Design of a Drone with a Robotic End-Effector

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ABSTRACT

The concept presented involves a combination of a quadcopter drone and an end-effector arm, which is designed with the capability of lifting and picking fruits from an elevated position. The inspiration for this concept was obtained from the swarm robots which have an effector arm to pick small cubes, cans to even collecting experimental samples as in case of space exploration. The system as per preliminary analysis would contain two physically separate components, but linked with a common algorithm which includes controlling of the drone's positions along with the movement of the arm.

Keywords

Drone, end effector, autonomous, payload.

1. INTRODUCTION

A robot is a machine that is programmable and capable of carrying out a series of complex actions automatically. Robots can be guided by an external control device or the control may be embedded within. Robots may be constructed to take on a human form, but most robots are machines designed to perform a task with little regard to how they look. Robots can be autonomous or semi-autonomous such as Honda's Advanced Step in Innovative Mobility, also known as ASIMO, and TOSY's Ping Pong Playing Robot (TOPIO) which are marvels in the field of robotics. In addition to this there is considerable progress seen in area of industrial robots, medical robots, patent assisting robots, human rehabilitation, athletic training robots, and a whole set of more applications. In addition to land-based robots there is also developments in the bots used for aerospace and marine applications. By mimicking a lifelike appearance or automating movements, a robot may convey a sense of intelligence or thought of its own.

An unmanned aerial vehicle (UAV), commonly known as a drone, is an aircraft without a human pilot aboard. UAVs are a component of an unmanned aircraft system (UAS) which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy either under remote control by a human operator, or fully or intermittently autonomously by on-board computers. For example, the widely-used predator drone for military purposes is the MQ-1 by General Atomics which is remote controlled, UAVs typically fall into one of six functional categories (i.e. target and decoy, reconnaissance, combat, logistics, R&D, civil and commercial).

With the advent of aerial robotics technology, UAVs became more sophisticated and led to development of quadcopters which gained popularity as mini-helicopters. A quadcopter, also known as a quadrotor helicopter, is lifted by means of four rotors. In operation, the quadcopters generally use two pairs of identical fixed pitched propellers; two clockwise (CW) and two counterclockwise (CCW). They use independent variation of the speed of each rotor to achieve control. By varying the speed of each rotor, it is possible to specifically generate a desired total thrust, to locate for the center of thrust both laterally and longitudinally, and to create a desire total torque or turning force. In addition to this development, quadcopters were designed to adopt an end effector. In robotics, an end effector is the device at the end of a robotic arm designed to interact with the environment. The exact nature of this device depends on the application of the robot.

In the strictest definition, which originates from serial robotic manipulators, the end effector is the last link (end) of the robot. At this endpoint, the tools are attached. In a wider sense, an end effector is the part of a robot that interacts with the work environment. This does not refer to the wheels of a mobile robot nor the feet of a humanoid robot which are not end-effectors because they are part of the robot's mobility.

End effectors may consist of a gripper or a tool. When referring to robotic end-effectors, there are four broad categories of robot grippers. These are (a) Impactive – jaws or claws which physically grasp by direct impact upon the object, (b) Ingressive – pins, needles or hackles which physically penetrate the surface of the object (used in textile, carbon and glass fiber handling), (c) Astrictive – suction forces applied to the objects surface (whether by vacuum, magneto- or electro adhesion) and (d) Contigutive – requiring direct contact for adhesion to take place (such as glue, surface tension or freezing) [10].

2. LITERATURE SURVEY

Mendoza et al. [1] introduced a conceptual design which involved using multiple quadrotors programmed to make use of the yaw movement, linked to each other using a bar containing end effectors as seen in Figure 1. This paper aimed to introduce and spread an extensive mathematical formality that is used to build a new kind of UAV manipulator. The main contribution of this paper was to introduce the possibility of linkages that could be created between two systems.

