Control 5.0: From Newton to Merton in Popper's Cyber-Social-Physical Spaces

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***Abstract*—The future of control in cyberspace of parallel worlds is discussed. It argues for the coming age of Control 5.0, the control technology for the new IT capable of dealing with artificial worlds with VR, AR, AI and robotics. The discipline of automation needs a new interpretation of its core knowledge and skill set of modeling, analysis, and control for cyber-social-physical systems, and a paradigm shift from Newtonian Systems with Newton's Laws or Big Laws with Small Data to Mertonian Systems with Merton's Laws or Small Laws with Big Data.**

***Index Terms*—Control 5.0, parallel control, knowledge automation, CPS, CSP, CPSS, Merton, Wiener, Popper.**

I. Double Control: Crisis or Opportunity

TWO recent recent events have triggered me to write this editorial. First, I was shocked by the stats of our 2016 graduates at Institute of Automation, Chinese Academy of Sciences (CASIA). According to the official listing of disciplines in China by Ministry of Education, under Level-1 discipline *Automation*, we have several Level-2 disciplines, such as *"Double Control"*, i.e., *Control Theory and Control Engineering*, traditionally the strongest, *pattern recognition and intelligent systems*, *computer applications*, and *social computing*, the newest. This year, among 53 MS graduates, only one has majored in *Control Engineering*, and among 88 PhD graduates, none in *"Double Control"*. This is a huge contrast to the situation over a decade ago when I started to take graduates at CASIA, around that time more than 60 % of our graduates were in *"Double Control"* major. Then, I was surprised by a loud conversation at a super market between two young cashiers. One said to the other that he has determined to get his graduate degree at a new private university I never heard of before, and guess what major is he going to take? *Artificial Intelligence*! His goal is to learn how to build robots to do his job automatically. I have hoped that he would choose automatic control or automation as his field, which offers precisely the knowledge and skill to fulfill his desire.

It is quite unique in the world that all most all major universities in China have a college explicitly named for and dedicated to the field of automation, some even has multiple colleges with automation in its names, a powerful indication of the popularity of automation once in China. Fortunately, after broadcasting my worry about the state of control education via *Wechat*, most of my colleagues in those automation colleges tell me the good news: their enrollments are still very strong, although trends are about the same, relatively less and less students are interested in traditional *"Double Control"*.

It is my strong belief that the core knowledge and skill set for modeling, analysis, and control in automation are still critical and in broad and deep demand in today's industrial, economic, and social activities. *Automation*, especially *"Double Control"*, should be thriving and in rapid growth under current course of technology and development. *AI* and *robotics*, and other intelligent techniques, are not competitors or distractors to automation, they should and must be its good friends and big promoters. Then why the decline in number of graduates in *"Double Control"*? I believe we need more effort in renewing our message to the new generation in their terms, their thinking, their interests and their culture. We must re-interpret the meaning of modeling, to include models in learning and natural language processing, for example, not just differential and difference equations; the range of analysis, to cover the network topology and cloud connectivity, not just stability and convergence; and the action of control, to consider market/organizational management and socio-economic decision-making, not just feedback control and physical regulation. In short, intelligent technology is the gold opportunity of *"Double Control"*, not its dark crisis.

As an attempt along this line of thinking for future control and motivated by the recent success of "Industrie 4.0" movement initiated by Germany alliance[1], I would like to share my thought on "Control 5.0"[2−3] and my belief that object and scope of control should be extended from Newtonian systems with Newton's Laws to Mertonian systems with Merton's Laws[4−5], and automation should be considered and carried out in cyber-social-physical (CSP) spaces or cyber-physical-social spaces (CPSS), instead of just in traditional physical spaces or cyber-physical spaces (CPS)[6−7].

II. Control 5.0: Old IT, Past IT, New IT

The recent victory of computer Go player AlphaGo is not only a milestone in the quest of AI but also an indication that IT now has entered a new era: from old IT the industrial technology, via past IT the information technology, to new IT the intelligent technology[8−9], i.e.,

$$\mathrm{IT} = \mathrm{Old\,IT} + \mathrm{Past\,IT} + \mathrm{New\,IT}.$$

Correspondingly, we need a new thinking about future control under the new interpretation of IT. As pointed out in [2-3], we believe that control should enter a new stage of development, namely, Control 5.0.

