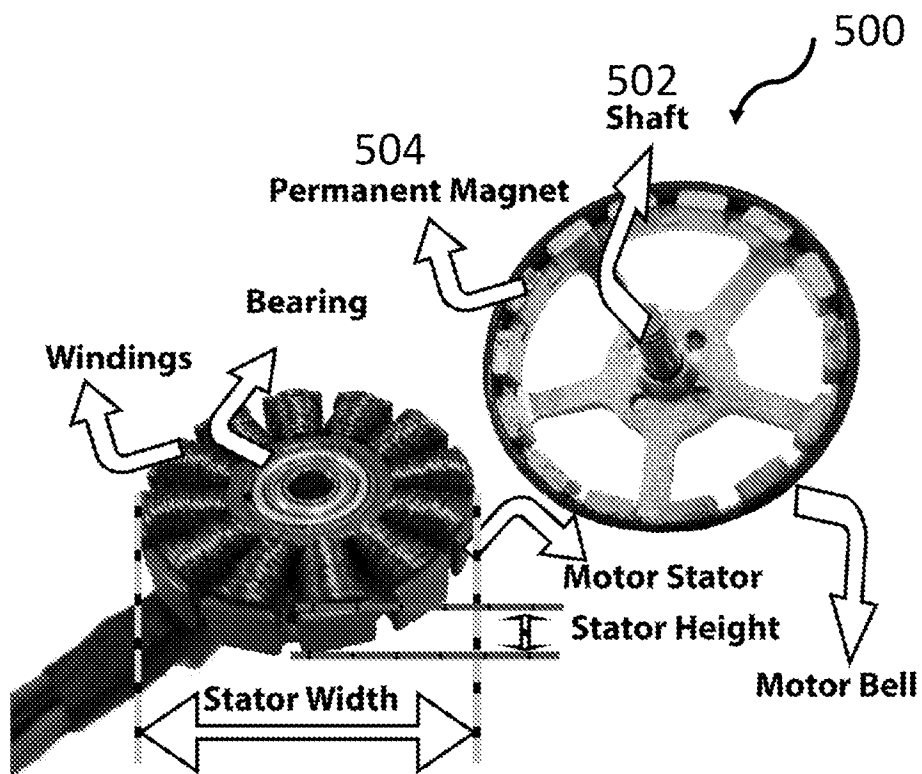


Figure 5

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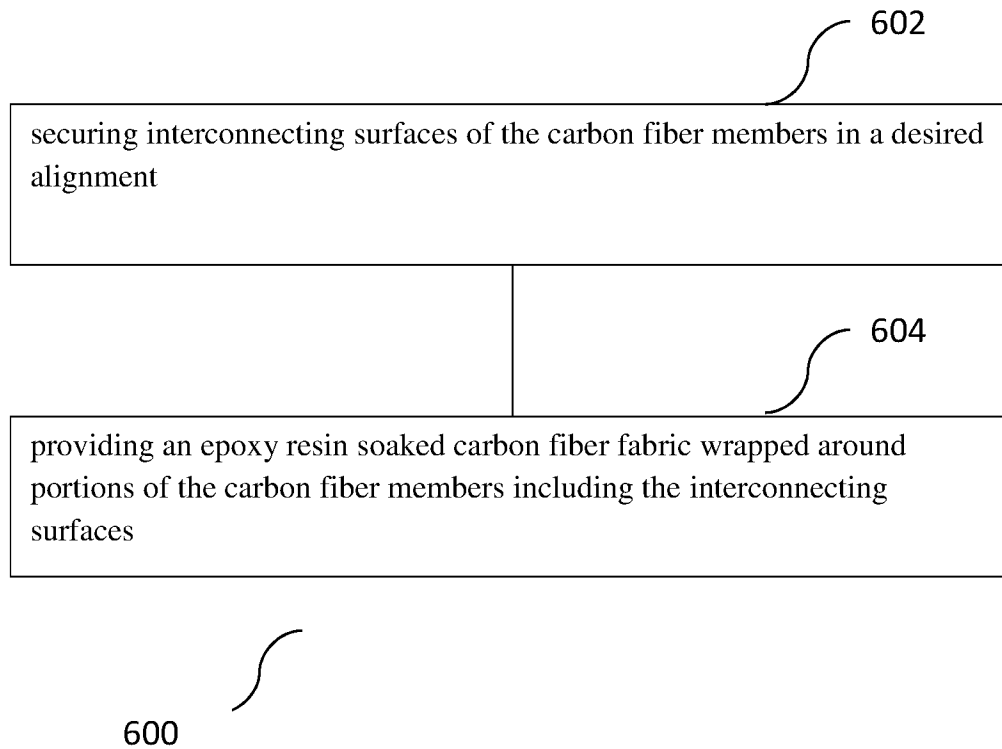