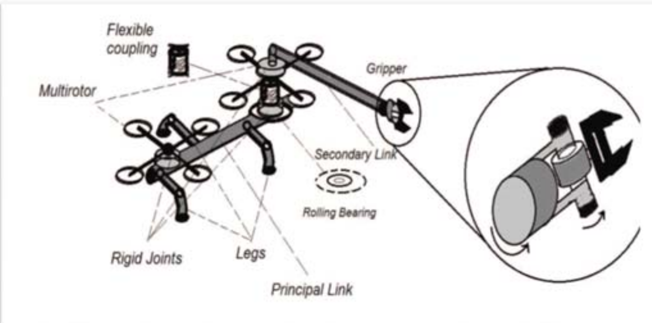

Figure 1. Air-arm and end-effector

A parallel manipulator with robustly maintained precise end effector position stowed below a quadrotor UAV used for lifting of light weight mass was developed by Danko et al. [2] They also proposed, constructing a six degree of freedom parallel manipulator which is used to robustly maintain precise end effector positions despite post-UAV perturbations. The parallel manipulator allows for very little moving mass and is easily stored below a quad rotor UAV as can be visualized from Figures 2 and 3.

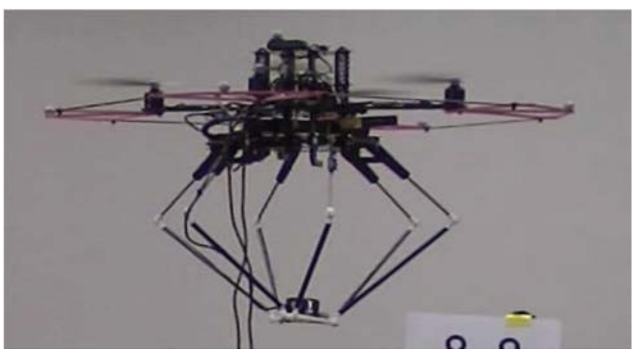

Figure 2. Parallel manipulator extended

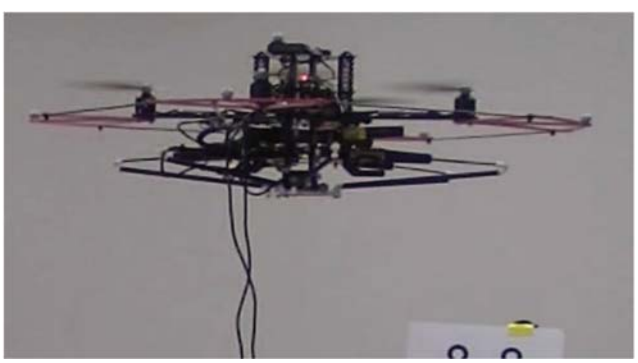

Figure 3. Parallel manipulator stowed

Paul et al. [3] introduced the concept of a hyper-redundant manipulator as seen in Figure 4 to be used for the mobile manipulating UAVs. The flexibility of the links was observed by authors when the arm was programmed in MATLAB for moving in the shape of eight as seen in Figure 5 for testing the controllers.

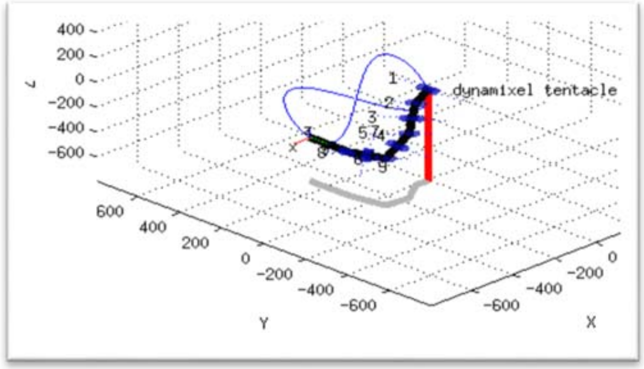

Figure 4. Hyper redundant arm

It can be controlled in such a way that links is moved within the arm's free space to help reduce negative impacts on the host platform's stability and the end effector to track environmental objects smoothly despite host platform motions. The hyper redundant manipulator does not include a spherical wrist, even though through preliminary reachability analysis, the manipulator had an improved reachable arm volume by over 20 %.

