2024 European Control Conference (ECC)
June 25-28, 2024. Stockholm, Sweden

DroPong: Enthusing Learners about Control Engineering by Revisiting the Pong Game with Aerial and Ground Drones*

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***Abstract*— This paper proposes an adapted version of the classic Pong game, tailored for educational purposes and illustrated with two ground mobile robots and one drone, therefore called DroPong. The goal of this paper is twofold: (i) motivating students to pursue within a Control Engineering specialization, by involving engineering students in the development of game-inspired diverting Robotic platforms for teaching and research; (ii) educating future generations by increasing the visibility of Science, more particularly Control Engineering and Robotics, via popularizing science activities for children during open-day events and science festivals. The developed open-access resources are available on a dedicated repository.**

I. INTRODUCTION

Finding strategies to motivate and enthuse students is a key challenge for teachers [1], [2]. It is well known that motivated students display pro-activeness, creativity, engagement and goal-oriented behaviors, with a notable progress during the learning process. Numerous pedagogical approaches have been developed to modify and adapt teaching methods, e.g., project-based learning, flipped classroom or other blending learning strategies, gamification, use of online and open educational resources, Massive Open Online Courses (MOOCs), Massive Open Online Laboratories (MOOLs), etc. More specifically, games in the classroom can change the way students approach learning, adding more interaction and fun, while being closer to real world feeling than classic (generally overloaded) academic scenarios. Gamification and serious games (e.g., [3], [4], [5], [6], [7]) have been recognized as efficient practice to improve the learners' motivation and engagement. Such game-based learning tools are now considered at different levels, from kids to graduate students activities.

For children, as well as students in Control Engineering, illustrative and motivating applications are generally well appreciated in complement to theory or as a primary source of learning motivation. Robotics is one widely-used application domain ([1], [2]), since students can obtain tangible results through experimentation on possible low-cost or open platforms broadly available for education.

Moreover, combining games and Robotics is quite easy and results in innovative applications and platforms that can be used for teaching, research, and popularizing science activities during open-day events in universities and research laboratories. Games have often been considered as benchmarks in research, as they require advanced skills close to human behavior, which is a challenge for assessing new theoretic methods and algorithms. Famous examples are related to video games used to illustrate the performance of Reinforcement Learning algorithms [8]. Transfer of classic games to real-world experiments involving robots have also been considered, to create *robot versus robot* or *robot versus human* experimentations. For example, the "Rock-paper-scissors" game has been implemented using a humanoid robot [9] with gesture recognition and human intention prediction capabilities to study human-robot interactions. A multi-drone platform has been developed in [10] to play "Tic-tac-toe" with a human. Illustrating Reinforcement Learning algorithms and studying human-swarm interactions, the authors also underline the tangible and interactive experience that the experimental platform proposes to the user and the resulting enhanced engagement of the participants when playing a game with real drones. Ping pong and air-hockey, are also two well known examples of games that have been considered for adaptation to real-world systems involving Robotics. Development of a robot to play ping-pong with a human player has been the objective of numerous works, e.g., from the early work of [11] to more recent work of [12], due to the challenging requirements in terms of high-speed trajectory estimation and motion control capabilities to be implemented when playing with humans. In a two-dimensional context, air-hockey has been considered in [13], [14] and [15] for *human versus robot* games and in [16] for *robot versus robot* games.

In this paper tailored for educational purposes, the classic Pong game is adapted to a real-world setup with two mobile ground robots acting as paddles and one drone as ball. Therefore, this paper reports recent feedback on the development and first uses of this new DroPong platform

*This work was supported by the IFAC Activity Fund via the project *(Re)CreativeRobot*.

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at CentraleSupélec[1], and investigates how the development and use of an interactive game involving real robots can be fruitful for Control Education, while promoting Control Engineering. The main objectives of this work, together with the corresponding outcomes and contributions (see Fig. 1), are the following:

- **For children** (DroPong *users*): providing one of the first interactions with Engineering (Control, Robotics) in a novel recreative *learning by doing* manner;
- **For graduate students** (DroPong *developers*): increasing their motivation to pursue in Control Engineering, developing their knowledge and practical skills in this field by active learning (e.g., *learning by doing*), and acquiring pedagogical skills (e.g., *learning by teaching*) by creating new teaching material and teaching workshops for children;
- **For teachers/researchers** (DroPong *project supervisors*): creating a new testbed to implement more advanced Control / Artificial Intelligence algorithms, developing better practices and free resources for Control teaching, improving the educational system by sharing their resources and practices with other laboratories/universities/schools.

