UNIVERSITY OF SOUTHERN DENMARK

Faculty of engineering

BEng Mechatronics

Mechatronics Semester Project 4

Ladybug

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1 Background

Possessing the ability of flight and minimising effort and casualties has always been desirable for the utility flight can provide. The first unmanned aircrafts can be dated back to 1849, where Austria seemingly had utilised unmanned air balloons with stuffed explosives to attack Venice. [?] Ever since an unmanned aircraft vehicle (UAV), is one that is flown by technological means or as a pre-programmed flight without pilot control, as defined by the ECAA Transport Agency [?], nowadays called drones, have risen in popularity.

Because of this, UAVs come in a wide range of sizes and weights. UAVs often include multirotor, radio-controlled miniature helicopters, and aeroplanes [?]. As a result, there are several methods to categorize drones. The performance parameters of UAVs, such as weight, wingspan, wing load, flight range, maximum flying altitude, speed, and production cost, are typically used to categorize them [?]. According to how the lift is produced, drones may also be divided into fixed-wing and rotating-wing types. According to the drone code category, the European Aviation Safety Agency (EASA) categorizes unmanned aircraft by weight. The EASA regulations for open categories, or drones without an EASA class designation, are summarized succinctly and simply in Figure ?? [?].

Self-built drones weighing up to 250 g, as described in Figure ??, may be used without registration if the drone is a toy or the drone is not equipped with a camera, the remaining drones must be registered, and the pilot must pass examinations [?]. In this paper, self-built rotary drones with four wings or propellers are the objective, making weight-based classification suitable.

UAS	Operation		Drone operator/pilot		
Max weight	**Subcategory**	**Operational restrictions**	**Drone operator registration**	**Remote pilot competence**	**Remote pilot minimum age**
< 250 g	A1 (can also fly in subcategory A3)	— No flight expected over uninvolved people (if it happens, overflight should be minimised) — No flight over assemblies of people	No, unless camera / sensor on board **and** the drone is not a toy	— No training required	No minimum age
< 500 g			Yes	— Read carefully the user manual — Complete the training and pass the exam defined by your national competent authority or have a 'Proof of completion for online training' for A1/A3 'open' subcategory	16*

Figure 1: Classification and restrictions for non-EASA class drones [?]

When it comes to the state-of-the-art project, PULP-DroNet is a deep learning-powered visual navigation engine that enables autonomous navigation of a pocket-size quadrotor in a previously unseen environment. Thanks to PULP-DroNet the nano-drone can explore the environment, avoiding collisions also with dynamic obstacles, in complete autonomy – no human operator, no ad-hoc external signals, and no remote laptop! This means that all the complex computations are done directly aboard the vehicle and very fast. The visual navigation engine is composed of both a software and a hardware part. [?]

When it comes to the future, the simulated pollination of agricultural plants by means of nano copter can provide collecting and delivering pollen in the mode of automatic control. A design of nano copter for pollination can be made on the basis of innovative modification of existing model by its reprogramming with regard to its flight controller that is to be fully adapted to computer interface. The robotic system is offered specially for artificial pollination in conditions of greenhouses and minor agricultural enterprises. [?]

2 Problem statement

The utility of smaller drones are immense, where it can be used in surveillance, toys and potentially to also be part of a swarm of drones. Although, there are smaller drones existing in the current market, we would like to challenge ourselves to build one ourselves, where certain goals ranging from functionality to budget are listed below.

2.1 Primary goals

- Net maximum weight of the drone is 250 grams. Weight under 250 grams ensures it falls under A1 category in EU regulations. 1
- Flight time of 20 seconds.
- Stress of the structural system should not exceed rupture point. System does not experience fracture.

2.2 Secondary goals

- Flight time of minimum one minute.
- Can land with acceleration less than 9.8 m/s2.
- Stress of the drone system should not exceed the yield point. System does not experience plastic deformation.
- Drone is remote controllable.
- Drone can fly in formation with another identical drone.
- Total production cost of the drone is under 500 DKK (Not including remote controller).
- Drone can play audio.