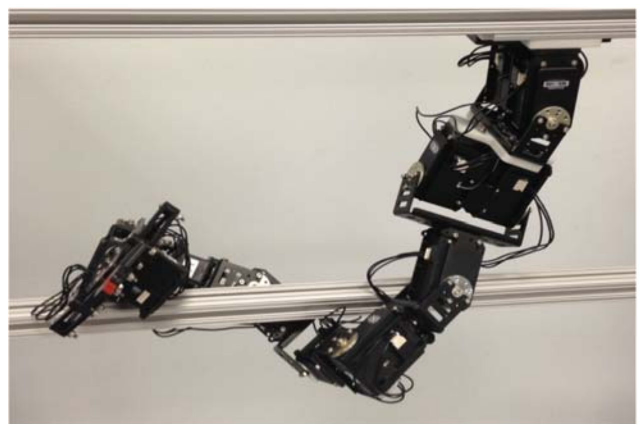

Figure 5. Hyper-redundant arm sweeping in the shape of "8"

Maier et al. [4] discussed about an approach allowing independent control of position and orientation of a UAV, whereby an arbitrary stable attitude controller could be used. The main contribution of this literature was to propose a new control approach for the entire system composed of Vertical Take and Landing (VTOL) UAV and a manipulator. The advantage of the presented approach is that the interaction forces between robots and UAV were considered explicitly and that a Lyapunov stability proof for the UAV subsystem could be derived directly. This approach extends the classical Cartesian impedance controller to account for the UAV's rigid body dynamics.

Zisimatos et al. [5] proposed a robotic hand which is efficient in grasping a series of everyday life objects, is general purpose, and is validated using series of experimental paradigms. This approach further improves the design of conventional grippers that are commonly used for grasping, both in industry and research due to its low complexity and relatively low cost. The authors introduced a new end effector system capable of lifting heavy weights and with grippers varying from two fingers to four fingers with a weight of 0.088 lb. to 0.53 lb. respectively as seen in Figure 6.

Figure 6. Different robot hands created using identical modular fingers and the modular fingers basis

Brown et al. [6] studied the kinematic and dynamic behavior of humans lifting heavy weights and applied it to a robotic arm which was made to lift heavy weights as a part of dynamic task. The authors discussed the kinematic and dynamic behavior of the robot with experimental results.

The results showed that the arm could lift 20 kg mass with the links having kinematics like that of human muscle. This approach uses a new methodology that is dynamic motion control. This technology is applicable not only for lifting but for pulling, peeling and destroying tasks.

Bhope et al. [7] gives an overall review of robot application employed over a period. The paper also provides information on the type of end effector used for fruit picking with pictorial representation as shown in Figure 7.

The robot mentioned in this paper deals with applications such as spraying and motorized weed control, fruit selection and inspecting the farms day and night for an efficient result which in turn reduces the farmer's effort. One of the advantages of the smaller machines employed in agriculture is that they are more satisfactory to the non-farm population.

Figure 7. Fruit picking robot

Sarig [8] discusses the technological improvements over the past decade related to fruit picking and the way robots have been programmed to locate the fruit in specified area without any damage to the fruit. The author developed an end effector with six degrees of freedom, having three rotational joints connecting neighboring links to cover the defined workspace. The author has made use of the Puma 560 robot arm which has forward and reverse kinematics whose controls are programmed through MATLAB Robotic Tool Box. The joint angles, velocities and torques of the robot arm were studied during example pick cycles which span the work space of representative peach and orange trees.

In addition to fruit picking robot as specified previously further developments was done by Henten et al. [9] who discussed the specific application of cucumber picking robots and the efficiency of the end effector. The manipulator was designed with seven degrees of freedom. The robot is equipped with computer vision system which could detect more than 95% of cucumbers in a green house. The ripeness of the cucumbers was determined based on the geometric models.

