Report on the Co4AIR Marathon – Drone Racing Competition

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TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

Co4AIR

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This contest is one of the key intellectual outputs of the project "Co4AIR - Computers, Cognition and Communication in Control: A strategIc paRtnership", funded by the European Commission through the Erasmus+ Key Action 203, Strategic Partnerships for Higher Education; see http://co4air.eu/. The overall objective was to design and implement a challenge called "Co4-marathon", which requires student teams to design, build, and test efficient solutions for a current and practical control problem.

A preliminary form of this contest was ClujUAV, a real-drone corridor navigation challenge held in the autumn of 2019 in Cluj-Napoca, Romania, see http://rocon.utcluj.ro/clujuav/. The results of this competition informed the design of the Co4AIR Marathon. A detailed report on ClujUAV can be found in (Tamas & al., 2020).

The present document refines the objectives of the contest (Section 1), presents its final design (Section 2), and reports on the first, trial edition of the contest held on July 1st 2021 (Section 3). Finally, based on feedback from the participating teams, a plan for revising the contest is given in Section 4. Section 5 concludes.

1. Objectives

The objectives of the Co4AIR Marathon, as stated in the project description, were to:

1. Motivate students to design, build, and test a solution for a current practical control problem (as stated above).
2. Challenge the brightest students from partner institutions and allow to compare the various teaching systems through the contest result.
3. Connect the contest to the Serious Game, Intellectual Output (IO) 2 of the project.
4. After the end of the project, promote the contest for usage at other universities in Europe.

During the actual design phase during the project, several other objectives and constraints arose:

5. Due to the reality of the COVID epidemic, it became clear that a live version of the contest would not be guaranteed or even possible. Therefore, an online contest was required, which should be easy to transition to a live contest whenever possible.

6. Looking at the profiles of the student audience of Co4AIR, and at the skill matrix derived in IO1 of the project, the contest had to address quite various student profiles, from people experienced in computer science but not in automation and control, to the reverse.

In addition to all this, the contest should of course be fun and involve an interesting problem that motivates students to participate and to invest significant effort into a solution.

2. Methodology and contest design

Methodology

To address Objective 1 and at the same time create a fun problem to solve, we decided to focus on autonomous control of a UAV (quadrotor drone) so as to navigate a race track consisting of markers that must be reached in sequence and as fast as possible. The drone is an unstable system, providing a challenging control problem to solve. At the same time, drones are very popular so the problem is motivating for the students. The race setting promotes competition and a strong personal investment into developing a good solution.

Objective 2 was achieved by running the trial version of the contest with teams from the partner institutions, see Section 3 for details.

To address Objective 3, we designed the IO2 – Serious Game and the Co4AIR Marathon in tandem. Both address UAVs in different scenarios, and we use the same drone dynamical model for both, so control and other algorithms are directly exchangeable. At the organizational level, contest teams are invited to play-test the Serious Game.

The strategy to tackle Objective 4 will be given in Section 5.

To handle the challenge under Objective 5, we decided to design the first version of the contest in simulation, but in a way that is easily transferrable to the real system. This was made possible by using the Simulink Support Package for Parrot Minidrones, where sim-to-real transitions are as close to seamless as possible. Moreover, we allowed the teams to also present a real-drone component of their solution, and scored this separately, to provide a middle ground between a fully simulated and a real-drone-only solution. Finally, to make the competition accessible, we chose the Parrot Mambo minidrone, which costs on the order of 100EUR.

Figure 1. Parrot Mambo minidrone (from parrot.com)

Finally, for Objective 6 we decided to make the contest modular and allow students to work either on computer vision to detect and place markers in the scene; or on automatic control of the drone. In-between these two endpoints lies the planning algorithm that generates the path of the drone to reach the markers, and this was placed under the computer vision umbrella.

It is worth noting here that the contest exploits several aspects of IO1 – Skill Matrix: key roles are played by Automatic Control for the control task, and Cognition and Machine Learning for computer vision and advanced control flavors. Moreover, Embedded Computers is important for the optional real-time implementation, and Communications are implicitly used since the computer communicates wirelessly with the drone.

The specific steps followed to develop the contest design were those from the proposal:

Step 1: Brainstorming on CO4-marathon

Step 2: Designing guidelines for building CO4-marathon

Step 3: Drafting rules for the contest

Step 4: Dissemination to all partners

Step 5: Collecting feedbacks from partners and adapting rules

Step 6: Sharing final rules ‘contest to partners and future participants

Step 7: Team enrollment, deadline and presentation

Step 8: Validation via a feedback from a group of students/teachers

We had to skip Step 9 (Integration of improvements into the summer school), because of the cancellation of the associated summer school.

