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Systems and Control for Societal Impact: TC9.2. Developments and Vision - Contribution to the CC9 Milestone Session 2023

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Abstract: Computer and Internet revolutions brought major transformations in our society along the last decades. With these recent main advances, numerous new possibilities in control/AI systems have arrived, generating new applications at all levels in the society, making impact studies become more crucial. This includes for example healthcare, industry, ground transportation, aerospace and energy management. As a societal driver, climate changes also urge to be addressed. The IFAC TC 9.2 addresses the impact of systems and control: on socio-technical systems and organizations, on the human individual, and on society in the global scale. The underlying question is how to plan the systems design in order to obtain the maximum of benefits and at the same time anticipate their possible adverse effects. This note contains a set of first hints towards these goals and highlights some of the TC9.2 current and future developments. It is part of the milestone session organised by the coordinating committee CC9 *"Control Challenges for Social Systems Milestone" at the IFAC World Congress in Yokohama in 2023.*

Keywords: Cyber Physical & Human Systems, Ethics, Control for Societal Impact

1. INTRODUCTION

Control has been hugely impacting the society at all levels. In (Samad and Annaswamy [2011]) and (Samad and Annaswamy [2014]), for example, success stories and challenges in control have been described with respect to a wide range of applications. Moreover, a research agenda on systems and control for the future of humanity has been provided in (Lamnabhi-Lagarrigue et al. [2017a]).

In this note, an overview of some key topics which belong to the set of TC9.2 goals, is presented. These are exposed in relation to other disciplines. Indeed, this activity asks often for collaborating with fields other than control and computer sciences as also pointed out in (Annaswamy et al. [2023b]). In this text, this collaboration will be briefly structured and highlighted.

Some of the TC 9.2 ongoing and future developments are then highlighted.

2. HIGHLIGHTING SOME TOPICS FOR THE CONTROL TOWARDS SOCIETAL IMPACT

We chose to begin by discussing first the new field of Cyber Physical and Human Systems (CPHS), that has emerged with the recent technological revolution. Indeed, impact studies are often closely related to the extent the machine is inter-playing very closely with humans. That's why TC9.2 adopts a human-centered approach.

2.1 Cyber Physical and Human Systems

The technological revolution of these last decades has generated a much closer relation between humans and cyber physical systems (CPS) (Lee and Seshia [2017]). A new research field was then born named Cyber Physical and Human Systems (CPHS).

CPHS are defined as interconnected systems that include physical systems, computing and communication systems, and human beings, and allow these entities to communicate with each other and make decisions across space and time (Sowe et al. [2016]).

Advances in this field require multidisciplinary and interdisciplinary collaboration, which should be done along of modeling, simulating, analyzing, controlling, optimizing and evaluating such systems (H-CPS-I [2014]), (Netto and Spurgeon [2017]), (Lamnabhi-Lagarrigue et al. [2017b]). The potentials and impacts from this new field, as mentioned, call also for reformulating and rethinking the systems design towards what it is called responsible automation, that is described for example in (Sampath and Khargonekar [2018], Khargonekar and Sampath [2020]).

With the nowadays systems - embedded, interconnected - together with the computer and control sciences, as mentioned, other disciplines appear to be important to be taken into account in order to consider all the new opportunities and challenges of CPHS towards systems with positive impacts. These are for example cognition,