Figure 8. Vegetable harvest robot in the greenhouse

3. OBJECTIVES OF PROPOSED WORK

The objectives of the proposed drone model are:

1. To help the physically handicapped person pick an object of necessity (Water bottle, food items, fruits etc.) from a far-off distance and bring it to his/her vicinity.

2. To help farmers in harvesting the fruits and vegetables thereby reducing the distance of travel in long fields and on a minor scale help develop automated farming.
3. Along with this the drone can be used to spray fertilizers and pesticides over the crops, thereby reducing health hazards of farmers.

4. MODEL SPECIFICATION

Based on the literature survey conducted, it was found that developing the prototype to suit the purpose of agriculture and domestic application is more effective in this situation as it would reduce the complexity of modeling and would be a significant innovation in the field of automated farming. Modeling of a drone for applications such as military and industrial would be complex.

Drone Parameters

1. Number of rotors: 4
2. Wings span: 23.22 in
3. Weight: 1.890 Kg (2.84 lbs.)
4. Electronic Speed controller: 20A
5. Arm material: Acrylonitrile Butadiene Styrene BS – A (ABS)
6. Propeller Material: ABS
7. Payload Capacity: 450 g (0.99 lbs.)
8. Length of arm: 11.81 in
9. Effector radius: 2.36 in

Camera Parameters

1. Height in pixels: 3000
2. Width in pixels: 4000
3. Lens focal length in mm: 3.61
4. Lens field of view: 94^0

Controller

1. Control System: Remote
2. Operating Range: 2000m
3. Controller Frequency: 2.4Hz
4. Controller Voltage: 7.4V

Battery

1. Battery Capacity: 7000 mAh
2. Battery type: Lithium Polymer 4S
3. Battery Power: 14.8V

Figure 9 represents the isometric view of the drone that has been modeled considering the specifications as given above. A clear picture of the placement of components has been shown in Figure 10, which shows that the drone has been designed carefully with each component being reserved with spaces meant for them. Figure 11 shows the assembled view of the drone with the end effector arm. The arm is enabled with a 2- DOF link with the effector having a rotational DOF which is equipped with suction cups to hold the payload firmly. Figures 12-17 represent the stress analyses that was performed when the drone was made to carry loads varying in mass and major concentration in the arms. Both displacement and Von-Mises simulation results have been presented with figures indicating that as the load increases, the displacement in the drone's arm increases and hence leading to the conclusion that a restricted amount of load can be carried. The arm could be manufactured using 3D printing technology and could be time-consuming and costlier than the conventional method wherein the arms are built using traditional manufacturing methods which is even more time consuming but less costly when compared to former. It is important to note that most of the products that will be used for prototyping the proposed model are 3D printed.