We are now ready to explain the final contest design.

Final design

Tasks

The objective of each team is to race along a sequence of visual markers with a Parrot Mambo drone, in a simulated environment. The markers are square, placed on the floor, and have colors that stand out. To prevent ambiguity when multiple markers are present in the camera view, they must be followed in order of their color: red, green, blue, red, green, blue, etc. The environment provides the feed of the down-facing camera of the drone, as well as accurate position and attitude signals for the drone; and it allows setting the motor commands. The drone parameters will be fixed, but the sequence of marker positions will be unknown to the teams until the day of the contest. The teams will have to design (a) a computer vision algorithm to detect the markers and produce waypoints for the controller; (b) a control algorithm that ensures the drone reaches each waypoint in the sequence to within a prespecified tolerance; or both (a) and (b). Teams may choose to do only (a) or only (b), in which case a default implementation of the missing component is supplied by the organizers. The programming environment is Matlab/Simulink.

Optionally, teams may also develop and demonstrate a real-life solution for the marker following task, with the true Parrot Mambo. To this end, teams should provide a video recording of the drone running the track, as well as any explanations required (max. 4 minutes per video). The simulation task should be replicated as closely as possible.

To prevent altering the parameters of the simulation, teams are only allowed to change specific blocks in the Simulink scheme, and at the end these blocks are integrated into the “clean” template. Therefore, changes to the expected inputs and outputs of these blocks or other modifications made to the rest of the project will not be carried over.

Instructions on these blocks, together with details on the competition and installation steps to get the baseline solution running, are provided to the teams in a guide document (Co4AIR Contest Guide). As an appendix to this guide, the default control strategy for the drone is explained from a mathematical point of view.

As a nice side-effect of providing default solutions to (a) and (b), we provide in fact to each team a baseline solution that is fully working (albeit slowly/poorly), so the students can already see the drone in motion from the start. A screenshot of the 3D simulator of the drone is provided in Figure 2.

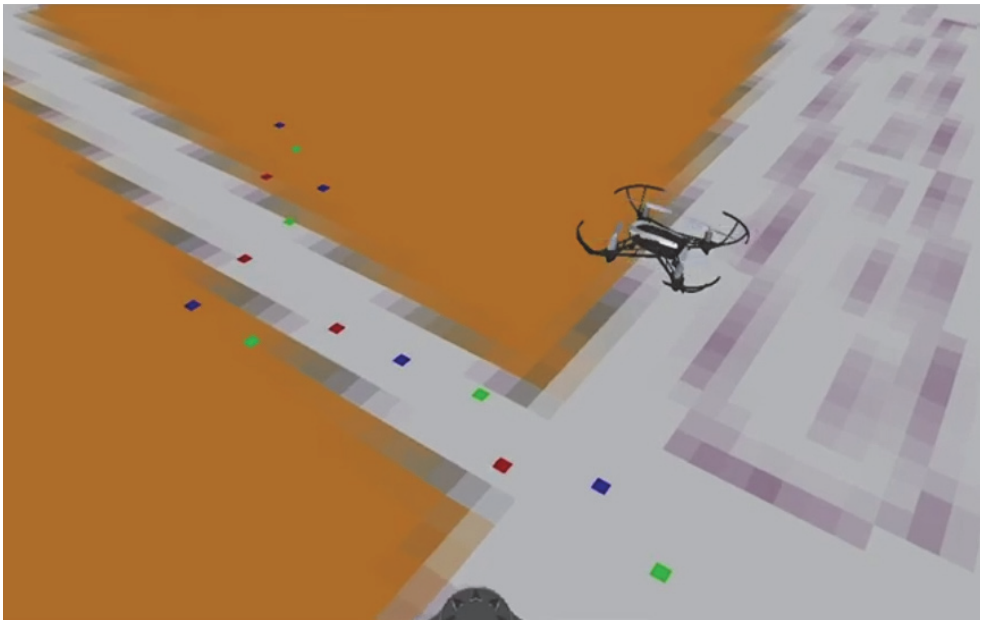

Figure 2. Competition simulator running the baseline solution (based on the Simulink Support Package for Parrot Minidrones)

Team composition and timeline

Teams of 2 or 3 students (PhD, MSc, or BSc) are accepted. All students in a team should preferably come from the same institution, but student levels can mix. Due to the nature of the task, which mixes control and computer vision, teams with expertise in either systems and control, computer science, or a mix of both, are all welcome.

Registration is done at least 5 weeks in advance of the competition by sending an email to the organizer, including team composition, institution, a team name and which among tasks (a), (b), or both the team aims to solve. A draft solution is to be sent 2 weeks in advance of the contest date, which is tested by the organizers for any integration issues, and feedback on correcting these issues is sent to the students. Then, the final solution is due one week in advance.