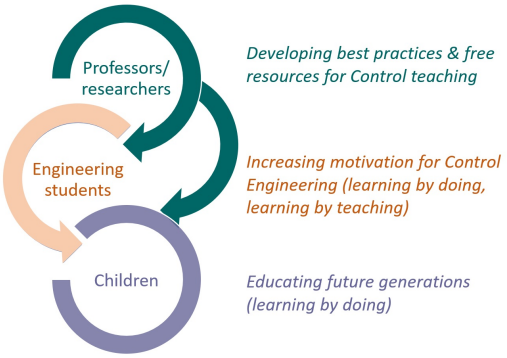

Fig. 1. Illustration of the impact of this work.

The paper is organized as follows. The next section outlines the main development stages of the DroPong platform. Section III provides technical details about the platform itself, while Section IV describes the workshop schedule. Before concluding remarks, Section V proposes some feedback derived from the use of the platform in Control Eduction and science festivals.

II. Platform Development

This section presents the main stages of the DroPong development. Several recent research and pedagogic projects in CentraleSupélec permitted to:

- Develop an indoor flight arena [17] at CentraleSupélec of $10\text{m} \times 5\text{m} \times 3\text{m}$, equipped with an OptiTrack motion capture system;
- Purchase several ground and unmanned aerial vehicles, to be used for research, teaching and popularizing science purposes [18].

From January to April 2023, the course "Control architectures of complex systems" took place for the third year students of CentraleSupélec specialized in Control Engineering. This course (see [19]) has 21h on-site (for a workload of approximative 35h/student), divided in lectures (6h), tutorials (6h), case-study (6h) and poster session (3h). During the lectures, the students get notions about modeling of multi-agent systems, communication graphs, consensus-based control, centralized/decentralized/distributed predictive control, etc. During the tutorials, several exercises on formation control of multi-vehicle systems are solved by the students in simulation. During the case study, the students work in small groups and propose themselves a scenario related to the course objectives and validated by the supervising team. Then, they solve their subject first in simulation and, then, by experimentation in the flight arena, using ground mobile vehicles and/or drones. One group of four students proposed and implemented a first 2D version of the Pong game using three TurtleBot Burger ground robots, i.e., two robots acting like paddles and one robot being considered as the ball.

In September 2022, a project "Multi-robot multi-drone games" was proposed for the first year students of CentraleSupélec, within the Projects cluster "Pedagogical Innovation and EdTech". Students made their choice in January 2023, and in February 2023, one team of five students started working on this project during the second semester of the scholar year 2022-2023. The idea was to develop the DroPong game using two ground robots and one drone. The students were supervised by the research engineer of the flight arena (who helped them with the implementation and the experiments), together with two professors/researchers. Approximative 80h on-site were dedicated in the students' agenda to this project, including the time for developing the deliverables and the project defence. Two oral presentations (in March and June 2023) were delivered within the "Pedagogical Innovation and EdTech" cluster (for an audience of approximative 40 students, together with their supervisors, and the co-heads of the cluster). This was a valuable opportunity for a first external feedback, including pedagogical, technical, and potential-users aspects. During this project, the students developed the actual DroPong game, together with pedagogical supports for a popularizing science workshop. In September 2023, the students continued working on the same project during their second year at CentraleSupélec.

III. DroPong Platform

Pong [20] is a classic well known video game developed in the 70's where two players (human and/or computer) compete in a simple and 2D adaptation of a table tennis game. In this game, each player disposes of a paddle that can be moved vertically along the left and right edges of a rectangle area to hit a ball and throw it back to the opponent. The ball evolves in this rectangle area by bouncing on the

[1]CentraleSupélec is an outstanding French graduate engineering school, called "Grande Ecole". Since 2020, CentraleSupélec is part of the Université Paris-Saclay.

top and the bottom edges. Whenever a player fails to hit the ball with its paddle, the opponent scores a point.

Inspired from the Pong game, the DroPong platform implements this concept but with robots in a real-world setup. Two mobile ground robots are used as paddles and a drone as a ball, to propose a 3D gaming experience.