4.1. Prototype Modeling

Figure 9. Isometric view of the drone

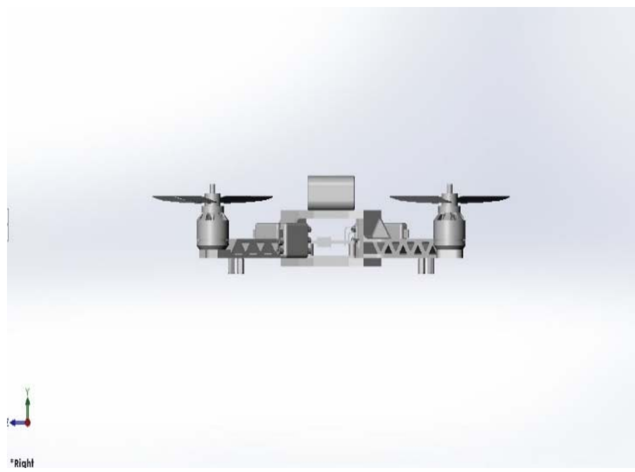

Figure 10. Right view of the drone

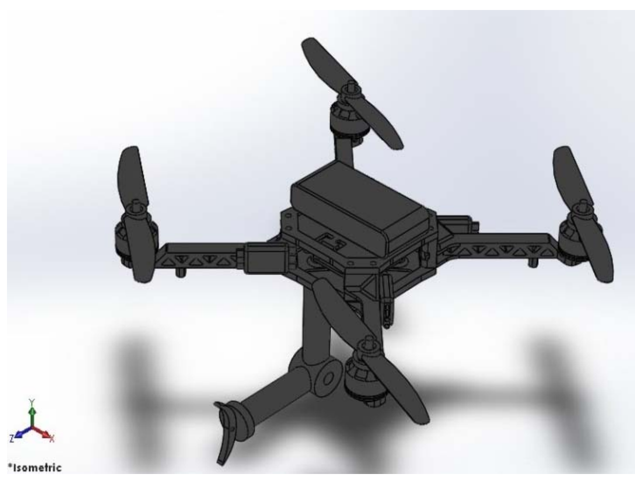

Figure 11. Assembled view of the drone

4.2.1 Displacement simulation results

The figures shown below indicate the displacement or the drone arm with increase in the mass of the payload lifted. The payload masses range from 0.75 N to 3N with intervals of 0.75 N.

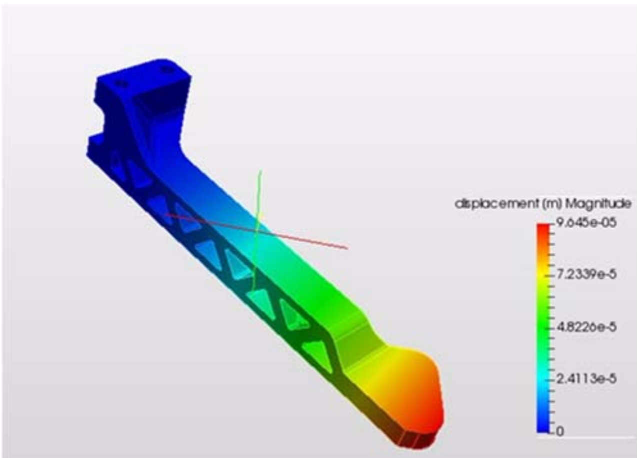

Figure 12. Displace results for 0.75 N

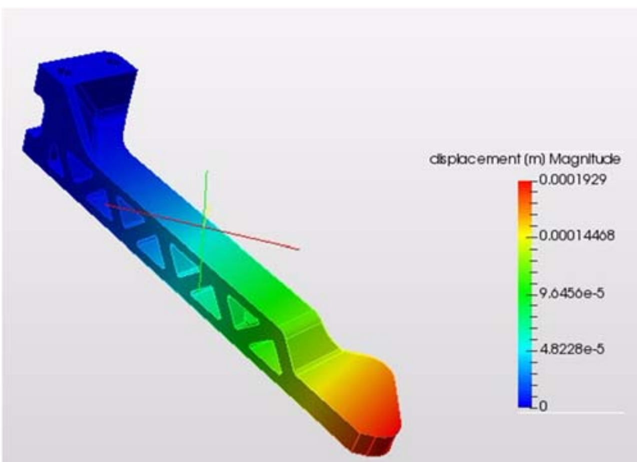

Figure 13. Displacement for 1.5 N

Figure 12 and 13 show the displacement for 0.1686 lbs. and 0.3372 lbs. respectively. Figure 12 shows that the load factor near the propeller region is critical. As the motor provides downward thrust, the beam must withstand the thrust near the propeller. When the analysis was carried out for 0.1686 lbs., the value of displacement obtained was about $9.645*10^{-5}$ m. The factor of safety of the ABS material is about 2.5. Similarly, for 0.3372 lbs. the displacement obtained was about 0.001929 m.

