LIGHT PAYLOAD QUADCOPTER DESIGN FOR THE TRANSPORTATION OF ESSENTIAL GOODS TO PEOPLE IN SELF-ISOLATION

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Abstract: *A quadcopter, also called a quadrotor helicopter or quadrotor is a multirotor helicopter that is lifted and propelled by four rotors. In case of lockdown or self-isolation, companies as well as governments can make use of unmanned aerial vehicles equipped with obstacle detection and collision avoidance technology. It is paramount to understand the importance of flight safety with unmanned aerial vehicles. If rules and restrictions are not followed because the user with the controller made an error or was unconscious, a sophisticated system will detect possible conflict and save the drone before collision. In this paper, a digital model was created using MatLab software, in order to analyze and understand how a quadcopter works in its environment. Using the trajectory tools, a well-defined trajectory is defined for a quadcopter in order to better represent its behavior during a light parcel transport assignment. The results obtained can be used to design a drone for the delivery of small packages containing essential goods for people in self-isolation.*

Keywords: *quadcopter design, safety issues, numerical simulation*

1. INTRODUCTION

A quadcopter (Fig. 1), also called a quadrotor helicopter or quadrotor is a multirotor helicopter that is lifted and propelled by four rotors. Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of rotors (vertically oriented propellers).

Quadcopters generally use two pairs of identical fixed pitch propellers; two clockwise (CW) and two counter clockwise (CCW). These use independent variation of the speed of each rotor to achieve control. By changing the speed of each rotor, it is possible to specifically generate a desired total thrust; to locate for the centre of thrust both laterally and longitudinally; and to create a desired total torque, or turning force. [1]

FIG. 1 Quadcopter design

In case of lockdown or self-isolation, companies as well as governments can make use of unmanned aerial vehicles equipped with obstacle detection and collision avoidance technology. By having the quadcopter equipped with various types of sensors (vision, ultrasonic, infrared, etc.) (Fig. 2a) and by creating a database with all stores and pharmacies within a certain area, it is possible to have essential items delivered to one's residence. Drones available, at the moment, can deliver payloads up to five kilograms and over a distance up to twenty-five kilometers (Fig. 2b).

One of the most important elements of this concept is the obstacle detection and collision avoidance technology. For any autonomous driving vehicle, be it a car, robot, or drone, to be able to detect obstacles and avoid collisions, it requires a number of complex technologies working together to create an integrated system. This entails many various sensors and software programming which include mathematical modelling, algorithms, machine learning and aspects of SLAM technology.

Most of the time, drones are equipped with sensors fusion. This is a process by which data from several different sensors are "fused" to compute something more than could be determined by any one sensor alone. Sensor fusion is a subcategory of data fusion and is also called multisensory data fusion or sensor-data fusion.

FIG. 2 (a) Position of sensor on a drone, (b) Flight pattern of a drone.

A quadcopter could have the best sensors available, but without software and algorithms, they are of no use. An algorithm is a detailed step-by-step instruction set that aims to solve a particular problem, in this case the problem of avoiding both moving and stationary object, detected by the sensors. Depending on the algorithm, the quadcopter will be able to compare real time data from stored referenced images of objects. There is a multitude of techniques which can be used for obstacle avoidance, but usually the best technique depends on the specific environment and it differs depending on type of device (cars/drones/robots). [2]

FIG. 3 "Air Prime" project by Amazon

2. QUADCOPTER DESIGN

While designing a quadcopter four aspects must be taken in consideration: the axis, the mass and inertia and the number of rotors. One of the most important features of an unmanned aerial vehicle is its mobility on all directions. This means that the quadcopter is able to move along the X-axis, which points in the direction along the nose of the quadcopter, along the Y-axis, which points to the right of the quadcopter, and along the Z-axis, which point downwards following the right-hand rule. All of the quadcopter's axis are centred in its centre of gravity (Fig. 4).