The playground is located in the flight arena of CentraleSupélec, where a rectangular area is delimited on the ground with colored tape (blue solid and dashed lines in Fig. 2). Two DJI RoboMaster S1 robots and one DJI RoboMaster Tello Talent drone are equipped with passive reflective markers to get real-time and accurate positioning information from an OptiTrack motion capture system.

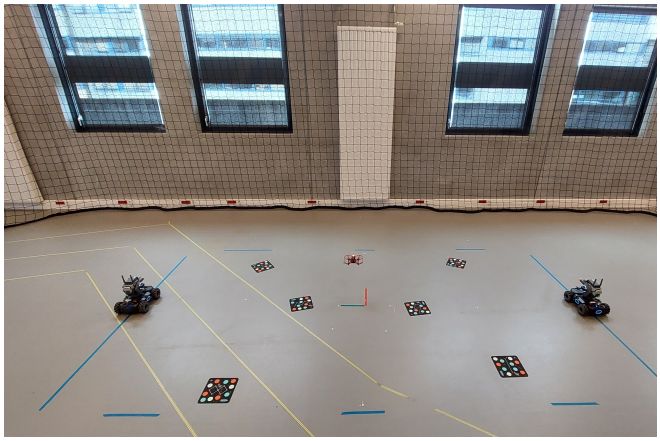

Fig. 2. Picture of a DroPong game running in the flight arena.

A schematic diagram of the entire system architecture is proposed in Fig. 3. As illustrated, the video stream from the motion capture cameras is sent to a computer (MoCap PC), part of the Optitrack system, which estimates the position and orientation of the drone and robots deduced from the corresponding markers locations, and sends this information to the DroPong laptop. This laptop is used to execute the DroPong software running the game and controlling the motion of the ball, and possibly of the paddle(s) depending on the chosen mode for the game: *human versus computer*, *human versus human*, *computer versus computer*. In the case of paddle(s) controlled by human player(s), joypad(s) can be connected to the laptop. Another possibility is to control the paddle mobile robot(s) directly from a smartphone using the RoboMaster application (provided by DJI). This possibility offers more flexibility and is more user friendly and suitable when using the DroPong platform for kids.

Notice that in a preliminary version, developed for first tests, a third ground mobile robot was considered as the ball, resulting in a safe-to-experiment 2D game as in the original Pong game.

The developed software architecture leverages the advantages of the Robot Operating System (ROS) framework (modularity of the code, drivers available for robot platforms, easy *sim-to-real* transfer, etc.). A simulator with emulated robot and drone behavior has been developed to test and validate the algorithms before deploying to the real world

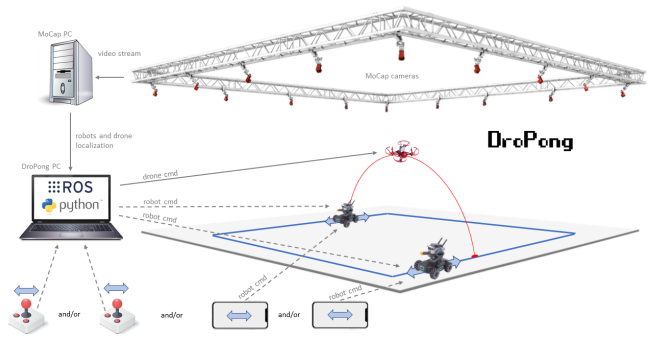

Fig. 3. Schematic diagram of the DroPong architecture.

platform. An example of visualization of the game in simulation using RViz is presented in Fig. 4.

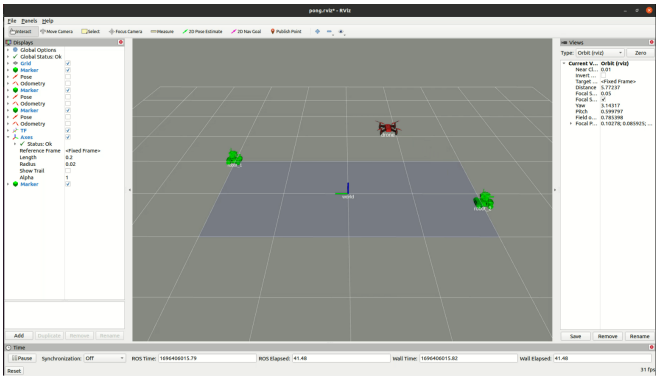

Fig. 4. Visualization of a simulated DroPong game in RViz.