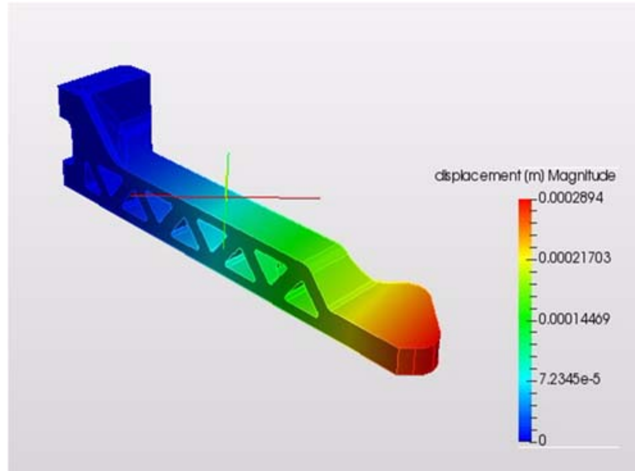

Figure 14. Displacement results for 2.25 N

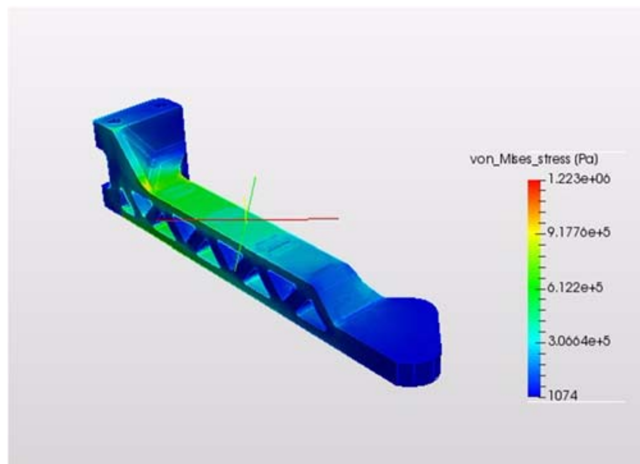

Figure 15. Displacement results for 3 N

Figure 14 and 15 show the displacement for 0.50 lbs. and 0.67 lbs. for a factor of safety of 2.5.

4.2.2 Von-Mises simulation results

This section illustrates the results of Von-Mises stresses that occur in the drone arm which increase with the increase in load that is carried.