FIG. 4 Position of the three axis for the quadcopter's movement

In terms of mass and inertia, it is assumed that the whole body of the vehicle works as a particle. A quadcopter's rotors are located parallel to the XY plane and on the axis going through the centre of gravity at 45 degrees and -45 degrees. Each of the rotor rotate in a different direction in order for the quadcopter to keep its balance during flight; the first and the third rotors rotate positively with respect to the Z-axis, while the second and the fourth rotors rotate negatively with respect to the body's Z-axis. (Fig.5) [4]

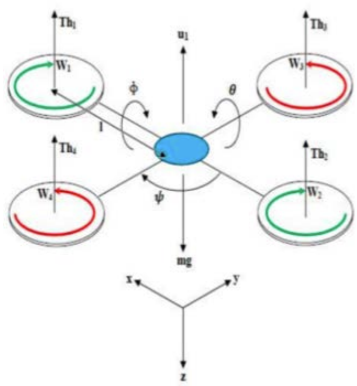

FIG. 5 Visual representation of the rotors movement of rotation in respect to the three axis

The parameters of the rotors (the degree in respect to X and Y axis, as well as the direction of the rotation) may depend on the number of rotors the unmanned aerial vehicle has [5]. The last, but not least aspect which must be taken into consideration when designing a quadcopter is its purpose, depending on that the vehicle might need special night-vision cameras and/or sensors, temperature sensors, etc. as well as a control unit, made of individual controllers for pitch/roll, yaw, and the quadcopter's position on the X, Y, and Z axis.

In conclusion, the quadcopter is an efficient and elegant design, and is a very popular layout for an unmanned aerial vehicle due to the fact it is relatively a simple design, it is symmetrical, and inexpensive to manufacture compared to other multi-rotor designs.

3. SAFETY CONCERNS IN DRONE OPERATION

This topic serves as a guidance material for software engineers. This section describes safety hazards of flying with drones, especially when a drone is controlled by an inexperienced person without knowledge of safety instructions. Then, information about possible collisions is provided. Consequently, there is a proposal for future systems improvements in order to achieve safe flight without collisions with ground, obstacles or aircraft. A summary of which detection and collision systems shall be developed and which ones are currently too complicated to create is presented in this section. Mentioned content can help students to understand importance of safe flight of unmanned aerial vehicles. If rules and restrictions are not followed because the user with the controller made an error or was unconscious, sophisticated system will detect possible conflict and save the drone before collision.

Safety is always the most important thing to consider in aviation. Unmanned aerial vehicles have rapidly spread over the world. Drones (quadcopters) are still considered to be children's toys. In fact, mid-air collision of a drone with aircraft is really dangerous accident (Fig. 6). It causes harm to the aerodynamic shape of the aircraft and it can even lead to engine destruction. That is the reason why drones have to be totally separated from other air traffic [13].

FIG. 6 Mid-air collision with a drone damaged aircraft's nose

The root problem of using drones is that drones are controlled by inexperienced and unlicensed people in contrast to highly regulated civil aviation. The task for regulatory organs is to determine how and where are drones are permitted to fly. They must compromise between undisturbed flying of drones and safety of civil aviation. Legislation is a bit late due to the fast development of drones. Restrictions are being established in order to regulate airspace protection. There are some rules that should be followed:

- Drones shouldn't fly over people.
- Drones shouldn't fly over private property without permission of its owner.

- Controller should always see his/her drone and keep direct eye contact from ground.
- Drones shouldn't fly in bad weather conditions, such as low visibility, wind, thunderstorm etc.
- Drones shouldn't fly close to obstacles, such as houses, trees, roads etc.
- Drones shouldn't fly in proximity to airports and restricted areas.
- Drones shouldn't fly in significant heights close to airspace (usually no more than 120 meters above ground). [13]

To prove that the lack of restrictions and regulations regarding drone usage, Fig. 7, is a representation of a drone that failed to hover and crashed over ski slope. The respective drone almost hit an athlete that was skiing at that moment, an event which could have had very bad consequences. That is why there must be strict rules and regulations, as well as fines or punishment for those who fail to comply with the rules, this is also why in some countries, and owners of drones weighting more than 250 grams must be registered by aviation authority.

