Int. J. Engng Ed. Vol. 21, No. 6, pp. 1112–1121, 2005
Printed in Great Britain.
0949-149X/91 $3.00+0.00

A Citation of Control Related Interdisciplinary Disciplines in Engineering Education*

N. P. MAHALIK, J. H. RYU, B. H. AHN and KIESON KIM
Department of Mechatronics and Department of Information and Communication, Gwangju Institute of Science and Technology, 1 Oryong dong, Buk-gu, Gwangju 500–712, South Korea. E-mail: nmahalik@gist.ac.kr

Improvements in control systems have long been reflected through continuous study, research and developmental activities. This paper presents a citation of control-related interdisciplinary disciplines (ID) that falls in the field of macro and micro automation and machine control systems. The paper first stresses the need for an interdisciplinary approach towards control engineering education. Then, it focuses on the subject contents for control related interdisciplinary topical domains. The scopes of various interdisciplinary domains such as microelectromechanical systems, mechatronics and micromechatronics, computronics and photonics, micro instrumentation and control, convergent networks, nanotechnology, real-time machine control, HILS, etc., will be highlighted in appropriate order. The impact of these emerging disciplines on control engineering will be elaborated in the last section.

INTRODUCTION

THE SCOPE of interdisciplinary disciplines (ID) has been evolving. For instance, mechatronics, which was offered initially as a specialized subject within the discipline of control engineering a decade ago, has established itself as an ID under which control laboratory and research center exist [1, 2]. Other examples are micromanufacturing, system engineering, co-design engineering and embedded systems. Contrast to this, one can make a note of the fact that in September 2006, the 50th year of International Federation of Control Automatic Control (IFAC) will be celebrated through a symposium on 'Mechatronics Systems'. This implies that mechatronics can become a topical field in the domain of control engineering, again. Apparently, many of the interdisciplinary control-related technological subjects (e.g., mechatronics, embedded systems, etc.), which are primarily linked with the mother discipline have been manipulated over the period of time to take different shapes. The present scenario thus differs from that of the recent past in the sense that the engineering disciplines are now dilating instead of diverging; this is because of the requirement of interdisciplinary knowledge at the production place [3]. Figure 1 illustrates a review on ID as far as various technical educations are concerned. The figure also illustrates how the new disciplines have emerged, reshaped, and merged again over the period of time.

Since the current technical education curriculum has been a reverse pyramid structure, all these emerged multi-faceted subjects can be integrated into a single boundary to materialize it as an ID, i.e., control engineering! Moreover, the interdisciplinary control engineering education must include the emerging topical subjects like micromechatronics, microelectromechanical systems, convergent network, co-designs, MEMS, control photonics and green control in order to accommodate the state-of-the-art methods, principles, techniques, fundamentals, and possibilities. This paper presents the scope of these emerging topical subjects and justifies how they will be relating to control engineering. Encompassing these disciplines can set the basis for an innovative approach to control engineering.

The paper has been organized as follows. In the next section, a brief review on the need for interdisciplinary technological education and its impact is presented in terms of citing an illustration. Next, the scope of up and coming topical subjects are presented by defining control engineering as a new interdisciplinary disciplinary. The third section explains the impact of these subjects followed by a brief discussion and suggestion about the level at which these topical subjects are to be introduced. The final section concludes and summaries the implied benefits, those can be achieved through this proposed approach.

INTERDISCIPLINARY TECHNOLOGICAL EDUCATIONS—AN ILLUSTRATION

Technological designs have become a high-risk endeavor due to the lack of knowledge and experiences on interdisciplinary subjects and methods.

* Accepted 24 July 2005.

