H01Q6: probleemoplossen en ontwerpen EAGLE: Project description and functional requirements specification

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September 2016

Coming year you will participate in the P&O EAGLE. This P&O will introduce you to real engineering, with an exciting mix of:

1. Teamwork
2. Combining various technical topics in Electronic Engineering
3. Experimenting and closing the gap between theory and reality

This document describes the EAGLE project. We will subsequently cover the project goal, its timing, the practical organization, and conclude with a list of other relevant documents you need to execute the project. We look forward to see your drones in May ... Let the EAGLEs fly!

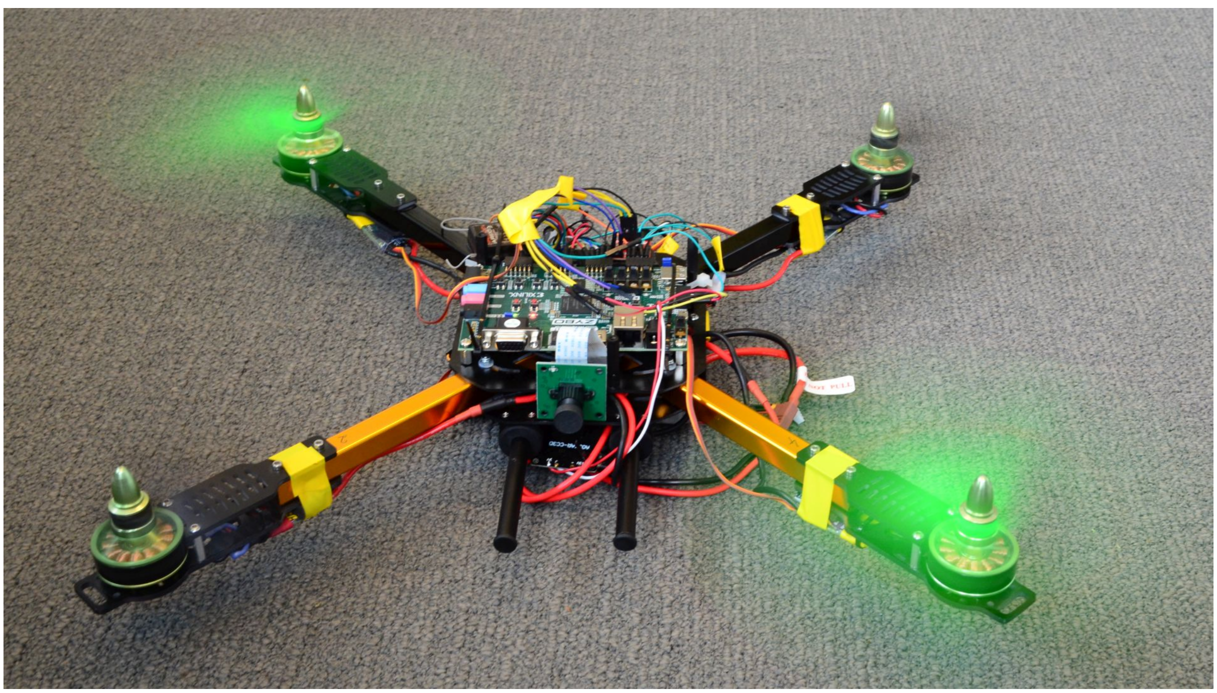

Figure 1: Let the EAGLEs fly!

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1 Project description

Small unmanned aerial vehicles, often referred to as drones, are becoming cheap and mature. When equipped with a variety of sensors, a camera, wireless communication, intelligence and autonomy, and even wireless power transfer, they open up a wide range of novel applications, going from wildlife monitoring to surveillance or even delivery of goods. Widespread use of those smart drones requires however a tight integration of various electronics building blocks: camera and vision, security and crypto, wireless communication and power transfer, and a stable control of the motor and autopilot. The main goal of the EAGLE project is to build those modules, integrate them into a flying system, and make them work together towards a smart drone. EAGLE does not only fly autonomously, it autonomously carries out a mission, finds it's own encrypted path, and finally finds it's destination and wirelessly powers as muchs lamps as possible.