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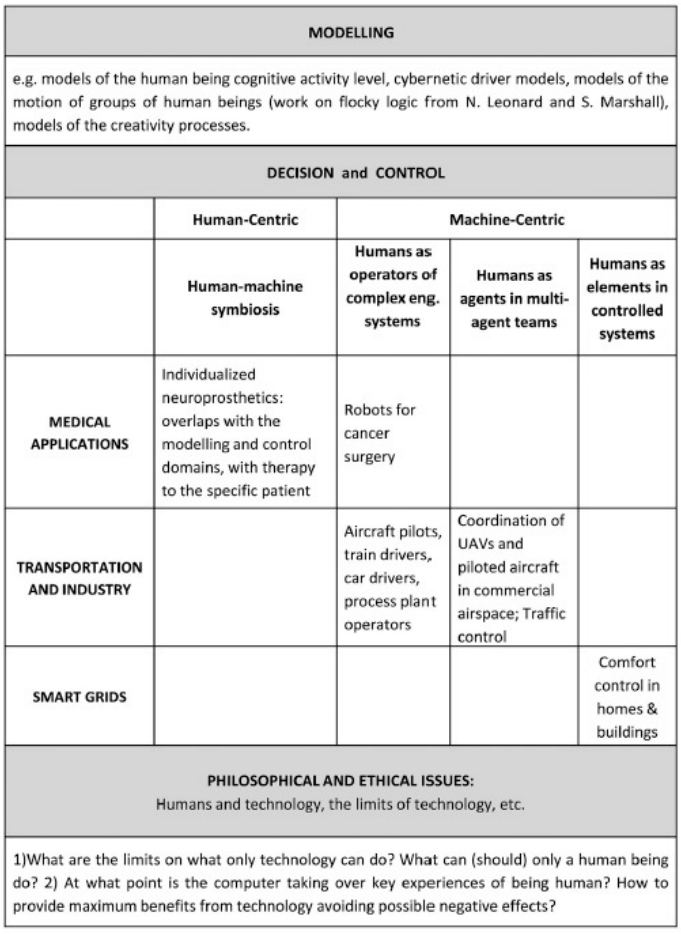

Fig. 1. The three stages (modeling, decision and control) for a CPHS design, with the four classes of interaction between the Human and the CPS, as defined in H-CPS-I 2014, in Paris. Please also see chapter 1 (T. Samad) in Part 1 in (Annaswamy et al. [2023a]). Note: figure from (Netto and Spurgeon [2017]).

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ergonomics, psychology, neuro-ergonomics, neurosciences, law, philosophy, sociology, political science and economics.

2.2 Classes of CPHS

To concretely address the problems, we can use the four classes of CPHS that have been described in (H-CPS-I [2014], Annaswamy et al. [2023a]) which help to classify and structure the different types of interactions. These classes are defined with respect to different levels of interaction of the human with the CPS, from the stronger Class 1 to the lighter Class 4 (see figure 1):

(1) Human-machine symbioses (eg. neurostimulation)
(2) Humans as operators or supervisors of complex systems (in transportation, in hazardous environments, in industry processes, etc)
(3) Humans as agents in multi-agent systems (eg. traffic control)
(4) The human as a part in controlled systems (eg. smart homes and buildings)

2.3 Prior and post studies aiming for positive impacts: some examples

Considering the potential significant influence of CPHS in humans, a set of prior and post studies shows to be important to the effectively systems design as succinctly exemplified below.

- Philosophy as a propulsion to design ethical control systems.

  Some fields of automation application raise what we call the moral dilemma. In the automated car research for example, this means that, in a critical situation, the machine should choose between two critical choices having no other option (see Bonnefon et al. [2016])

  The philosopher J.V. Hoven tackles this problem (den Hoven et al. [2012]) by outlining the role of the engineering development to avoid moral dilemmas in automation: "*When thinking about ethics, technology is often only mentioned as the source of our problems, not as a potential solution to our moral dilemmas. When thinking about technology, ethics is often only mentioned as a constraint on developments, not as a source and spring of innovation. ....we argue that ethics can be the source of technological development rather than just a constraint and technological progress can create moral progress rather than just moral problems.*"

  Indeed, J.V. Hoven argues that sometimes the moral dilemmas are amendable by a technical solution. That *"solutions to a dilemma may also be found by changing the situation in such a way that we can satisfy all our value commitments."* The question is how to achieve this design to avoid moral dilemmas? And are we in the correct timing of technological development to build certain solutions or shall we postpone some technological deployments till the underlying necessary technology be more mature?

  J.V. Hoven speaks of the engineer responsibility to prevent situations which are morally dilemmatic. This would prevent the famous moral dilemma discussed by (Bonnefon et al. [2016]). Moreover, deploying an automated vehicle containing moral choices could lead to dangerous effects since a driver would be driving such vehicle and then accepting it. Indeed, (Winner [1986]) discusses exactly the limits to impose to technology in an age of highly automated systems. How to make good usage of the numerous benefits of technology while imposing strict necessary limits?

  As pointed out: are we in the correct timing to deploy certain technologies? For example, certainly, huge advances have been achieved in the last decades in automated cars. Still, their deployment in the current point of time could be critical given the complexity of the transportation system and the present technology level. This could lead very often to moral dilemmas in the road as exposed, a situation that is not desirable.
- Full automation, manual or mixed mode?: before automating a system, it is crucial to identify whether and when it is possible, relevant and desirable to do it, or, on the other hand, to keep the human in the control. As for example, we can cite bicycles or new

innovating mobility modes as personal transporters as options for mobility, whenever possible and safe; Also, study is needed on how to share the control resources between algorithms and humans (e.g., advanced driving assistance systems (Netto et al. [2020]), multimodality, human-robot interaction).