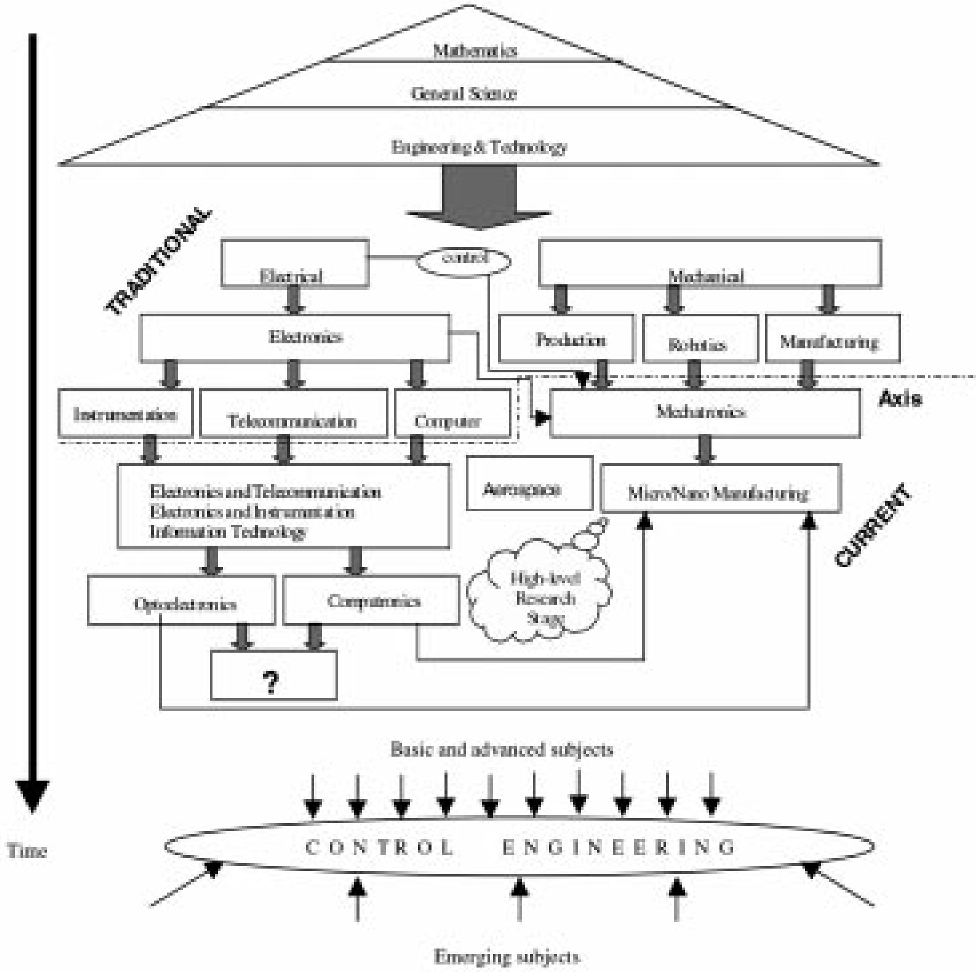

Fig. 1. Convergent scenario of the technical disciplines.

Advanced designs are a highly complex and inter-interdisciplinary nature involving logic-based blending of simultaneous knowledge-base from discrete fundamentals. An example is evident. In designing a *smart* motorized actuator utilizing both feedback and *sensorless* scheme (control algorithm employing constant volt-per-Hertz ratio of the starter voltage [4]) six types of traditional engineers and one mathematician would be employed:

- a mechanical engineer would design the mechanical structure with the knowledge to optimize the design parameters to overcome the effect of vibration, and thermal deformation;
- an electrical engineer would be brought in to ensure the windings conforming to IEEE standards;
- the electronic engineer would design the highly sensitive optical encoders, other sensory devices and the processing unit;
- a control engineer would study the stability and controllability issues;
- a computer engineer would interface the actuator so it could be monitored and controlled remotely using a *convergent network* (CoN);
- a communication engineer would consider the use of optical fiber in the design to counter the factory floor interference and bandwidth limitations;
- a mathematician would suggest how to implement the soft-computing algorithm in order to make the actuator a smart one.

Some might hold the above example as a simple one. But, if design examples of space shuttles, air crafts, industrial machines, automobile engines, robots, semi-autonomous machineries are taken the real question as to how multidisciplinary knowledge plays a paramount role can be better understood.

CONTROL ENGINEERING AS A NEW ID

Basic control engineering subjects are digital electronics, microprocessors and microcontrollers, control theory, dynamics, digital computers and instrumentation. The advanced subjects include robotics, embedded systems, soft computing, simulation, and development tools. Because of tremendous advances in related technology, the control