In December 2018, Gatwick Airport stopped its operation for 24 hours because some drones were flying close to the airport. This deliberate incident affected more than 760 flights and it encouraged airports to build drone detectors and manufactures to work on advanced systems as well.

FIG. 7 Drone crashing over ski slope

The best way to avoid collisions is to separate different means of transport and create simple restrictions that can be easily followed. For future development and wide application of drones, however, it is important to integrate all traffic means together and share one airspace. This is a challenging idea and it will be very difficult to establish such a complex system. It will take a long time to solve this problem, but it might be possible with new technologies and more precise locators and sensors.

The reason why to achieve it is that for future drone delivery and other services, the restrictions are too strict and there is not enough space specified for drones exclusively. Drones can't fly too high currently and always must be seen visually. Drones are high technology devices and their function can be enhanced by sophisticated systems. The limit for installation these extensions is the need of light weight and low battery consumption. New systems include flight stabilization, precision flight, obstacle detection and manoeuvre resolution.

Which collisions can occur when drone is in the air? There are dangerous barriers (Fig. 8), some of them are even invisible, and the user must be aware of them. Drones should not fly close to these obstacles because it is unsafe for the drone itself or for other aircrafts. Various early warning systems for detecting hazards are in development.

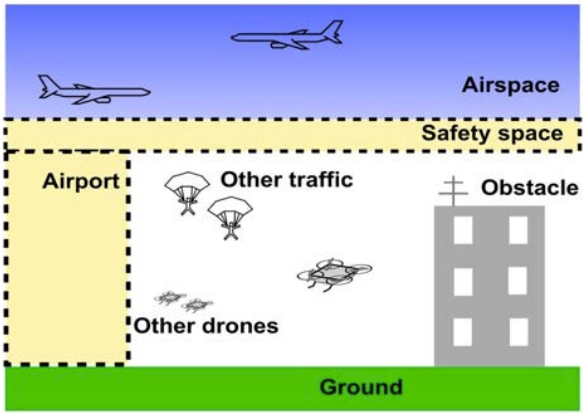

FIG. 8 Drone fly zones and obstacles

Protection against controlled flight into terrain or hard landing is mainly the controller's task. Drones usually have several sensors detecting nearby objects. If there is a downward sensor, a control unit is able to calculate a too fast decent close to the ground in cooperation with accelerometers. The majority of drones equipped with GPS locators can simply execute automatic smooth landings using the downward sensor.

Many unmanned aerial vehicles have already been equipped with obstacle detection systems. When a drone approaches an obstacle too fast, the system makes a resolution and lets the drone hover in sufficient distance from obstacle. The current limitation is in sensors. Sensors have limited ability to detect obstacles. They can detect an object that is as far as approximately fifty meters. It reliably detects obstacles as far as twenty-five meters. [15] Since maximum velocity reaches significant speed (about 20 meters per second), there is just a bit more than a second until impact. During this time, the control unit must process the inputs and stop the drone from moving toward obstacle. That is almost impossible at high speeds, to brake and avoid obstacle collision. Another problem is that the sensors can't reliably detect shiny and reflective surfaces, don't work properly in darkness and do not detect very small, or thin objects (electric wires).

The key task for protection against collision with an obstacle is to improve sensors. The problem is short range and unreliability of object detection. Better sensor characteristics enable drones to detect obstacle earlier and stop them before collision. Other improvement could be looking into precise 3D database that anticipates obstacle location or scanning objects by camera remembering their exact shape and position in space (so called Simultaneous localization and mapping technology). [16]

Collisions with aircrafts can lead to very severe consequences. That is the reason why these two machines must not come together. Aircraft fly in segregated airspace. For drones it is prohibited to fly into airspace that is determined for aircrafts. Aircrafts are served by air traffic controllers (ATC) and all movements are based on air traffic controller's permission (clearance). There is no chance for ATC to handle drones because they aren't seen on a radar and human controllers aren't on board. Aircrafts can fly up to 250 knots (460 km/h) in lower altitudes and so sensors on a drone can't detect aircrafts. Pilots also can't see drones in time in order to perform a maneuver. Drones have to stay away from controlled airspace. Airspace usually starts 300 meters above ground level, drones shouldn't fly above 120 meters.