Control 1.0 was centered around mechanical devices, from float regulators for ancient water clocks and modern toilets, and pressure regulators and centrifugal governors for various systems driven by steam engines and other forms of mechanical power. After J.C. Maxwell's stability analysis of Watt's flyball governor (1868) and E. J. Routh's general stability criterion (1877), based on differential equations or their characteristic equations, the theory of control systems was firmly established. Control 2.0 was mainly about electrical circuit systems, transfer functions and frequency-domain analysis. With Control 2.0, steam engines were replaced by electrical motors, human society was moving from transportation networks to power grids.

With emergence of microprocessors and digital computers 60 years ago, control entered Control 3.0 with state representation and Z-transformation, Kalman Filters, PLC/DCS, real-time control, and modern control theory flourished and became mathematically intensive. The birth of Internet brought in

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Control 4.0 about 20 years ago, however, with the accelerated grow of new IT today, control development is in a fast transition to the new stage of Control 5.0.

Internet of Things (IoT), big data, cloud computing, AI, robotics, argumented reality, virtual reality, and software-defined systems/everything (SDX) have provided the hardware/software infrastructure and content for Control 5.0. The principle of Control 5.0 is the virtual-real duality (VRD). i.e., intrinsically separating model representation from physical objects and making them independent. In Control 1.0 to 4.0, our effort is making models approximating reality of controlled plants as accurate as possible, since we are dealing with Newtonian systems with Newton's Laws, or Big Laws with Small Data, where causality normally prevails. But in Control 5.0, often our objective is "transforming" actual realities to virtual realities, since we are involving with Mertonian Systems with Merton's Laws, or Small Laws with Big Data, where only association revealed by data or experiences is available, and causality is a luxury that is no longer attainable with limited resources for uncertainty, diversity, and complexity.

To implement VRD for Control 5.0, ACP-based Parallel Control has been proposed as a data-driven approach for deep modeling, analytics, and decision-making, in which Artificial Societies or SDX are used for modeling and representation, Computational Experiments are utilized for analysis and evaluation, and Parallel Execution based virtual-real interactions are employed for control and management[10−13]. SDX provides a platform for self operating or play which generates big data necessary for knowledge extraction and reinforcement learning. Parallel control offers us an effective mechanism for combing Newton's Laws with Merton's Laws, and integrating descriptive control, predictive control, and prescriptive control, thus covering the entire range of newly defined IT functions, from old, past, to new.

III. The Future of Control in Wiener's Cyberspace of Popper's Parallel Worlds

Over the past decade, ACP-based parallel systems approach have been applied to many fields, from algorithm development for parallel learning, parallel games, parallel dynamic programing, prescriptive simulation, to real-world applications of parallel control, intelligence, management, and transportation[14−19]. Currently, research and development in this direction are team-oriented and require large resources. In a sense, we are constructing software defined processes, plants, enterprises, and organizations with a large number of algorithms, and those SDX then become data generators and factories for powering data-driven analytics and decision-making of Control 5.0. Knowledge automation, as industrial automation for modern industries, will be essential and critical for the success of parallel control and Control 5.0.

According to Karl Popper's philosophy, the reality is consisting of three worlds in parallel, i.e., physical, mental and artificial worlds. Control 1.0 and 2.0 are mainly dealing with powers and transportation for the physical world, while Control 3.0 and 4.0 are focusing on information and networks in the mental world, now Control 5.0 is bringing in the new artificial world, which has been hidden in the first two worlds before, where resources are data and intelligence, and tools are VR, AR, AI, Robots, and other intelligent machines. Therefore, we must consider and design Control 5.0 systems in cyber-social-physical spaces or cyber-physical-social spaces that cover all three worlds, the current cyber-physical spaces will not be sufficient for Control 5.0 operations.

Clearly, "Double Control" in CSP or CPSS will open an new and endless frontier for automation. Actually, this is still within the vision that Norbert Wiener had outlined in his Cybernetics 70 years ago, but today, IoT, big data, big computing, big decision, and new IT has made the future of control in cyberspaces of parallel worlds more close to reality.

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