Although based on ROS, the code architecture offers the possibility to integrate contributions by people who are not familiar with ROS. The behavior of the drone ball and/or of the paddle(s) when controlled by computer are indeed implemented in dedicated pure Python scripts, involving no ROS specific code.

In the current version of the DroPong platform, the motion of the ball is planar, i.e. at a constant altitude over the playground. A simplified behavior model has been implemented, making the drone bounce at the edges of the rectangular area, and when flying over the ground robots to emulate the hit by the paddle. More advanced behaviors are currently under implementation for the drone, considering 3D motion with bounces (see examples of trajectories on Fig. 5) parameterized in terms of bounce angle and ground speed. The 3D trajectory will be available in the next release of the DroPong platform for improved gaming experience for the players.

In the current version, reference velocities are also directly sent as control inputs to the drone. A feedback controller will be implemented in the next version of the platform to improve tracking performance. From a pedagogical point of view, this part can be exploited to make students work on Control Engineering concepts such as PID or state feedback controllers, during practical work sessions.

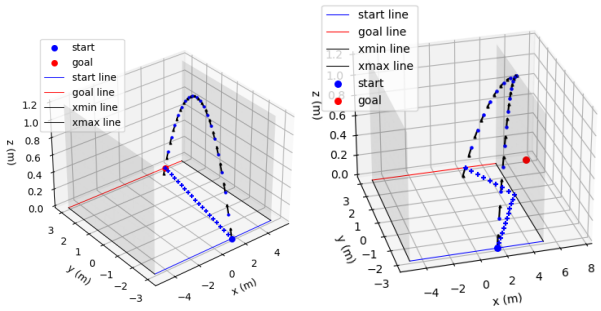

Fig. 5. 3D trajectories for the drone accounting for possible bounces at the playground boundaries: no bounce (on the left hand side), bounce at the right boundary (on the right hand side).

A repository containing the open-source code is available at `https://github.com/L2S-lab/dropong`. A video illustrating the different stages of the DroPong development (2D case with three ground robots, 3D case with two ground robots and one drone, both in simulation and experimentation) is provided at `https://youtu.be/whsnMcFf8ZQ`.

IV. DroPong for Control Education and Science Festivals

This section focuses on the developed DroPong-based educational activities and the related scientific events.

A. DroPong Workshop for children - short version

Most of the visits organized in CentraleSupélec are short (about 30 minutes) in order to illustrate the research activities of the different laboratories of the school. Therefore, the content of the workshop has to be focused and very well synchronized. The short visits are organized as follows:

1) Short introduction of the speakers (together with their engineering background) and of the flight arena;
2) Interactive introduction (which can be adapted to diverse age groups) of Control, mainly explaining the notion of feedback, using part of the first video from the *Girls in Control* international workshop [21], [22];
3) Interactive presentation of the DroPong game;
4) Short description of the mobile robots and drones used for the DroPong game;
5) Live demonstration of the DroPong game (see Fig. 6). Volunteers from the public are asked to experiment the game;
6) Discussion on applying the concept of feedback during the DroPong game, e.g., making a link between the game of Chase (where one person runs after another player) and the DroPong (where the robot follows the drone on one direction) and discussing the sensor, the actuator, and controller roles;
7) Quick survey for quantitative feedback from the audience.

B. DroPong Workshop for children - long version

Longer versions of the DroPong Workshop can have several additional items with respect to the 30min versions:

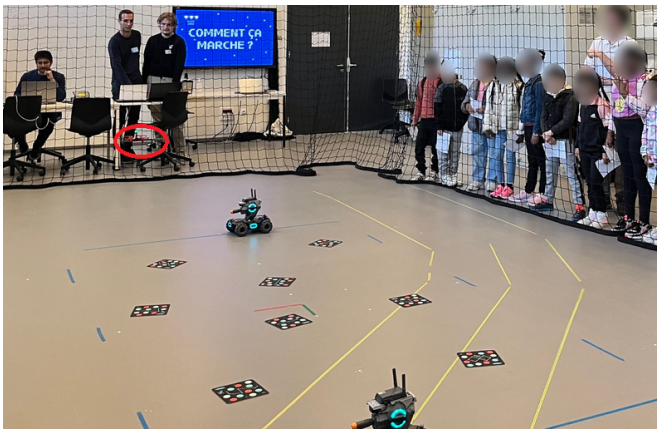

Fig. 6. DroPong game for children during the French science festival "Fête de la Science" 2023 with one drone (encircled in red) and two ground robots.