- Studying the previewed impact of the desired system on the human or on the social system, prior to the design, can guide it. This goal requires the development of appropriate methods and tools that consider the automation, the time scales in which the control system is actuating, the individuals, and the social environment.

  An example is the paradigm of the technological artifact (Bødker and Nylandsted Klokmose [2011]) that can be used as a framework to analyze the relation between the human and the machine. Indeed, technical artifacts do need not only to be characterized exclusively through its structural characteristics, such as their size, material composition, weight, etc.

  Instead, characterizing a thing as an artifact requires words that refer to human intentions and actions; such as 'function', 'use', 'purpose' and 'design' (Bødker and Nylandsted Klokmose [2011]). By using the artifact paradigm one could analyze the previewed impact of the designed artifact before deployment by studying not the object itself but the use of the object we are designing.
- Analyzing society transformation by recent technologies (AI/IoT/robotics) and also with the use of methods of the theory of control.

  One can cite as an example the analysis and regulation of social network influences on the society. This post impact analysis of computer/control on society could help choosing new solutions in an optimized way (Salem et al. [2020]).
- Liability issues in relation with the previewed automated system.

  Technology and Law evolve in parallel, with technology usually some steps forward. Indeed, as an example, many driving assistance systems have appeared in the last decades (Scholliers et al. [2011]), which made evolve the international treaties on road safety and notably, the Vienna Convention.

  In 2016, the first amendment to the Vienna Convention has been signed to allow "automated systems" provided that the human could deactivate the system (Amendment [2016]). In 2022, a new amendment has been signed to allow further developments of automated systems (Amendment [2022]).

  As pointed out in (Cummings and Britton [2023]), regulatory agencies typically struggle to keep pace with technological change, often referred to as the pacing problem (Krisher and Billeaud [2018]). The same authors point out that the inertia created by the procedural requirements of administrative law causes agencies and regulations to lag behind technological innovation, which is especially problematic in the current rapid autonomous technology development.

  (Cummings and Britton [2023]) discuss as well how three different US federal regulatory agencies, the Federal Aviation Administration (FAA), the Food and Drug Administration (FDA), and the National Highway Transportation and Safety Administration (NHTSA) approach regulation of new technologies in general, and more specifically their progress with automated and autonomous systems.

  Discussing further on legal issues related to technology, responsibility might be in addition difficult to identify in ICPS (Industrial Cyber Physical Systems), as pointed out in (Jonas and Lamnabhi-Lagarrigue [2022]), due to the complex and interconnected nature of actual systems and the absence of a clear demarcation between products and services.

  Also, (Jonas and Lamnabhi-Lagarrigue [2022]) points out that the establishment of a specific legal personality for autonomous systems and, by extension, for ICPS was initially envisaged, but this idea has now been set aside and the European institutions are in favor of a specific liability regime.

  Legal issues are indeed fundamental, and are in close relation with the social acceptance of the system, and the consequential industrial success of this system (Netto et al. [2020], Martinesco et al. [2019], Thekkilakattil and Dodig-Crnkovic [2015]).

  Indeed, if these blocking points above could be addressed, by studying possible liability issues in relation to the targeted system that is wished to be designed, it could result in an anticipation element, to avoid massive investment on systems that could hardly be deployed safely.

  In the author's view, more collaboration should be motivated between Control and Law researchers.
- Digital twins. As technology evolves, digital twins are now a new instrument for demonstrating the benefits and impact of the control discipline on societal outcomes (Wang et al. [2020]).