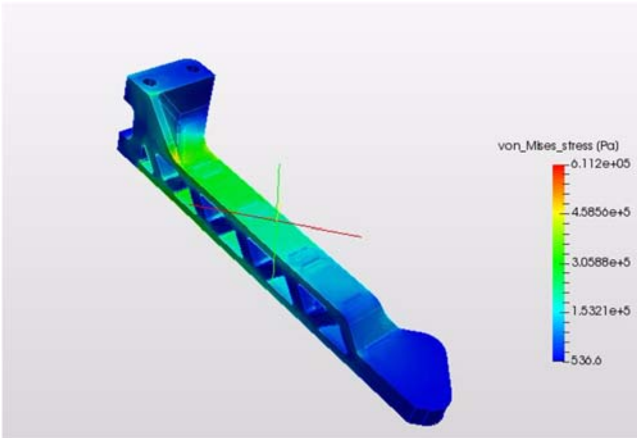

Figure 15. Von-Mises results for 0.75 N

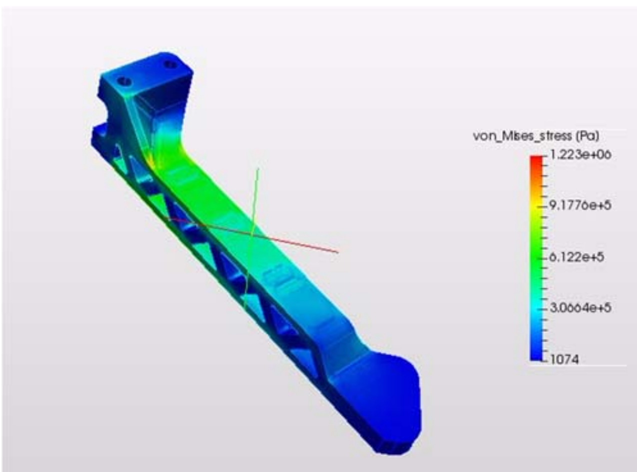

Figure 16. Von-Mises results for 1.5 N

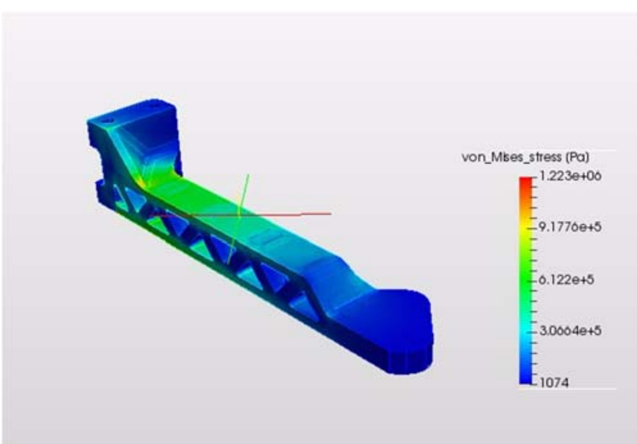

Figure 17. Von-Mises results for 2.25 N

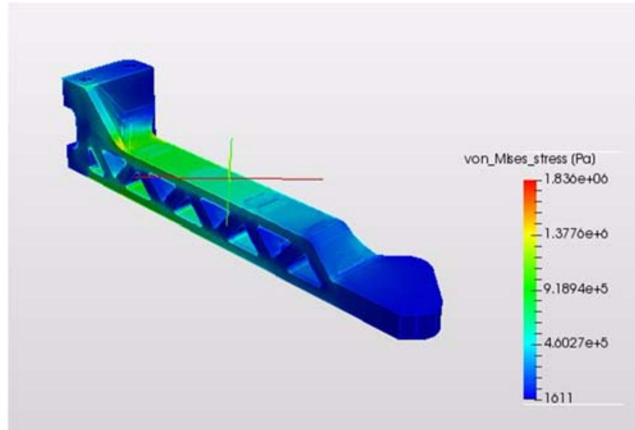

Figure 17. Von-Mises results for 3 N

Figures 16 and 17 show the stress analysis for varying loads. From the analyses conducted, it was concluded that the Von-Mises stresses increase with increase in the load applied on the arm. The arm is being designed to carry light weight loads and the results of analyses show that loading the arm with furthermore load results in a structural damage or failure. For higher loads, we obtained $1.8636*10^6$ Pa which was an ideal value for our proposed design.

5. COST OF MANUFACTURING

The estimated costs of each parts that are used to build the drone model are shown in Table 1. The value of each part presented here has been carefully chosen to avoid compromises with the working of drone. As Table 1 succinctly summarizes, 3D printing of the parts takes up the largest percentage of the overall cost. Hence, as the cost of 3D printing comes down, so will the overall cost of the system. The second most expensive item is observed to be the LiPo battery. Other costly items in descending order are the motor and the remote-control unit.

Table 1. Estimated cost of Manufacturing

COMPONENT	QUANTITY (UNITS)	COST (US $)
3D Printing (Arms, baseplate, motor mount, drone arm)	14	272.47
Motors	4	72.22
Propeller	4	15.00
LiPo Battery	1	90.00
Electronic Speed controller (ESC)	1	21.30
Camera	1	42.00
Arduino-Uno Microcontroller	1	24.99
Remote control	1	49.99
Miscellaneous (Fasteners, connectors)	-	15.00
Total		$602.97