1) The presentation of the speakers still needs to remain short and focused on their engineering background.
2) We propose to start directly with a short demonstration session of the DroPong to impress the audience. This will be used as an icebreaker allowing further discussions.
3) We propose to continue with a short illustration of one theoretical concept, e.g. the *feedback* notion in Control, followed by a discussion related to the DroPong demonstration and possible new scenarios to be proposed and tested by the audience. In addition to the identification of the main elements of the control loop (sensor, actuator, controller), more elements could be added to explain the P, PI, PID controllers, together with the feed-forward action.
4) Theoretical concepts related to other engineering branches can be further explored on the same rhythm (short theoretical illustration, discussion and link to the DroPong game), e.g., Robotics, Informatics, Mechanics, Artificial Intelligence, etc.
5) The next step consists in providing some pedagogical material dedicated to the notions they learned. Two examples of educative forms (used for the French version of the workshop) are illustrated in Fig. 7, in order to guide the first steps in Informatics and Mechanics, and to have the possibility to revise the explained notions.
6) We propose to finalize the DroPong session in a game mode, i.e., a short DroPong competition (battle mode), single mode or team mode, involving volunteers from the audience. This is also a good moment to take their feedback, as learners and DroPong users as well.
7) In the end, a group picture or individual pictures could be a nice souvenir of the DroPong workshop.

C. DroPong for students in Control Engineering

Presenting the DroPong for students will be the opportunity to introduce advanced Control techniques, for instance:

- Predictive control (prediction horizons, constraints);

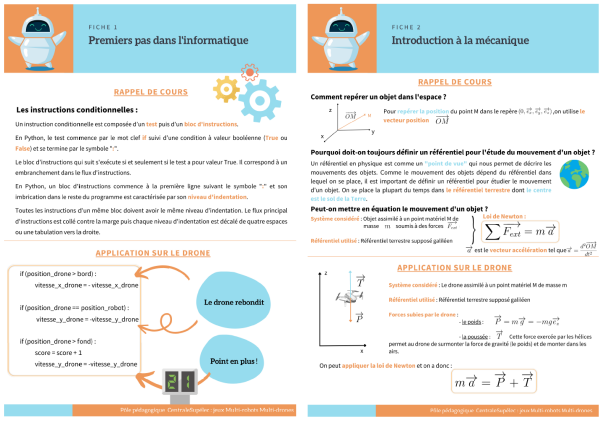

Fig. 7. Two examples of educative forms used for the French version of the DroPong workshop.

- Graph theory and multi-agents system control, e.g. consensus-based control, leader-follower control approaches;
- State estimation and observer-based approaches, for instance involving sensor-fusion;
- Learning-based control approaches, etc.

Additional developments are ongoing work in order to propose DroPong-based developments for these theoretical concepts.

V. Analysis

This section synthesizes the main DroPong events, together with some feedback, both from the learners and the teaching team.

A. DroPong events in 2023

In 2023, the short version of the DroPong Workshop was presented during three events for around 120 participants:

- The traditional Closing day OSER ("Journée de Clôture OSER" [23]), May 2023, organized by the CentraleSupélec students' association OSER [24], committed to equal opportunity, inclusion and diversity: *two groups of 25 teenagers each* (including one group of girls only);
- High school students' visit, May 2023, organized by the Center for Diversity and Inclusion ("Centre des diversités et de l'inclusion"): *one group of 20 teenagers*;
- The national French science festival "Fête de la Science", October 2023, organized by Université Paris-Saclay: *two groups of 8 year old children* (about 50 kids in total).

A long version of the DroPong Workshop is scheduled in July 2024, during the Summer Camp CentraleSupélec which welcomes teenagers to discover the students' activities, together with the research topics of the research laboratories of CentraleSupélec.