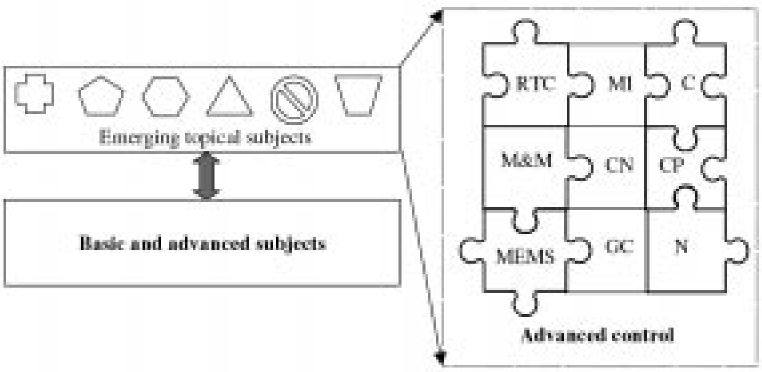

Fig. 2. New interdisciplinary control engineering with emerging topical subjects.

engineering education has to be reshaped in order to meet the required knowledge base at the production place. Looking at the present scenario, this will be only materialized if and only if this discipline is taken as an ID. The emerging control-related subjects are: real-time system (RTS), mechatronics and micromechatronics, computronics, microinstrumentation, convergent network, green control, MEMS, control photonics and nanotechnology (Fig. 2). In the sequel, a brief description on the scope of these emerging topical subjects have been given.

Real-time control

Real-time system (RTS) architectures, in which the input corresponds to some movement in the physical world and the output relates to that same movement, are governed by time constraints [5]. Classification of RTS can be found in [6]. Various attributes such as scheduling, correct handling of physical time, predictive solution to unpredictable external stimuli arrivals, interprocess communication, context switching, simultaneity, determinism, and dependability characterises the RTS. Accordingly, the topical subjects of study are temporal modeling, Petrinet, resource conscious hardware-software co-design (embedded issues), real-time executives, distributed and real-time operating systems.

Mechatronics and micromechatronics

Mechatronics is the synergistic integration of mechanical engineering with electronics and intelligent control algorithms in the design and manufacture of products process. Mechatronics, although not new but when compared with many of the traditional branches of engineering, it is also relatively not old and appears to be firmly established. Ten technical areas such as motion control, robotics, automotive systems, intelligent control, actuators and sensors, modeling and design, system integration, vibrations and noise control are classified under this topical subject [7, 8]. Broadly the scope of mechatronics is illustrated in Fig. 3. Micromechatronics deals with microscale machines, which in turns incorporates MEMS. The synergistic integration aspects with respect to

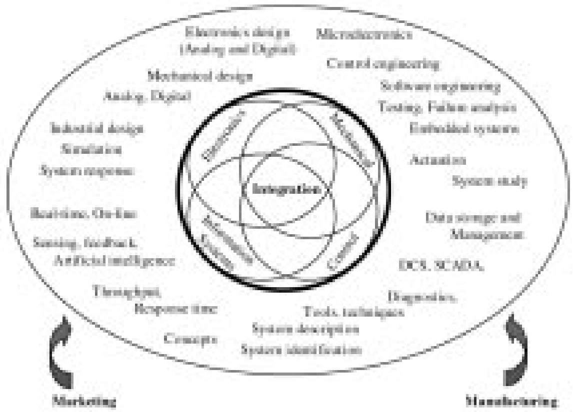

Fig. 3. Scope of mechatronics.

microscale machines are not identical to the macroscale machines and systems. The topical subjects are system description and identification, modeling, system integration, machine control software, and CASE.

Microinstrumentation

Recently, there is a drive towards miniaturization. Microinstrumentation [9]; a thin-film technology-based instruments design concept is going to be adopted as the advanced instrumentation platform for most of the scientific, industrial and academic study because of inherent sophistication and reliability. Broadly, the subject of study is material science for microstructures, micro-instrumentation devices, transduction principle for microstructures, theory and optimizations, microsystem, interfacing and integration, micronetworking, modeling, and performance issues. Although the nature of the course structure has yet to be defined, there exist abundance numbers of microinstrumentation platform. Their operational characteristics, efficiency, flexibility, etc., are the matter of study.