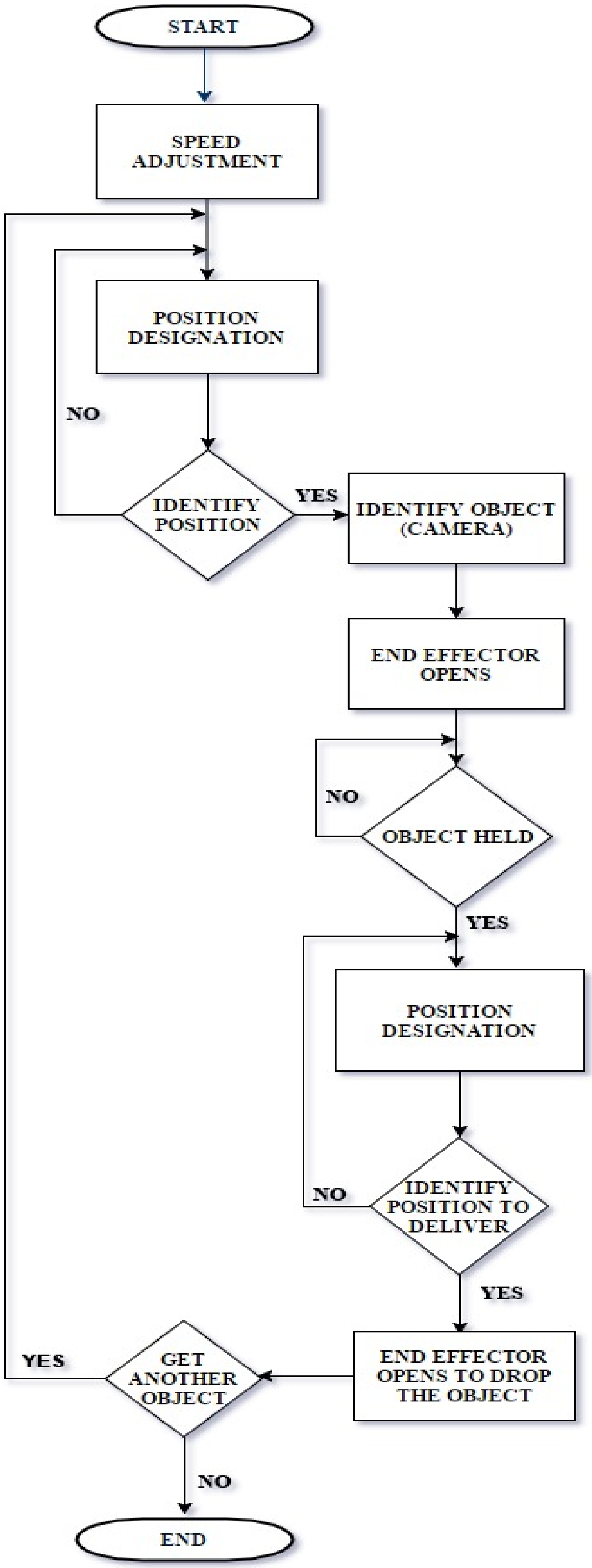

Figure 18. Flowchart for drone and end-effector control

6. DRONE WORKING ALGORITHM

Figure 18 represents the algorithm of the proposed drone. The process of lifting the payload initially begins with switching on the power supply from batteries to other electronic components such as the motor and the electronic speed controller. As soon as the systems and the microcontroller powers up the rotors, the speed is adjusted for vertical take-off. The drone is now in air with the arm preset to grab the required object.

The drone is designated with the position, which is monitored by the controller (human) through the camera attached to it. Once the location of the drone is set as per the instructions provided by the controller, the drone's speed is decreased and the end effector opens and grabs the required object firmly with the help of suction cups attached along the internal lining of the effector. This process is repeated until the required object is obtained through series of trials by the controller.

This problem can be eliminated in the future by the development of autonomous self-guided system. The drone after grabbing the object hovers towards the controller based on the instruction specified by the operator. The drone is kept away at a safe distance and the end effector based on designated position of the operator drops the object in his/her vicinity. This process is repeated continuously and the estimated endurance for the current proposed drone model is about 15-20 min.

7. CONCLUSION

The function of the robot is defined in the simplest of way which enables the UAV to perform a specific task. The materials and parts selection have been considered based on detailed evaluation of drones available in the market along with the mass of payload to be carried. The end-effector is modeled such that it is equipped with suction cups which give a better grip to the object help by the arm also the arm is stationary with the links being adjusted manually. The drone model presented here is controlled by means of a remote, where further developments can be pursued to have a complete autonomous system with capabilities of self-positioning, tracking and voice control of the drone.

8. ACKNOWLEDGMENT

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