To achieve this goal, groups of approximately 9 or 10 students will be formed. Each group will conceive, design, and realize their own drone. However, with your team you are not only responsible for the technical tasks. You will also have to draft a plan, distribute work in the team, help each other out when you are in trouble and so on. To provide you with all the necessary information to be able to do start this project, the remainder of this document will first detail the EAGLE mission, and the different parts that we believe should be completed. We will also describe how the project will be guided by professors and assistants and how you will be evaluated. Study this carefully, and then consult with your coaches on how you will achieve this in your team. What coaches? Just read on if you want to know.

1.1 The EAGLE mission

The EAGLE mission is to create a drone that is able to autonomously fly towards a final destination, where it will wirelessly power a LED-wall. The location of the LED-wall is unknown to the drone. The drone will have to follow a trail of QR codes placed on the floor in a grid of red lines, which leads him to the mission destination. The figure below summarizes this mission in a graphical way.

- **Manual takeoff:** EAGLE's mission will start on the ground, always from the same starting position, facing the same direction. Through manual control a pilot using the Remote Control (RC), will control the take-off of EAGLE and fly it to the location of the first QR code. You can see where to fly to by relying on a wireless video link between the drone and a PC. This enables you to manually position the drone above the first QR code. When reaching this code, the pilot switches the drone to autonomous flight mode.

- **Autonomous flight:** In this stage, EAGLE is flying autonomously, trying to find the location of the LED wall. The drone can do this by image processing to follow a trail of QR codes, the location of which is unknown beforehand. The drone starts by hoovering above the first QR code on the floor. During the hoovering the drone will decode the QR code. This first QR code will hold (encrypted) information pointing to the location of the next QR code, with locations given relative to a grid of red lines marked on the floor. The drone should autonomously fly to the next QR code, hoover above it, and repeat the same steps again to follow a trail of QR codes. The last QR code will signal the drone that this is the position of the LED wall. The drone should slowly hoover down to a lower height, and then shut down the engines and switch to "inductive power transfer" mode. During the "autonomous flight" mode, the RC is normally only used as a safety measure, through its kill switch, which immediately shuts down the drone (see further).

- **Inductive power transfer:** In the last mission stage, EAGLE found its destination, and is now ready to power the LED-wall. The last QR code in the room, on which EAGLE landed, is surrounded by a copper coil which is connected to a power receiving circuit, able to power the LED-wall. By inductively transferring power from a coil on the drone, to the coil underneath the QR code, the LED-wall will be powered from the drone's batteries. It is important to note that the better you landed in the previous mission stage, and the better you implemented your inductive power transfer module, the more efficient you will be able to transfer the power to the LEDs, and the more LEDs will light up. Mission completed!