Airspace is controlled by human ATC and it will certainly remain like this more than 10 years ahead. Airspace should be more automated in future using free flight concept, but it won't enable drones to fly within airspace. Aircrafts use Traffic Collision Avoidance System (TCAS) to get rid of collision in case of ATC failure. Drones aren't concerned in this system. A possible idea is to install mode S receiver into drone. Mode S is a signal (information about position and height) transmitted by all big aircraft. The drone could find out that some aircraft is heading in its direction and the drone would immediately decent. However, in the following years drones must stay segregated from airspace. Another idea is to limit airspace a bit and create restricted areas for drones only or conditional routes, as military aircraft sometimes use. Drones equipped with precise altimeter could have limits to not fly above a stated level.

As aircraft take off and land on runways, not to fly too high by drones is not a sufficient condition. They can't fly close to an airport or close to other restricted areas, such as military areas or nuclear power stations. This negative trend is growing year to year and there is no satisfactory restriction to eliminate drones in airport proximity.

If a database with restricted areas exists, drones with GPS will know where is a boundary where not to fly. Such maps with restricted areas are created, it is not difficult to provide it to a drone control unit. The task is to enable access to this database and a lot of unintentional entries to airport areas will be simply prevented.

Small aircraft and parachute belong into this category. Presence of them close to ground is conditioned mainly by visual caution. Small aircraft should fly higher than drones shall. In busy traffic areas controllers of drones are usually warned by signs to not fly there.

It is not easy to solve these possible collisions that are based just on visual awareness. Other traffic is quite slow in low heights and so better sensors could be able to detect them and avoid collision. New sensors technologies will perhaps cope with distant flying object detection. These progressive technologies are for example ultrasonic sensors, time-of-flight sensors or Lidar (Light detection and ranging).

These collisions are not prevented unless obstacle detection system reveals resolution. Drones should be flown at low density traffic areas. Controllers shall guard theirs drone and shouldn't come closer to others.

Some automatic broadcast transponder could be developed and installed to all unmanned aerial vehicles. Other devices would calculate relative position to the particular drone and be aware of danger in case of air proximity. Then maneuver can be executed. Otherwise drones could send information about their position via datalink and share movements with drones in surroundings. There was a drone show during the Winter Olympic Games in Pyeongchang county in South Korea. 1218 drones cooperated to each other and made a perfect light show.

Vertical downward acceleration close to terrain shall be reduced. Modern drones can be equipped with a precise altimeter. The altimeter might be either radio altimeter that measures precise height over terrain even in high heights or barometric that provides altitude based on local pressure. A more reliable altimeter offers more automatic functions (for example flying at determined height above ground) and protects the drone against collision with the ground. On the other hand, such altimeters are significantly heavier and for cautious controllers a downward sensor is enough.

4. NUMERICAL SIMULATION AND CONCLUSION

In order to analyse and understand how a quadcopter works in its environment, a digital model was created using MatLab software. The model (Figure 9) is mainly composed of six independent blocks that communicate with each other:

- command block: command and control the quadcopter;
- sensors block: record the different data and variables that act on the quadcopter;
- environment block: subjecting the quadcopter to the different forces / constraints of our terrestrial environment;
- flight control system block: record and analyse the previous blocks in order to issue commands to the quadcopter;
- airframe block: analyse the quadcopter's behaviour in its environment;
- visualization block: communicating with the user using 3d models and sensors;