B. Learners' feedback

Quantitative feedback has been acquired from the two groups during the "Fête de la Science" 2023. There were 22 and 26 answers, respectively collected from the two groups of kids. As the time was short, we focused on only three questions: Q1. "Would you like to discover more about Robotics?"; Q2. "Did you find the real Pong game more fun than the virtual one?"; Q3. "Did you learned new things about Robotics?". The participants' feedback is illustrated in Fig. 8. The results show that the children were happy with the workshop. Qualitative feedback was even more motivating: the kids asked a lot of questions, they were enthusiastic about the robots and the drone, and they liked the protection glasses. The first group had some additional time, thus the kids were very happy to take a souvenir picture with one drone (for security reasons, the battery of the drone was removed during the photo session).

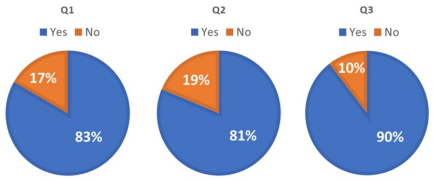

Fig. 8. Kids' feedback after the DroPong game during the French science festival "Fête de la Science" 2023.

The first year students of CentraleSupélec were very motivated to work on this project, both from a scientific perspective and a pedagogical experience. One key factor of their motivation was to develop educational material for children, offering them insights on Science and Engineering, in particular in Control Engineering, Robotics and Informatics. They also appreciated the *collaborative learning* environment during their project.

C. Lessons learned

Diversity is an important element when organizing workshops for children. After running several workshops, we found that having a mixed team with professors and students is beneficial for everyone:

- The students' work is better highlighted;
- The students are more confident when they work in team with their project advisors;
- From the children's view, both the students and the professors offer examples of diverse academic paths for engineering;
- The professors also learn from the students, allowing them to keep up with trends, etc. In addition, incorporating new technologies and hand-on experiments in the teaching activities increases the learners' engagement, enhancing students' success.

In spite of the beneficial impact on young generations, developing experimental material to make Control Engineering accessible to children is time consuming. However, the qualitative feedback from the children is an impressive source of motivation. This kind of workshops is one of the first opportunities for kids to discover the engineering profession and it is our duty to render this moment memorable.

However, quantitative feedback is not easy to get during short visits (30min). We realized that for most of the kids, it

was the first time they were supposed to give a feedback. In order to have their feedback in a short time, without needing additional materials (pens, pencils, etc.), we distributed them a printed paper survey, with only three questions. The kids had to tear off the corresponding edges, marked with "like"/"dislike" icons. However, for the next events, these icons will be replaced with "happy"/"unhappy" emoji that keep their meaning unchanged when turning over the paper sheet (to avoid confusion).

VI. Conclusions

This paper proposed a new educational game called DroPong, adapted from the classic Pong game to a real-world setup with two mobile ground robots acting as paddles and one drone as ball. The purpose of DroPong is to increase the visibility of Control Engineering among engineering students and to let children discover Control, Robotics, and Engineering during open-day events and science festivals, in a memorable hand-on fashion. The developed resources are open-access `https://github.com/L2S-lab/dropong`.

Current works focus on the implementation of more advanced Control algorithms, on testing algorithms with human-in-the-loop interaction, on developing simplified testbeds for real world experimentation of Artifical Intelligence algorithms (e.g., supervised learning, Reinforcement Learning). The implementation of the 3D trajectory for the drone will be available in a new release of the DroPong.

In the near future, more visits will be organized for children to help increasing their interest for Engineering.

Following the example of the "Girls in Control" workshop [22], a long term perspective consists in proposing the DroPong workshop in different languages.

Acknowledgment

The authors acknowledge all the participants of the workshop "(Re)CreativeRobot", together with the organizers of the scientific festival "Fête de la Science" 2023, Université Paris-Saclay. The authors would like to thank Laure Baudart, Thomas Notz, Charles Petit, Louis Warin, third year students at CentraleSupélec in Control Engineering, for the implementation of the 2D Pong game on ground robots during their course on "Control architectures of complex systems". The authors are grateful to Lionel Husson (co-head of the students' projects cluster "Pedagogical Innovation and EdTech" at CentraleSupélec) for the enriching pedagogical discussions, and to the IFAC TC 9.4 on *Control Education* and IFAC TC 9.2 on *Systems and Control for Societal Impact* for supporting this work and for providing constructive feedback during the respective committee meetings at the IFAC World Congress 2023.

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