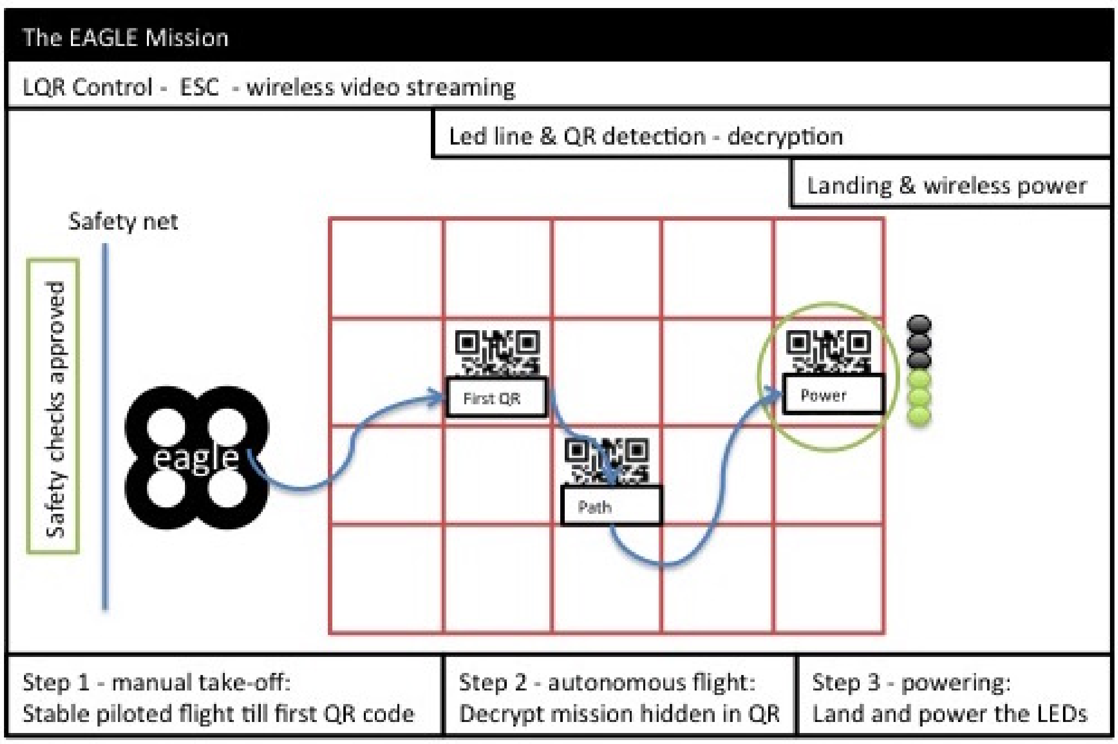

Figure 2: The EAGLE mission is to create a drone that autonomously carries out a mission: finding a secret path through QR codes towards a strip of LEDs that are to be powered wirelessly. The mission can only start if all safety checks are approved.

1.2 More about the EAGLE

The EAGLE is a classical drone system. It consists of a frame with four motors and propellers. It also has various sensors on board, e.g. to determine its orientation relative to the gravitation field, or the distance from the ground, as well as a downward looking camera. To fly in a stable manner, and be able to fly autonomously, the inputs from the sensors need to be analyzed, in real time, and used to control the speed of each of the four motors. Before this actually also works there is of course still a lot to do and, rest assured, you will not have to implement everything from scratch. What exactly is expected from your team is described below. But before that you might want to have a look at another document "the EAGLE platform". It explains what the starting point is, which hardware we make available to you, which software tools there are and so on. It is also full of links to basic information about drones and how they work. The first time skipping back and forth between the two documents might be a good plan. We decided to keep them separate so that the information on the platform and on the project setup are separated for future use.

1.3 The EAGLE modules to be designed

To successfully complete the three stages, you need following 6 modules correctly working and integrated:

1. **Electronic Speed Control (ESC) :** The ESCs are the electronic components that power the motors of the drone, and hence make the propellers spin at the correct speed. An ESC takes in a digital signal from the drone's controller, and translates this to the correct drive currents for the motors to run at the desired speed.

2. **Attitude and navigation control :** For its stabilization, the drone has to continuously run a control loop, which uses the inputs from the inertial sensors to compute the required propeller speed for each of the drone's 4 propellers. This stabilization (also called "the attitude control") is both needed in manual flight mode, and in autonomous flight mode to prevent it from drifting away. During autonomous flight mode, a second navigation controller is needed, to also control the direction and speed of flight.

3. **Wireless video link :** To allow a manual pilot to see what the drone sees, a wireless video link has to be set up between the drone and a PC outside the flight arena. This video link will use the DVBT standard.

4. **Image processing :** To allow the drone to fly autonomously, it should also process the video stream on board. The downward facing camera, constantly films the floor below the drone. Using a red line grid on the floor (see Figure) you should program algorithms to detect the red lines, and compute the drone's (x,y) location from them. Also, the QR codes, positioned in the grid, should be detected.

5. **Cryptography :** QR codes are encrypted and authenticated, such that your drone knows which codes are meant for him, and which codes are malicious codes, not to be trusted. Every QR code should hence be decrypted and verified. In case the code is meant for the drone, the drone can decode the QR code to derive the (x,y) location of the next QR code on the red line grid.

6. **Wireless power transfer :** To enable inductive power transfer to the LED-wall, you will design the necessary electronics on the drone side to drive the inductive coil, and on the other side to receive the power. By optimizing your design, you can maximize the amount of transferred power, and hence the amount of LEDs that will light up on the wall.