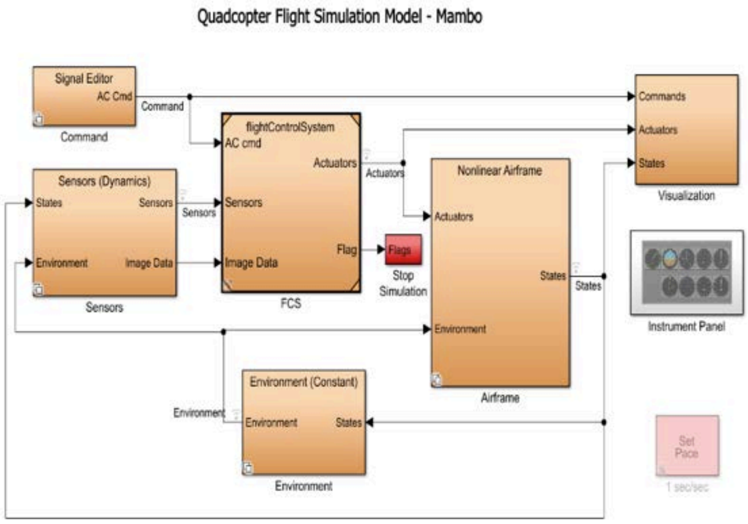

FIG. 9 Visualization of the six independent blocks

The main focus of this paper is on the command and visualization blocks; using the trajectory tools, a well-defined trajectory is defined for a quadcopter in order to better represent its behavior for a light parcel transport use. No fly zones are defined in order to restrict the quadcopter's flight path in some places (Fig. 10).

FIG. 10 MatLab visualization tool

In order to load this trajectory, it is necessary to switch the control mode to data so that the quadcopter can follow the different crossing points chosen beforehand. (Fig. 11)

For visualization, a 3D simulator as well as a control panel are used in order to analyze in real time the different variables of the quadcopter. (Fig. 12)