Figure 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2019/050322

A. CLASSIFICATION OF SUBJECT MATTER

See Supplemental Box

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B60L, B29C, H02S

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)

Database: FAMPAT

Keywords: Multi-copter, drone, UAV, quadcopter, rotorcraft, solar, photovoltaic, fully, totally, solely, battery, super-capacitor, carbon fiber, wrapped, cover, bind, encase, patch, fabric, cloth, 无人机, 旋翼机, 飞行器, 太阳能, 纯, 无, 电池, 电容, 碳纤维, 包扎, 缠, 裹, 布, 织 and related terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2018/094797 A1 (WEN JINWEI) 31 May 2018 Para [0009], [0019] and Fig.1, 3 of the original non-English language document (a machine translation is enclosed only for your reference)	1-8, 10-29, 31-37, 39-56 9, 30, 38, 57
X	CN 204726661 U (NANCHANG HANGKONG UNIVERSITY) 28 October 2015 Para [0002]-[0004] and Fig.1 of the original non-English language document (a machine translation is enclosed only for your reference)	1-57
A	US 2018/0029477 A1 (GOJCAJ S.) 1 February 2018 Whole document, in particular Para [0008] and Fig.1, 2	
Y	CN 106741907 A (BEIJING TIANYU XINCHAO AVIATION TECHNOLOGY CO LTD) 31 May 2017 Para [0003] and Fig.1 of the original non-English language document (a machine translation is enclosed only for your reference)	9, 30, 38, 57

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

*Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

17/09/2019

(day/month/year)

Date of mailing of the international search report

18/09/2019

(day/month/year)

Name and mailing address of the ISA/SG



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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2019/050322

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 103029293 A (HARBIN INSTITUTE OF TECHNOLOGY) 10 April 2013 Para [0003]- [0007] of the original non-English language document (a machine translation is enclosed only for your reference)	58-61
X	WO 90/10570 A1 (CALFEE C. D.) 20 September 1990 Pg.8 L2-21 and Fig.3	58-61
X	CyclingTips: Black magic: How carbon fibre bicycle frames are made. 4 January 2018 [Retrieved on 2019-09-17 from https://cyclingtips.com/2018/01/how-carbon-fibre-bicycle-frames-are-made/] Section [TUBE TO TUBE]	58-61
A	BikeRadar: Graphene bicycles - the potential future of composites. 4 February 2015 [Retrieved on 2019-09-17 from https://www.bikeradar.com/features/graphene-bicycles-the-potential-future-of-composites/] Whole document	
A	Sustainable Nano: Nanomaterials in bicycles???? Part 1. 16 February 2016 [Retrieved on 2019-09-17 from http://sustainable-nano.com/2016/02/16/nanomaterials-in-bicycles-part-1/] Whole document	
P,X	TWI642597 B (PSJ INTERNATIONAL LTD) 1 December 2018 & US 2019/0161187 A1 Para [0087]-[0088] and Fig.6, 7 of the patent family member	1-4, 9, 11, 13, 29, 31-33, 38, 40, 42

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2019/050322

Supplemental Box (Classification of Subject Matter)

Int. Cl.

B60L 8/00 (2006.01)

B29C 65/54 (2006.01)

H02S 10/40 (2014.01)

H02S 30/10 (2014.01)

B29C 65/50 (2006.01)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2019/050322**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:

because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:

because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:

because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please refer to Supplemental Box (Continuation of Box No. III).

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2019/050322

Supplemental Box **(Continuation of Box No. III)**

This International Searching Authority found multiple inventions in this international application, as follows:

Group 1: Claims 1-57

A multi-copter capable of solar powered operation without requiring an on-board energy storage device.

Group 2: Claims 58-61

A method of interconnecting carbon fiber members comprising providing an epoxy resin soaked carbon fiber fabric wrapped around portions of the carbon fiber members.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied a priori.

Please refer to **Box No. IV** of Written Opinion of The International Searching Authority (Form PCT/ISA/237) for detailed explanation.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2019/050322

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2018/094797 A1	31/05/2018	CN 206187335 U	24/05/2017
CN 204726661 U	28/10/2015	NONE	
US 2018/0029477 A1	01/02/2018	NONE	
CN 106741907 A	31/05/2017	NONE	
CN 103029293 A	10/04/2013	NONE	
WO 90/10570 A1	20/09/1990	EP 0440753 A1 DE 69009726 T2 US 5116071 A US RE35335 E	14/08/1991 12/01/1995 26/05/1992 24/09/1996