Evaluation

A jury formed out of the supervisors of the teams from each participating institution and an external expert evaluates the solutions on the competition day. Each team presents their technical approach (up to 10 minutes per team, including questions from the jury), and then the solution is demonstrated. It is the organizers who run the simulations, with the method of each team integrated in the clean template.

Teams will be sorted in descending order of their score, computed with the following formula:

$$P + \left(1 - \frac{T}{T_{max}}\right) + \left(1 - \frac{M}{M_{tot}}\right) + B + R \quad (1)$$

where:

- *P* is the team's presentation and technical approach score
- *T* is the time to complete the task (via the safe landing of the drone), and T_{max} is a maximal time, which is also assigned on crashing the drone or timing out
- *M* is the number of markers missed during the run (position not reached within the required tolerance), out of a total number M_{tot} of markers
- *B* is a bonus received if the team performed both tasks (a) and (b)
- *R* is a bonus score that evaluates the real-life solution with the actual drone, if any

The specific values for the range of the parameters *P* and *R* and the value of *B* in (1) were announced only at the start of the competition, to motivate students to develop a solution that works well overall, instead of overfitting to the specific score function used.

3. Trial contest edition

The first edition of the contest was organized by the Co4AIR team on the 1st of July 2021. The website of the competition is at https://co4air-marathon.squarespace.com, see also Figure 3.

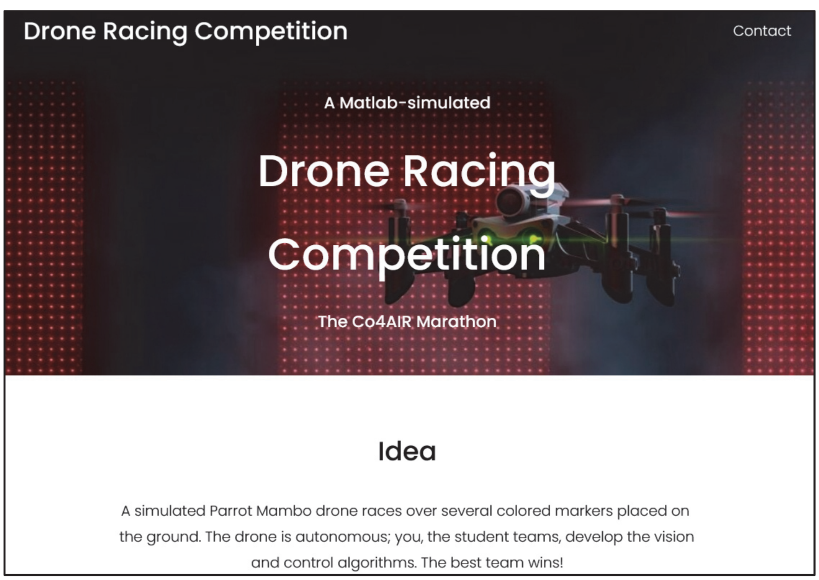

Figure 3. Competition website

The timeline designed above was respected, up to some minor extensions to the registration and solution submission deadlines. We had submissions from 5 teams, with the composition from the table below.

Table 1

Contest teams

Team	Institution	Student	Study level
AirwolfRTS	University of Maribor	Student 1	PhD
		Student 2	PhD
		Student 3	MSc
5C++	University of Wuerzburg	Student 1	MSc
		Student 2	MSc
		Student 3	MSc
QuadcopTeam	Universite Polytechnique Hauts de France	Student 1	MSc
		Student 2	MSc
		Student 3	MSc
libellule	Universite Polytechnique Hauts de France	Student 1	PhD
		Student 2	BSc
		Student 3	BSc
Millenial Mambo	Technical University of Cluj-Napoca	Student 1	MSc
		Student 2	BSc

Note that the teams mix all levels of students together, which is a positive effect of the competition.

We managed to obtain sponsorships from 3 companies: Analog Devices, National Instruments, and Robotics.AI, which meant we could offer actual physical prizes, in the form of embedded computing hardware, to the teams taking the first two places. We offered presentation slots to each of our sponsors at the beginning of the competition.

The draft solution submission proved useful, since compatibility problems were identified with many of the students' solutions, which could then be fixed for the final solution.

The jury was formed out of the team supervisors, together with an external expert recommended by the head of National Instruments.

After discussions with the jury, organized prior to the competition, we arrived at the following parameters in the score function: $P = 0.5$, $B = 0.5$, $R = 0.25$. The rationale for P and B is that these components should be half of the real-race time and marker components, so that the actual race performance counts more. R was selected smaller because not all the teams had access to – or the financial possibility to acquire – the real drone.