1.4 The flight arena

The six components described above will be designed by your team. You will integrate them on a drone platform, equipped with a Zybo-processing platform. The drone will already contain a working RC link, inertial measurement units, a sonar, motors, and a power management block powering the whole drone. More explanation on the given platform can be found in the document "H01Q6: probleemoplossen en ontwerpen EAGLE: The hardware platform".

Drones are only allowed to fly, or function with propellers, inside a flight arena. The flight arena is separated from the working space by safety nets necessary to avoid accidents. To be allowed to use propellers, and utilize the flight zone, students will have to demonstrate that all safety checks, as stated in the EAGLE safety instructions, are implemented correctly. Please carefully read Section 5 for more information regarding safety.

On the floor in this flight arena, a raster is made with red tape (for (x,y) localization) and the black and white QR-codes are placed horizontally at unknown locations on the raster grid. All QR-codes are facing the same direction, which is also the direction the drone is facing when it takes off. Every QR code, after decoding, points to the location of the next QR code. The last QR code in the room is surrounded by a copper coil which is connected to a power receiving circuit, powering the LED wall.

2 Project timing and project organization

The project will last across the whole academic year, with the final demonstration of the resulting EAGLE drones in May. To streamline the project, guide you along the way, and enable intermediate evaluations, the project is divided in 4 phases. Each phase has its own milestones which need to be met in order to be on track and be able to finish the project successfully. You will have support from a coach assigned to your team, as well as from task experts.

2.1 Project phases and milestones

The project will consist of following subsequent phases (the timing of "T1" till "T6" of this academic year can be found on Toledo):

1. **Understand & plan phase (start – T1) :** In this phase, you will follow a project introduction session, go through the EAGLE documentation, assign tasks to every team member, and create a realistic project plan of who does what and when (Gantt chart).
2. **Modeling phase (T1 – T2) :** In this phase, you will start this project's subtasks, and work towards a first set of milestones, and the first EAGLE demonstration&poster-session. In this phase, the work mainly evolves around making models and simplified versions of the different modules.
3. **Module phase (T2 – T4) :** In this phase, you will implement the six individual modules of the drone. Each module should work on its own by the 2nd demonstration&poster session in March, where you will demo their correct functioning. These targets are also captured in a second set of milestones.
4. **Integration phase (T4 – T6) :** In the final phase, all modules will gradually be integrated into the drone platform, and your drone will become more and more autonomous. The project ends with a final demonstration&presentation session, and of course a true ESAT reception!

At the end of every project phase, there are deadlines for targeted milestones. The achieved milestones will be demonstrated in the subsequent demonstration session. In Table 1 a brief listing of all milestones can be found. More details on these milestones can be found in the description documents of the individual modules. There is a difference between hard milestones, and soft milestones. All milestones have to be met in the end but hard milestones have a fixed date before which they must be realized. For soft milestones you can define the date yourself. Most milestones are also a prerequisite towards other activities (e.g. that we will fabricate your PCBs, that you get propellers, or that you can use the flight arena). Other milestones are mainly meant for evaluation. All this information can be found in Table 1.

Table 1: Milestones

Deadline	Milestone
T1	- Project Gantt chart + person allocations - Wireless Link module: VHDL blocks implemented
T2	**- First set of demos ready** - Electronic Speed Control module: Open loop breadboard design done - Wireless Link module: Video streaming finished - Image Processing module: Red line detection finished - Wireless Transfer module: Design finished and first prototype
T2-T3	- Demos of working modules (e.g. flying on gimbal with RC) ! prerequisite for: Flight diploma: you may keep propellers and RC handset + enter the flight zone
T3	**- Hovering drone with manual control, video transmission** - Electronic Speed Control module: PCB design finished ! prerequisite for: PCB fabrication - Wireless Link module: Video streaming on drone ! prerequisite for: image processing tests on drone - Control module: attitude control on drone - Image Processing module: red line detection & localization finished ! prerequisite for: navigation control experiments - Wireless Transfer module: PCB design finished ! prerequisite for: PCB fabrication
T4	**- Second set of demos ready** **- Simple navigation maneuvres** - Electronic Speed Control module: ESCs ready - Control module: navigation control on drone - Image Processing module: QR detection finished - Cryptography module: python tests for cipher
T5	- Electronic Speed Control module: ESCs on drone - Wireless Transfer module: Wireless power transfer from drone to load - Cryptography module: decryption on PC finished
T6	**- Demo of the whole system** ! prerequisite for: ESAT reception