2.4 Some more key issues

With the increasing penetration of CPS in human's lives, it is also important to consider the compromise between complexity and reliability that include:

- How to couple Artificial Intelligence (AI) with control and at the same time ensure transparency, accountability, explicability and reliability? (EAD [2019]). The answer to this question will influence the performance - in its multiple dimensions: technological, economic, social, will affect also the safety and the liability of the resulting system. AI raises also questions of intelligibility of the system by the human, a fundamental issue for a successful human-machine interaction. Indeed, the lack of system intelligibility is certainly a central point in understanding human autonomy interaction failure (Dekker and Woods [2002], Klein et al. [2004]).
- In car automation scenarios - assuming that mixed automated and manual mode machines will evolve together: the issue of the human cognitive representation modelling of the automated and of the other manually driven systems is essential. It is closely related to the improvement of the decision making and the overall safety.
- The control design shall consider time scales and capacities of the human in relation to the automated system, as well as different automation levels and

different intrusion levels of the automated system with respect to the human. As an example we can cite advanced driving assistance systems that are constructed for dealing with different time scales with respect to the predicted time left before a potential accident occurs (Netto et al. [2020], Scholliers et al. [2011]).
- The paradoxe of automation. Automation often leads to a change in the role of the system's operator, that becomes a supervisor of the automated system. This change can potentially cause negative effects on the human performance, described for example by the notion of the paradoxe of automation: "If you build systems where operators are rarely required to respond, then they will rarely respond when required" (Bainbridge [1983], Harford [2016]). In other domains different from car driving, the problem is frequently treated with the help of training programs for example through scenarios in the simulators, like in the aerospace domain.
- The gap between the theory and practice. Closing the gap between them could greatly increase the impact of the control discipline on society, as well as influence public policies related to the deployment of new technologies (Visioli [2020]).
- Reversibility of systems: can we change the direction of an on-going technological transformation?

3. DEVELOPMENTS WITHIN THE TC9.2 IN THE TRIENIUM 2020-2023

The TC9.2 present and future goals include stimulating actions within the IFAC World Congress, fostering its main event, the CPHS Workshop, stimulating educational activities in collaboration with the TC9.4, structuring new research topics and collaborating with the different technical committees in IFAC, as it is described in the following.

3.1 IFAC World Congress 2023

Besides contributing through one invited session and one open invited track, the TC 9.2 is contributing to the IFAC World Congress 2023 through different ways:

(1) CC 9 Milestone invited section submitted by the CC 9 Chair Larry Stapleton. The present paper takes part into this section, to highlight first topics towards the TC9.2 goals.
(2) "Smart Cities Forum". The TC9.2 is contributing to its organisation in collaboration with TC9.3. The forum is led by Michi Kohno, President and Chief Executive Officer of Michi Creative City Designers Inc. in Japan.
(3) Demonstration session. TC9.2 is contributing by the submitted demonstrator paper (Verrelli et al. [2023]) on the Kids in Control action described in subsection 3.3.

3.2 IFAC CPHS Workshop

The main event created and sponsored by the TC9.2 is the Cyber Physical and Human Systems Workshop (Netto and Spurgeon [2017]), (Lamnabhi-Lagarrigue et al. [2017b]). From 2020 the workshop CPHS is also sponsored by the IFAC Technical Committee 9.1 Economic, Business and Financial Systems.

The main goal of the CPHS workshop is to tackle the new challenges, opportunities and impacts provoked by this new technological and scientific breakthrough. In this sense, ethical issues are intimately involved as mentioned. How to plan the control design for positive impacts avoiding possible nefast effects?

Following the succes of the first editions (H-CPS-I [2014], CPHS [2016] and CPHS [2018]), a CPHS steering committee has been created in 2019 constituted by the following members: Aaron D. Ames, Saurabh Amin (chair), Anuradha Annaswamy, John Baras, Masayuki Fujita, Takanori Ida, Karl Henrik Johansson, Pramod P. Khargonekar, Françoise Lamnabhi-Lagarrigue, Mariana Netto, Tariq Samad, Sarah Spurgeon and Dawn Tilbury.

Two CPHS editions have been held successfully in the last trienium 2020-2023: the CPHS 2020 edition (CPHS [2020]), in Beijing, China, has been held successfully even during covid pandemics. And the successful 2022 edition that has been held in December 2022 in Houston (CPHS [2022]).

The organization of the 2024 edition is being launched. The CPHS series are sponsored by IFAC and co-sponsored by IEEE CSS.

3.3 Educational actions within TC9.2 sponsored by the IFAC Activity Fund

The TC 9.2. has two ongoing education actions, in collaboration with TC 9.4 and TC 9.3, that are briefly described below.

Indeed, in Rossiter et al. [2023], control experts from our community highlight how (mostly undergraduate) control curricula should evolve to get students involved in learning given the huge advances we have been witnessing in control these last decades.

The control education actions described below are mostly for kids and teens, but with the same goal of getting involved students in learning control.