Computronics

The technological education on computronics (electronic control using computing) has not yet emerged. Computronics should not be considered as the synonym of CSE (Computer Science and

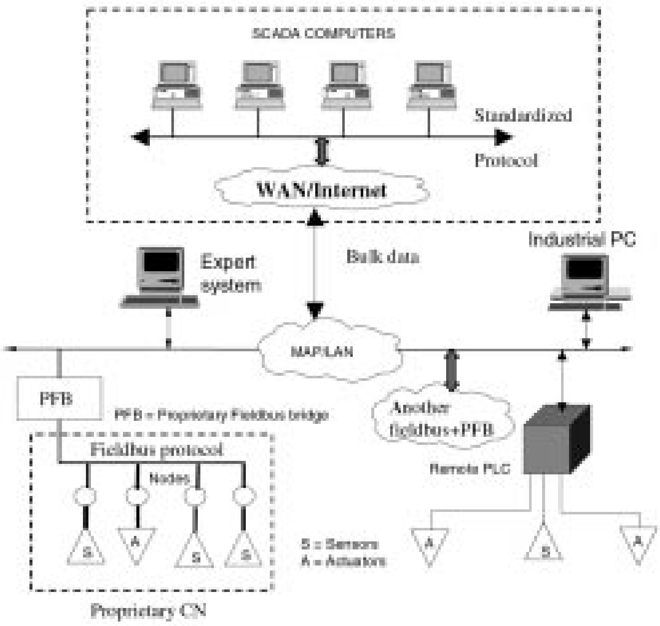

Fig. 4. DN and CN for monitoring and control (a traditional CoN).

Engineering), but from a control point of view it has innumerable roles to play in terms of identifying itself as an optimized hardware/software co-platform. The main subjects for computronics discipline would be peripheral interfacings, optimized hardware/software co-design (embedded technology), very high-level languages (GUI), computational mathematics, simulation and graphics, soft-computing, image processing, distributed and parallel processing, fieldbus technology, industrial computers, cellular and quantum computing.

MEMS

Microelectromechanical systems (MEMS) have already found significant applications in many sectors including automotive, aircraft industries, civil structures, chemical industry, pharmaceuticals, manufacturing, defense, environmental, and so on [10]. The subjects of study under MEMS are, micromachining, microsensors and actuators, MOEMS, RF MEMS, microfluidics, BioMEMS, multi-scale design and performance study. Micromachining is essentially a demanding methodology for the fabrication of MEMS devices [11]. Various energy transduction principles such as thermal, magnetic, optical, electrical, mechanical, etc., are employed designing the microsensors and actuators. Radio frequency (RF) MEMS devices have a broad range of control applications in the field of military, wireless communication, navigation and so on [12]. Microfluidics refers the study of micro-scale devices capable of handling and controlling small volumes of fluids in the order of nano-, pico- and even femtoliter volumes. The scope of MEMS technology has recently been extended to health sciences and chemical industry giving rise to BioMEMS products. Areas include surgical instruments, artificial organs, genomics, and drug discovery. Physical interactions relevant to the micro-scale structures include the study of multi-physical and multi-scale interaction phenomenon [13, 14]. As always performance study is key to any technology.

Convergent networks

The concept of *convergent automation*, a factory-level automation and control is emerging and can be realized using the convergent network (CoN), a unified network architecture validating the idea of *network-of-objects* (NOO). This demands interfacing of a data network (DN) with the control network (CN) (Fig. 4) functionalities required for all of the layers will be attended. There has been some confusion between DN and CN as they adopt a similar concept of digital signal communication. DN is usually a network of computers that are capable of transmitting large quantities of data in the order of Mb/s. The timing of messages and their transfer is not critical again. A CN, conversely, interconnects field devices (sensors, actuators and switches) in rugged industrial environments. Message-based data, however, in small quantities is transmitted in a time that is predetermined. DN systems are configured with LAN, WAN or MAP-based protocol. The Fieldbus technology-based distributed control scheme has been accepted as a control networking system [15].

Control photonics

The requirement of optical components in information and communication, automotive, aerospace, medical, power sectors, measurement and control sectors are shown in Fig. 5 [16]. As noticed, the requirement of optical components in automation and control applications are significant. Starting from laser to the AO (all-optical) chip there could exist hundreds of equivalent components as

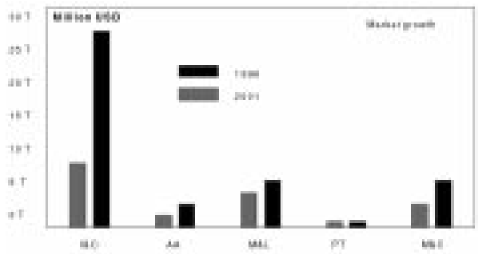

Fig. 5. Market growth of I and C.

compared to electronic systems. The present status of photonics is optoelectronics. Control photonics can be taken as a topical subject which should include novel materials and device process technology, transmission and interconnects, optical MEMS devices and components, beam splitters/lenses/gratings/filters, modulators, MUX/DEMUX, digital light processing (DLP) technology, diffractive light valve (DLV) technology, emitters and detectors, nanophotonics, etc. [17, 18].