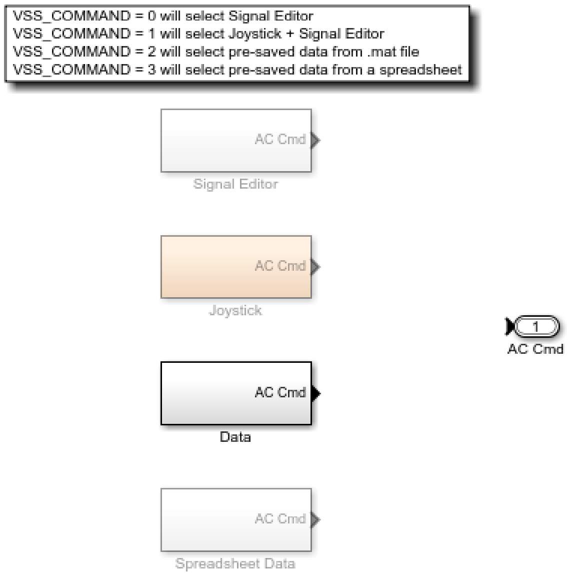

FIG. 11 MatLab software control model

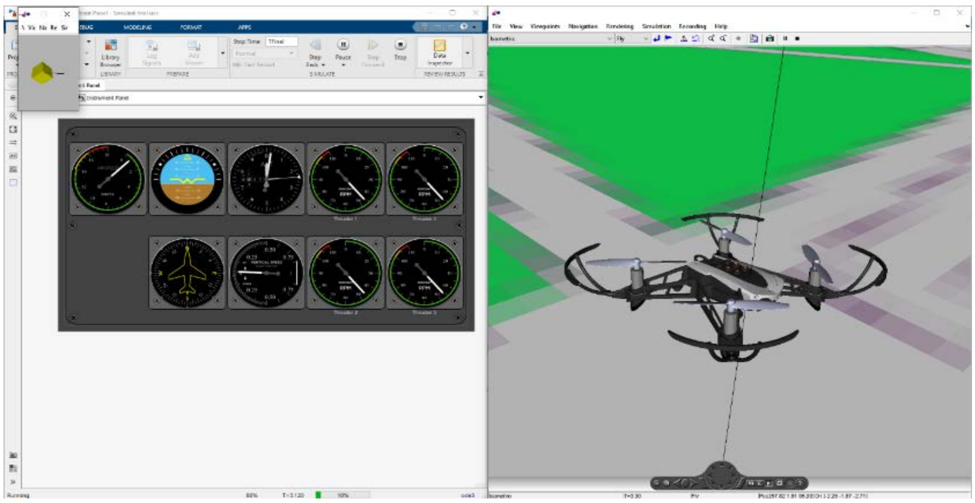

FIG. 12 MatLab software 3D simulator

In order to create the trajectory, a new tool from MatLab (Fig. 13), creating a more intuitive trajectory generator than the old one used for the first test. The new trajectory includes a take-off, a longitudinal forward movement, a transverse movement, a longitudinal backward movement and, finally, landing. The aim is to observe the behaviour of the quadcopter as well as the data differences with the first simulation.

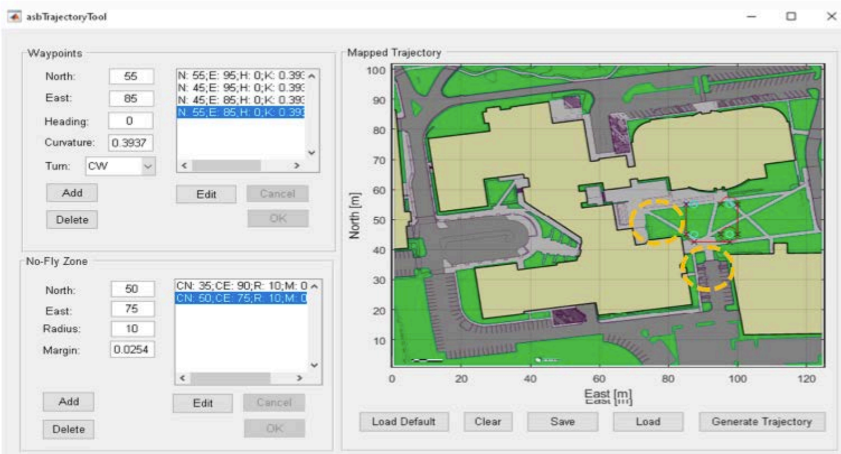

FIG. 13 MatLab tool for no-fly zone creation

The new tool, allows for the creation of no-fly zones, just as in reality. In this way, the drone will have to avoid those zones and use different trajectories that could be less efficient. The aim is to observe how the drone deals with the constraints of the no-fly zones, and as with the previous simulation, to analyse the data made available by the 3D simulation (Fig.14) in order to better understand how the drone functions and its reactions.

FIG. 14 3D simulation (Video link of the 3D simulation: https://youtu.be/NUJvz_HUxgg)

CONCLUSION

Quadcopter are unmanned aerial vehicles that some delivery companies started using for delivering small packages. Even though there is precedent, it has only been done occasionally. The use of quadcopters can prove essential in special situations, helping bring food, drinks or medicine to people in isolation, but it is an overall new concept which must still requires research and testing before implementing it.

The PESTEL analysis, which is an assessment of the external environment's influence was done to evaluate the potential using drones as means of transportation on a large scale. This analysis consisted evaluation from a political, economic, socio-cultural, legal, technological and environmental point of view. Another aspect like, battery life, cost, safety of the package and weather conditions, were taken into account.

In order to analyse and understand how a quadcopter works in its environment, a digital model was created using MatLab software. Different collision avoidance solutions for avoiding an obstacle, collisions with aircrafts, flying close to the airports, prevention of collisions with other traffic and collisions with other drones were identified. Using the trajectory tools, a well-defined trajectory is defined for a quadcopter in order to better represent its behaviour for a light parcel transport use. No fly zones are defined in order to restrict the quadcopter's flight path in some places.

The quadcopter is one of the simplest and most elegant designs for an unmanned aerial vehicle, one of the easiest to control, as shown in the simulation, and one of the less expensive to manufacture, given its simplicity. There are still regulations to be implemented and investments and technological progress to be made until the mass implementation of a delivery by drone system can be possible.

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