Presentations and actual races were interspersed to maintain audience interest. To make the competition more exciting, it was also decided that the time score T and marker score M would be averaged between two race tracks: one where the markers are nearly along a line, which favors speed, and another where there the track given by the marker sequence often switches direction at various large angles, which favors maneuverability.

None of the teams fully implemented both the computer vision or control tasks – but nearly all of them worked on the path planning part. We thus decided to award all the teams that did this part 30% of the bonus B.One unforeseen circumstance arose: on the more difficult, maneuvrability track, some solutions landed prematurely, achieving small time but with many missed markers. To prevent favoring such failed solutions due to their short time, we decided in on-the-spot jury discussions that for any solution that misses more than half the markers, the maximal time will be assigned.

The final ranking of the teams was: 1st place (with prize) QuadcopTeam, 2nd place (with prize) AirwolfRTS, 3rd place libellule, 4th place Millenial Mambo, and 5th place 5C++.

4. Participant feedback and improvements in the next edition

We organized a survey will all contestants, where we attempted to gauge:

- Their experience with the contest, overall and specifically on the online format.
- How useful the contest was for them and whether they would like to see such events integrated in their curriculum.
- Their opinion on the scoring rules
- What should be improved in general, for the online experience, etc.
- In what way should each participant's competition support them
- How students prefer their contest performance to be recognized

We received 9 responses from the 14 participants, i.e. a very good 64% response rate which shows the level of engagement that they had with the contest.

Overall feedback

The overall opinion about the contest was largely positive. Here are some key points:

- The students are overwhelmingly in favor of including such a contest in their regular studies (all 9 in favor out of which 8 at the maximum end of the scale) – this is a **key conclusion** of our trial, as it shows the potential of our contest as a teaching tool.
- All responses rated the experience as good (6) or very good (3), and the online experience as good (5) or very good (4) (although the students admitted the challenges in making such a competition work well in an online setting).
- 8 out of 9 students thought the contest helps in their day-to-day academic activities – another key point.
- Perhaps surprisingly, just a basic ranking of their team was the top-voted option for performance recognition. Apparently, actual prizes in cash or hardware are not that important for the students. This means that sponsorships should be used towards a better organization of the event itself, rather than prizes.

Points for improvement

Students suggested many possible improvements, and we highlight here some salient points:

- An introduction event where the competition, procedure, baseline solution, etc. are presented and the teams get to know each other. We definitely plan to include this in the final design, right after the registration stage.
- A specific way of integrating the contest in the curriculum, via a special lecture dedicated to it and ECTS scores. We will consider this as a leading recommendation for integration.
- The students were surprised by the very challenging "maneuverability" track and suggest that we include more example tracks with the baseline solution. We will absolutely include this in the final design.
- A "live score" table where people can see their performance on the fly. We will implement this since it adds interactivity.

- Students suggested knowing the scoring weights in advance. Due to the reasons explained before, we prefer to not do this, but we will try to figure out a middle ground where we explain which parts of the solution will be more important without giving exact numbers.

Now, several issues that we observed ourselves as organizers:

- It is difficult to increase scores in simulation just from the computer vision component, because the camera is "perfect." To better take into account computer-vision solutions, we will consider adding noise to the camera image, scoring the marker detection component separately, or a combination of the two.
- Students make minor mistakes in complying to the instructions (like including their controller in a non-standard place in the scheme, or forgetting to include the latest fixes in the solution they send) which have major impact on their score. To address this, in the final design the students should be allowed to examine the quality of their solution after integration in the template, which will allow them to discover integration bugs.
- The real-time solution required a lot of effort but was a small part of the score. While this was partly an unavoidable consequence of the online format of the contest, where simulation mattered more, juries should make the real-time component of the score more commensurate with the effort required.
- We also noticed that it is not the most technically interesting solutions that get the best times. Instead, tuning a simple controller empirically often works best in practice. If this is deemed undesirable, juries may increase the technical approach scoring weight.

5. Conclusions and outlook

The overarching line of the feedback above is that students find our contest useful, and would absolutely like to see such an event in their curriculum. We therefore believe that the Co4AIR Marathon is a useful educational tool, and that the objective of this intellectual output has been successfully achieved.

To move on to the next step, after revising the contest design as described above, we would like to promote adoption of this contest both in our universities and others. To achieve this, we plan to publicize the contest both within our own network, and also using European, Erasmus+ dissemination channels.

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References

Co4AIR Contest Guide. (n.d.). Retrieved from Co4AIR Contest: https://co4air-marathon.squarespace.com/s/guide_final.pdf

Tamas, L., & al. (2020). The ClujUAV student competition: A corridor navigation challenge with autonomous drones. *IFAC World Congress.*