2.2 TA support and guidance

As the course name suggests, one of the goals is that you develop your capabilities to solve problems independently. Nevertheless, it is entirely possible that at some stage of the project, you need some help. When at the end of a work session you have the feeling that you are still stuck with the same problem and have made no progress at all, it is best to ask for help. Otherwise, you risk losing too much time in one phase of the project.

The Toledo site for this course contains all administrative and technical information. If you have a question that might be relevant to other students as well, then the chances are high that the answer is already in Toledo. When you have a problem, please first check the documents in Toledo.

More than 20 professors and TA's are involved in this project (See the Toledo page for their names and responsibilities). You can ask any of them for support, but in general your questions will be addressed the most efficiently if you keep in mind the following task division:

Coaches: Two coaches have been assigned to each EAGLE team. The coaches can help you with planning, management problems, and all general electrical-engineering problems.

Domain experts: There is a domain expert for each of the modules (Electronic speed control, LQR control, wireless video link, image processing, cryptography, wireless power transfer). The domain experts can help you with deeper technical problems that are relevant to their module.

If the TA's cannot answer your technical questions, if you have questions about grading, if you have a problem with a TA or with a colleague student, please contact one of the professors leading this course. Primary contact: Wim Dehaene

3 Project reporting

As in every engineering project, you will regularly have to report on your progress. In this project, a mixture of different reporting styles are combined. They form, together with permanent evaluation, also the basis of the grading system in EAGLE (see Section 4: Evaluation).

EAGLE will require 3 different types of reporting from you:

1. **Blog (every milestone moment T1-to-6):** During the project, there are 6 moments in which you are required to report as a team on a self-made blog. The blog is written on Toledo. In this blog, you will monthly report 1.) on your achieved progress according to your own plan and the given milestones, 2.) on what problems you encountered, 3.) on whether the plan has to be modified and why, and 4.) on the consequences of these modifications. You will on these instants also be asked to fill in some self- and peer-evaluation questions. These blogs and assessments are all done through the assignment section on Toledo.

2. **Demo&poster sessions (on T2 and T4):** At the end of the Modeling Phase and at the end of the Module Phase, you will give a demonstration of the milestones met so far to all TA's and professors. You will also prepare at least 3 posters highlighting your progress so far.

3. **Demo&presentation (on T6):** At the closing of the project, at the end of the Integration Phase, you will give a full demo of your drone, and give a presentation about the project as a whole.

4 Evaluation

The EAGLE project is a course in your curriculum, and hence grades are to be given. Grading is done based on technical achievements (meeting milestones), as well as on cooperation and evolution during the year. This means that you will be given ample opportunity to learn and improve yourself during the year. If things go a bit sturdy in the beginning but towards the end you get the hang of it that is great! Engineering is something you have to learn. Of course the opposite is also true. If you start with a lot of enthusiasm, you still need to ensure that also along the rest of the project things get actually done and organized.

The reporting done by your team (see Section 3) is an important instrument in this grading process. Every time you are required to submit a blog and self-assessment, the EAGLE guidance team will also evaluate you (six times). You will get immediate insights into these scores, so you know where you stand.

In Table 2 you will find the time frame of each evaluation, and their relative weight. The assessment criteria can be found in the assessment rubric in Toledo.