(1) KIDS IN CONTROL: A workshop for promoting STEM and Automatic Control for kids from 8 to 10 years old. Project lead: Alessandra Parisio, TC9.3 (University of Manchester), Cristiano Maria Verrelli, TC9.2 (University of Rome Tor Vergata)
   - Special declination for International Primary Schools (Verrelli Cristiano M. along with M. El Arayshi and M. Tiberti (Verrelli et al. [2023])).

     Aim: to present before the kids' eyes the most beautiful ideas lying at the root of the design of control algorithms and control strategies, with a simple and emotionally- and intellectually- involving language.

     Activity: An on-site workshop, whose goal is to help kids of 8-10 years achieving intellectual independence and self efficacy towards automatic control. More precisely, it envisioned a 2-hours experience, in which the participants:

- are made familiar with intuitively understandable applications of automatic control in various fields of life (including automotive, sport and fitness, home automation, robotics);
- are made familiar with intuitively understandable ideas of control strategies (open-loop and feedback, sensor, actuators, dynamic evolution);
- use https://scratch.mit.edu/, a visual coding platform, and https://www.microbit.org/, a low cost educational board that can be programmed through https://scratch.mit.edu/, as hardware-in-the-loop, within a video-game scenario.
- understand, from a mathematical point of view, the design of control algorithms for electric motors and
- see their experimental application to DC motors, as well as to an autonomous electric vehicle with 2 in-wheel motors (scale 1:10).

(2) (Re)Creative Mobile Robotics for Kids – (Re)CreativeRobot

(Joint work TC9.2 and TC9.4 on Control Education)

It proposes on-site interactive perennial workshops for children to develop practical skills on mobile robots and drones.

This action is led by Cristina Stoica Maniu, (CentraleSupélec/L2S, Université Paris-Saclay, France) together with Sylvain Bertrand (ONERA DTIS, Université Paris-Saclay, France) and Aarsh Thakker (CentraleSupélec/L2S). Several students from the "Innovative pedagogy and EdTech" Projects Cluster of CentraleSupélec are part of this project.

Diverse events have been organized, e.g. an interactive workshop during the national French science festival "Fête de la Science" 2022, several demo sessions and workshops for teenagers visiting CentraleSupélec, specific workshops for girls visiting CentraleSupélec in order to motivate them to pursuit within a scientific career. In addition, two sessions have been performed by the students of CentraleSupelec at the primary school Roger Ferdinand in Palaiseau, in the Paris region (Maniu and et al [2023]).

3.4 CPHS book

The CPHS topic has been structured recently by members of the CPHS Steering Committee through the edition of a book in the IEEE Press Series on Technology Management, Innovation, and Leadership (Editor Tariq Samad), Wiley. This book has been written under the leadership of Anuradha Annaswamy (Editor), Pramod P. Khargonekar (Editor), Françoise Lamnabhi-Lagarrigue (Editor) and Sarah K. Spurgeon (Editor). The book is in press and is scheduled for July 2023 (Annaswamy et al. [2023a]).

3.5 Interaction with the IFAC Technical Committees

TC9.2 has been interacting for example, with TC9.3 for contributing to the organisation of the Smart Cities Forum in the IFAC World Congress, led by Dr. Michi Kohno as mentioned above, and TC9.2 has been interacting with TC9.3 also for the action Kids in Control. TC9.2 has also been interacting with TC9.4. for the educational action (Re)Creative Mobile Robotics for Kid as also described above. Furthermore, TC9.2 collaborates with TC9.1 as main IFAC sponsors of the Cyber-Physical and Human Systems workshop. Finally, the TC9.2 chair has served as member of the award committee for the HMS 2022 symposium organized by the IFAC TC4.5 technical committee. New interactions, especially with the applied coordinating committees 4-8 are highly desirable and will be motivated in the next trienium.

4. CONCLUSIONS

The TC9.2 takes part in addressing the design of control/AI systems by considering all the described dimensions, and many others, for its huge societal benefits. Its future plans come as a continuation of the current works described in Section 3. In particular, we wish to purse the structuring of the TC9.2 scope and its interaction with CC 4-8, taking into account the recent impacting literature as for example the CPHS book (Annaswamy et al. [2023a]) and the report on control for societal-scale challenges (Annaswamy et al. [2023b]). We also wish to launch a series of interviews with members of the committee and making them available in youtube for students.

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