2.3 Constraints

- Budget for entirety of project is 2000 DKK.
- Time available to finish the project is 4 months.
- Drone should have a minimum hover time of 5 seconds.
- Drone should be fully functional and able to take off again after landing.
- No use of flight controller software or unmanned vehicle Autopilot software Suite, capable of controlling autonomous vehicles.

3 Test Specifications

3.1 Primary goals:

- To test this, the drone will be weighed with a scale of a precision on 0,1 grams.
- In order to test the flight time, a stopwatch will be started from the moment the drone leaves the ground and is stopped as soon as it lands.
- This goal will be the tested trough FEM, ensuring that the chosen material for the drones body, will not rupture.

3.2 Secondary goals

- This will be tested with the same method as primary goals tests point 2.
- This will be tested with a mobile phone, recording the drones landing, using the drones position compared to the timestamp of the video.
- This will be tested with the same goals as primary goals test point 3.
- This will be tested by the possibility of sending wireless signals to the drone, with the drone reacting to those send signals.
- This will be tested purely by ear, listening to the drones output.

- This will be tested by mobile phone video, looking at the drones positions at given timestamps.
- This will be tested trough summing the price for each single part, ensuring that it doesn't exceed 500 DKK.

3.3 Constraints

- This will be done with the same method as the secondary goals test, though ensuring the project cost is over 2000 DKK.
- To evaluate the time constraint point of the project, the goal fullfilments will be evaluated in the end of the project period. In the case that all primary goals are fulfilled, the constraint is succeeded.
- This will be tested with a stopwatch, ensuring that the hover time is atleast 5 seconds.
- This will be tested with making the drone take off right after a landing, making sure that the drone is fully operational at the second take-off.
- This will fulfilled by not employing any of the aforementioned in the drone.

4 Design and manufacturing of quadrotor

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5 Designing the drone

The main body of the drone is created as a PCB, in order for the body to host both the structural element and the electrical connections of the drone. Since the project formulation's main goals dictates the drones size and mechanical properties, the drones size was chosen to be $100mm^2$, so that the PCB could accommodate all the needed components of the drone. The PCB shape itself was designed in Siemens NX as a simple outline with holes for the motor mounts. This outline was exported in a DXF format into Autodesk Eagle were the actual PCB was designed from the needed electrical circuit. The electrical schematic was created in Eagle's schematic designer and then automatically converted to a PCB board with the auto-router feature. The trace width of the PCB is specifically chosen to be 30 mills so it can supply the needed 1.72 amps [**?**] for the motors at maximum rpm. The microcontroller of the drone is mounted by pin headers, the motors by the motor mounts and the remaining components by soldering onto the top layer. The position of the microcontroller is offset from the center, in order to ensure that the In-built IMU is centered to the exact middle of the PCB.

[CAD View] DroneCAD.png [PCB View] PCBpicture.png

Figure 2: Drone model

In order to control the speed of the motors, one of the potential options would be to use an H-bridge to control the DC motors. However that would be excessive, as the motors does not need to run in reverse as contain many components As a less power consuning simple and lighter option, a single N-channel mosfet was used for each motor.

Figure 3: Motor control with MOSFET.

As illustrated in figure **??**, the drain of the MOSFET is connected to the motor, which is supplied by the battery, and the source of the MOSFET is grounded. Meanwhile, the VG pins are connected to one of the PWM pins of the nRF52840 MCU, where the opening of the gate is proportional to the PWM. Thus, when VG (simulated by PWM) is smaller than the V threshold of the MOSFET, the motors are static, and if VG surpasses V threshold, then the motors start spinning with higher RPM as PWM is increased. The MOSFETs used for this situation are FDD8896 [?], as it has a low threshold voltage of 2.5V (MCU pins can supply up to 3.3V), and can handle up 94A in continuous drain current.

