From cybernetics to mechatronics: Seven decades of interdisciplinary engineering

Werner Schiehlen

Institute of Engineering and Computational Mechanics, University of Stuttgart, Pfaffenwaldring 9, D-70569 Stuttgart, Germany

Cybernetics is a transdisciplinary approach for exploring controlled systems. Norbert Wiener defined cybernetics in 1948 as "the scientific study of control and communication in the animal and the machine." Moreover, in 1950 Wiener popularized the social implications of cybernetics, drawing analogies between automatic systems like a regulated steam engine and human institutions in the society. The word Cybernetics comes from the Greek word kybernetēs meaning steersman, navigator, or, figuratively, governor.

Mechatronics, which is also called mechatronic engineering, is an interdisciplinary branch of engineering that focuses on the engineering of both electrical and mechanical systems. And it includes today also a combination of robotics, electronics, computers, telecommunications, control systems, and production engineering. The word Mechatronics originated in Japanese-English and was created by Tetsuro Mori, an engineer of Yaskawa Electric Corporation. The word mechatronics was registered as trademark by the company in Japan with the registration number of "46-32714" in 1971. However, afterward the company released the right of using the word to the public. Nowadays, the word is translated in each language and the word is considered as an essential term for industry.

Until the mid-20th century, science was mainly organized in single-disciplinary groups. By myself I could experience this starting my academic education 1957 at the University of Stuttgart. At that time control engineering was considered independently at two departments offering either Electrical or Mechanical Engineering degrees with two different textbooks by Leonhard [2] and Hutarew [3]. Today, the University of Stuttgart if offering two interdisciplinary degrees in Engineering Cybernetics as well as Mechatronics, too.

1 Introduction

Cybernetics is an interdisciplinary approach for exploring regulatory systems - their structures, constraints, and possibilities. Norbert Wiener [1] defined 1948 cybernetics as “the scientific study of control and communication in the animal and the machine.” Moreover, in 1950 Wiener popularized the social implications of cybernetics, drawing analogies between automatic systems like a regulated steam engine and human institutions in the society. The word Cybernetics comes from the Greek word kybernetēs meaning steersman, navigator, or, figuratively, governor.

Cybernetics is a transdisciplinary approach for exploring controlled systems. Norbert Wiener defined cybernetics in 1948 as “the scientific study of control and communication in the animal and the machine.” Moreover, in 1950 Wiener popularized the social implications of cybernetics, drawing analogies between automatic systems like a regulated steam engine and human institutions in the society. The word Cybernetics comes from the Greek word kybernetēs meaning steersman, navigator, or, figuratively, governor.

Cybernetics is a transdisciplinary approach for exploring controlled systems. Norbert Wiener defined cybernetics in 1948 as “the scientific study of control and communication in the animal and the machine.” Moreover, in 1950 Wiener popularized the social implications of cybernetics, drawing analogies between automatic systems like a regulated steam engine and human institutions in the society. The word Cybernetics comes from the Greek word kybernetēs meaning steersman, navigator, or, figuratively, governor.

2 Cybernetics History

Thus, as far back as 1944, the group of scientists about physiologist A. Rosenblueth and mathematician N. Wiener had already become aware of the essential unity of the set of problems centering about communication, control, and statistical mechanics, whether in the machine or in living tissue. "After much consideration, we came to the conclusion that the existing terminology has a too heavy bias to one side or another to serve the future development of a field as well as it should. We have decided to call the entire field of control and communication theory, whether in the machine or in the animal, by the name Cybernetics what means the Greek word steersman". The subdivisions of Cybernetics include Biology, Computer Science, Engineering Cybernetics, Management, Mathematics, Psychology, Sociology, Education, Art, Architecture and Design, Earth System Science, Sport and Law.

On Engineering Cybernetics H. S. Tsien [4] published 1954 the following statements: The “cybernetics” of Wiener is the science of organizing of interdisciplinary components for stability and purposeful actions. In fact, the primary concern of cybernetics are the qualitative aspects of the interrelations among the various components of a system and the synthetic behavior of the complete mechanism. The purpose of ‘Engineering Cybernetics’ is then to study those parts of the broad science of cybernetics which have direct engineering applications in designing controlled or guided systems. And Z. Dao [5] celebrated 2014 the 60th anniversary of Engineering Cybernetics.
3 Mechatronics History

One of the trailblazers of Mechatronics was Kurt Magnus, a former student of gyroscopes and vibrations with Ludwig Prandtl and Max Schuler at the University of Göttingen. After WW2 in 1946 Magnus was deported to the USSR for 7 years. During this time he read the books of W.W. Solidownikow on control theory and noticed the close relationship between vibration and control systems as documented in his report [6]. Mechatronics emerged as a separate discipline from a marriage between mechanics and electronics. In 1957, the first computer numerical control (CNC) machine tool was developed at MIT in the US. CNC technology paved the way for computer aided design (CAD) and computer aided manufacturing (CAM) thus accelerating to the grand growth of mechatronics. The recent book of U. S. Dixit [7] summarizes this success story. The subdivisions of Mechatronics include Smart Sensors, Machine Vision, Unmanned Vehicles, Flexible Robotic Manipulators, Harmonic Drive Transmission, Direct Drive, Magnetic Bearings, Mobile Robots, Automated Guides Vehicles, Cloud Computing, Household Robots, Self-driving Cars and Trucks.

4 Interdisciplinary Engineering

The basic principle in Engineering Cybernetics and Mechatronics means feedback with control and communication by sensing and acting. Some examples are presented.