Table 2: Time frame and weights of the evaluations

Timeframe	To deliver	To be evaluated	Percentage of soft skills	Percentage of hard skills
T1	Blog	Planning Teamwork	0%	/
T2	Blog Demonstration Self- and peerevaluation	Adjustment of planning Teamwork Milestones	17%	33%
T3	Blog	Adjustment of planning Teamwork	17%	/
T4	Blog Demonstration Self- and peerevaluation	Adjustment of planning Teamwork Milestones	17%	33%
T5	Blog	Adjustment of planning Teamwork	17%	/
T6	Blog Demonstration Self- and peerevaluation	Result Teamwork Milestones	32%	33%

5 Drone safety measures

The drones you will be constructing and operating are not toys. They have powerful motors (200W) and sharp propellers that spin at 7000 RPM and can cause serious wounds. Furthermore they use lithium polymer batteries (lipo's), which can catch fire if they are badly handled. Moreover, flying a drone is not overly difficult, but some practice is required. Therefore the following precautions are taken.

5.1 Safety coordinator

Whenever you are doing experiments with lipo's or motors/propellers, someone of the team should take on the role of safety coordinator. He/She makes sure that nobody forgets to take proper precautions in their enthusiasm, and everyone present follows the rules below.

5.2 Cuts from rotating parts

A number of safety procedures are already coded in the Zybo platform given to you. You are never allowed to disable these procedures in the code, and must demonstrate to us that they are still functional before you can get propellers to mount on the motors.

- **Arming procedure**: This procedure is coded on the Zybo platform to prevent accidental activation of motors when the drone is powered up. This code ensures that the motors can only spin after the throttle stick on the RC is held in the lower RIGHT corner for 2 seconds (arming). Holding the throttle in the lower LEFT corner for 2 seconds will again prevent motors from spinning in any flight mode (drone disarmed).
- **Heartbeat procedure**: This procedure is coded on the Zybo platform to avoid uncontrolled flying of the drone when the software crashes. Therefore, the flight software gives a heartbeat signal each second to the FPGA hardware, indicating that it is still working. If the heartbeat signal is missed for 1 sec, the motors are stopped immediately.

- **Fail-safe procedure**: This procedure is coded on the Zybo platform to avoid uncontrolled flying of the drone when the RC connection is lost. If no RC signal is received for more than 1 second, the motors are stopped immediately.
- **Kill switch**: This procedure is coded on the Zybo platform to allow the motors to be stopped immediately by toggling this switch on the RC, regardless of the current flight mode or software status.
- **ESC's**: When no valid PWM signal is received from the FPGA, the ESC's should always stop the motors immediately.

5.3 Flight arena and flying rights

Aforementioned procedures will make the drone safer, but you shouldn't rely on them to keep you from getting hurt. For that reason, we have installed a flight arena in the drone room, which is shielded from the rest of the room with a safety net. In and around this arena, following rules are implied:

- You only get your propellers after 1.) demonstrating the safety procedures described in previous subsection, 2.) receiving instructions on how to fly safely, 3.) practicing on a flight simulator and 4.) being cleared for flight by the supervisor.
- Each compartment of the safety net can contain maximum one person and one quadcopter at the same time. As long as a person is inside the net together with a copter, the kill switch should be set to disable the motors and the copter should be disarmed.
- Drones with propellers mounted can only be powered up inside the safety net, and armed when all persons are outside the net. Never have an armed copter with props on outside the safety net.
- You are only allowed to do experiments with propellers on the motors with at least two persons present in the drone room.
- When experimenting with the drone with live motors, long hair should be tied and you can have no loose clothing (scarfs,...) or jewelry on you that could get caught by the spinning motors or propellers.

Supervisors will be very strict on all these points, and persons violating the rules will loose the right to work in the drone room.

5.4 Lipo fire

To minimize the danger of batteries catching fire, always follow the charging and handling procedures for lipo batteries, as stated in the battery documentation. Furthermore charging is only allowed on the dedicated charging stations in the drone room. Always double check that the settings on the charger are correct for your battery and NEVER charge batteries unattended. Charge copter batteries only in the charging stations labeled COPTER. Charge transmitter batteries only in the station labeled Transmitter.

6 Project documentation

This document introduced the EAGLE project to you. You will find further details on the EAGLE platform, the different sub-modules and -tasks, and the tools you will need in the corresponding documents on Toledo. They can be found on Toledo under "Course Information > Module information", resp. "Course Information > Hardware", and "Course Information > Software".