As there is high currents being drawn from the motors, one of the things needed to be configured was protection against overcurrent being drawn from the microcontroller. When the motors are switched on or off, a surge current arises which can result in additional overcurrent being pulled from the microcontroller if the battery is not alone capable of supplying the current.

Figure 4: Current flow during continuous operation.

Figure 5: Potential current flow due to surge current.

In order to prevent reverse current from the MCU, during a surge, one of the potential options to utilise would be a diode placed in the following configuration.

Figure 6: Diode added to prevent reverse current flow from MCU.

Additionally decoupling capacitors were added in parallel to the positive and negative motor pins and the MCU BAT+ and BAT- pins.

Figure 7: Example of decoupling capacitor for stable voltage to MCU.

The diode utilised is 1N5818 [?], as it has a low forward voltage of under 0.5V, resulting in low power losses. Moreover, the decoupling capacitors are cermaic capacitors as they generally smaller in size, and they are rated at 100 nF, which follows the general guidelines of decoupling capacitor values. [?]

With the combination of the CAD-outline and the electrical schematic, PCB Gerber files could be output for production. The only excess parts needed for the drone would be motor mounts and prop guards (prop guards solely for testing, not for final use). The Motor mounts act as both landing legs and motor mounts. They would be designed in order for the motors to press fit into the central hole, mounted onto the PCB by screws into the motor mount going through the PCB. The designed mounting parts was printed in PLA on a Prusa MK3S+ 3D printer. The Parts were printed with a single perimeter and 3% infill in order for each leg to weigh 1.1 grams while still having the nescessary structure to have a stable press-fit.

Droneleg.png

[Motor Mount]

Dronepressfit.png

[Mounted Motor]

Dronepropguard.png

[Prop Guard]

Figure 8: 3D-Printed drone parts

The project formulation states that the "Stress of the drone's structural system should not exceed rupture point. System does not experience fracture". This was tested through Ansys Mechanical Static Structural Analysis. Using the CAD model of the drone, the following boundary conditions were applied: Fixed constraint on the bottom area (excluding the drones arms), Z direction forces (upwards) was applied on each of the motor mount screw holes according to the found motor thrust, a single force vector in the Z direction (downwards) was applied to the top face (excluding the drones arms), to resemble the gravity force caused by the weight of the drone. Besides the boundary condition, the setup contained a mesh refinement of 3 steps, a material assignment of FR4 Fiber Glass Epoxy Board and a solution setting of equivalent stress. Below is a picture of the stress simulation of the initial design, which showed clear stress concentrations in the corners where the motor arms runs into the body section. The stress concentration had a magnitude of 1.6839 MPa which is satisfactory regarding the requirement of fracture, since the tensile strength of the given material is 320 MPa [?].

Ansys1.png

Figure 9: Initial Ansys Simulation

Although it was clear that the drone body would be strong enough to operate under max power, the stress concentrations were undesirable. Therefore 20 mm radii was added to the stress all corner points of the drone body. Repeating the simulation with the same boundary conditions, it was clear that the added radii removed the stress concentrations and instead distributed the stress over a broader area of the motor arms. Furthermore, it was found that the maximum stress was found to be 0.87154 MPa, which is approximately half the maximum strength of the initial model that had the stress concentrations.

Ansys2.png

Figure 10: Final Ansys Simulation

To power the drone a single cell Turnigy Li-Po battery is used, at 3.7 - 4.2 V and 300 mAh. The battery is chosen specifically to be able to supply the needed current of the drone. With a C-rating of 35C, the battery is able to discharge continously at 10.5 amps which is sufficent for the electrical circuit. The motors used are 8520 brushed Coreless DC-motors, which properties are characterized in the control chapter under thrust testing.

battery.jpeg

[Turnigy Battery] [8520

8520.jpg

DC-motor]

Figure 11: Motor and Battery used on the drone

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