Kurt Magnus explains in his book [8] in detail a horizontally stabilized platform used in inertial navigation systems. Fig. 1 shows the feedback control by sensors of acceleration and angular velocity.

Eveline Gottzein developed in her Ph.D. thesis [9] supervised by Kurt Magnus the magnetic wheel for magnetically levitated trains (MAGLEV). In Fig. 2 the separately controlled magnetic elements are shown providing lateral and vertical guidance without any friction while the longitudinal propulsion is generated by a frictionless linear motor. A MAGLEV vehicle does not have any contact with the non-existing trolley wire. At the time being, the maximum speed the Japanese L0 Series trains is 603 km/h.

Wolf Stadler describes in his book [11] the relation between analytical robotics and mechatronics. Typical robot components and actions are shown in Fig. 3.

Fig. 1: Inertial navigation system. Adapted from [8], page 473. Copyright 1971 by Springer.

Fig. 2: MAGLEV suspension. Adapted from [10], page 12. Copyright 2010 by Springer.
5 Interdisciplinary Curricula

Sciences have to take care not only for research but also for the academic education of the upcoming generation. The roots of Engineering Cybernetics Curricula point also back to Kurt Magnus, 1958 appointed as head of the Institute of Mechanics in Stuttgart. Magnus completed his team interdisciplinarily with the mathematician Peter Sagirow and the electrical engineer Helmut Sorg. Later in 1971, Peter Sagirow, Helmut Sorg and Ernst Dieter Gilles, head of the Institute of System Dynamics and Control, founded the curriculum Engineering Cybernetics at the University of Stuttgart. The creation of the very successful study program celebrated its 40th anniversary in 2011 honoring in particular Peter Sagirow.

During the last seven decades emerged two new interdisciplinary sciences Engineering Cybernetics and Mechatronics. At the time being the following curricula are offered in Germany. Engineering Cybernetics: TH Ilmenau, Uni Magdeburg, Uni Stuttgart. Mechatronics: RWTH Aachen, TU Berlin, TU Braunschweig, TU Darmstadt, TU Dresden, LU Hannover, KIT Karlsruhe, TU München and Uni Stuttgart, often denoted as the leading German universities of Technology, as well as a growing number of universities in smaller places in Germany.

Worldwide, there are many more interdisciplinary curricula offered, however, the total has not been published up to date. It can been estimated as 200 or more. For example, the Norwegian University of Science and Technology has its own Department of Engineering Cybernetics with 42 professors, 15 postdocs and 70 PhD students.

The roots of Mechatronics curricula point also back to the curriculum Automation in Production (autip) founded 1997 by the Institutes of Engineering and Computational Mechanics, and Control Engineering of Machine Tools and Manufacturing Units at the University of Stuttgart.

The autip curriculum was established for interdisciplinary generalists not interested in early specialization in mechanical engineering. The founders, Günter Pritschow represented communication theory while I by myself was dealing with multi-body system dynamics, a tool most useful for vehicle dynamics, robotics and biomechanical problems including hearing and walking. Furthermore, a general introduction to electrical engineering, computer science, manufacturing and control theory was included. The curriculum autip with Diploma degree was renamed in Mechatronics with Bachelor/Master degree by October 1, 2008.

6 Commemorative Plaque

The Werner-von-Siemens-Ring is one of the highest awards for engineering sciences in Germany. It is awarded since 1916 about every three years to remind on the 100th birthday of Werner von Siemens.

The Foundation Werner-von-Siemens-Ring awards not only its ring but it honors by a plaque as well deceased scientists who did excellent service to engineering and natural sciences. In addition, a commemorative brochure [12] was published by the Foundation in 2018.
7 Conclusion

From the early contribution of Norbert Wiener in 1948 to the recent recognition of the outstanding merits of Kurt Magnus by the Foundation Werner-von-Siemens-Ring it took seven decades. Interdisciplinary research and education are now well established and will support the future development in many fields of science.

References

[1] N. Wiener: Cybernetics (MIT Press, Cambridge, 1948 and 1961).
[2] A. Leonhard: Die selbsttätige Regelung (in German) (Springer, Berlin, 1957).
[3] G. Hutarew: Regelungstechnik (in German) (Springer, Berlin, 1955).
[4] H.S. Tsi: Engineering Cybernetics (Springer, Berlin, 1957).
[5] Z. Gao: Eng. Cyb. 60 years, Control Theory Techn. 12, 97-109 (2014).
[6] K. Magnus: Ueber ein Verfahren zur Untersuchung nichtlinearer Schwingungs- und Regelungs-Systeme (in German). VDI-Forschungshft 451 (VDI-Verlag, Düsseldorf, 1955).
[7] U.S. Dixit et.al.: History of Mechatronics (in A Brief History of Mechanical Engineering). (Springer, Cham, 2017).
[8] K. Magnus: Kreisel (in German) (Springer, Berlin, 1971).
[9] E. Gottzein: Das „Magnetische Rad“ (in German) (VDI-Verlag, Düsseldorf, 1984).
[10] K. Popp and W. Schiehlen: Ground Vehicle Dynamics (Springer, Berlin, 2010).
[11] W. Stadler: Analytical Robotics and Mechatronics (McGraw-Hill, New York, 1995).
[12] Gedenkschrift zur Gedenktafel für Prof. Kurt Magnus (with contributions by H. Bremer, F. Pfeiffer, W. Schiehlen and J.F. Wagner) (Stiftung Werner-von-Siemens-Ring, Berlin, 2018).