Green control

Environment must be protected by implementing LCA (life cycle assessment) methodology [19]. LCA is a method for systematically assessing the environmental impact of a product right from the extraction and processing of raw materials to manufacturing, transportation and distribution, maintenance, recycling, reuse and final disposal [20]. The control platforms and devices must be recycled, re-designed and remanufactured (3R concept) to assure the greener environment. The study and research activities include, LCA concepts, eco-labels, 3-R principles, green circle, LCI (life cycle information) methodology [21], tools and techniques and implementation scenarios.

Nanotechnology

Some universities are already teaching nanotechnology at the UG levels, although the technology is still in its infancy [22]. Looking at the present state-of-the-art technology this course, therefore, can be taught either as a core discipline or an elective subject at the PG level. Some of the topical areas are: nanoscale phenomena, atomic and mesoscale modeling, carbon nano structures and devices, nanocomposites, bio materials and systems, bio nano computational methods, biosensors, fluidics, nanomedicine, etc.

RELATIONSHIP AND IMPACT OF NEW EMERGING DISCIPLINES ON CONTROL

Real-time prospective

The designs of next-generation real-time control systems are highly complex and interdisciplinary in nature that involves optimization of real-time performance parameters and adoption of state-of-the-art methodological know-how. Some examples of RTSs in control domains are embedded control, process control, instrumentation, robotics, SCADA, FMS, discrete manufacturing, automotive, packaging, semiconductor manufacturing, milling, drilling, etc. From a very technological viewpoint, control design has become an intensive high-risk platform because of discrepancies in pre-emptiveness, timeliness and predictability. Since most of these control systems are characterized by PASTS (predictability, acknowledgement, synchronization, timing, simultaneity), study on RTS at the primitive stage will have greater impact on the overall control design [23]. Further, most of the control systems are (as shown in Fig. 6) indexed by *response time*.

Response time maps time constraints, which in turn corresponds to PASTS. Many control engineers working in the simulation side do not feel the pros and cons of the real-time constraints. It has been mistakenly understood that a real-time implementation should be faster enough so that the pre-emptive requirements and deadlines can be met. Theoretical study on RTS is lacking. The study on RTS will improve the understandability with regard to cross, seamless and robust integration of real-time infrastructure and their *straight-through* capabilities. Moreover, the cooperative behavior of both process control and tactical mamina (macro-, micro-, nano) machine systems can be well understood. This will have opportunity to implement new and improved methods such as visualization, temporal task distribution, process and scheduling design, control software architecture, while advocating the real-time open system standards.

Mechatronics prospective

Approximately half of the control platforms are electromechanical in nature. Novel theories, principles, techniques, methodologies and standards have to be incorporated to define the new horizon. Synergistic integration of control algorithm, elec-

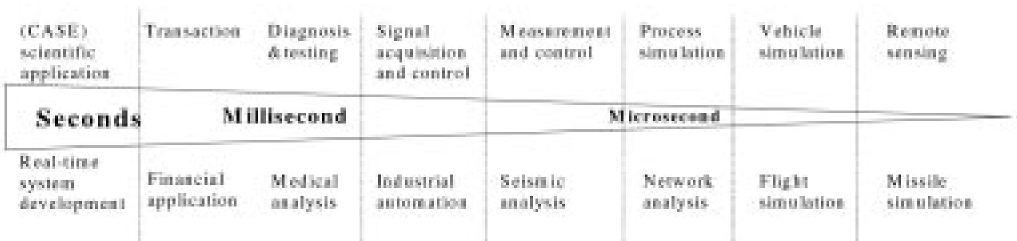

Fig. 6. Response time versus application areas.

tronic interfacings, display, and runtime management connectivity is desirable for optimum temporal and operational accomplishment. Dominant functional subsystems, perception, cognition, execution design architecture and approaches are all addressed through the mechatronic study and design practice. This in turn can make it possible for acceptance of a modular component-based design approach [24].

Benefits that can be obtained through a components-based approach are connectivity, agile and responsive control, field-level programming, and virtual machine design and simulation assisting concurrent design processes thereby enhancing efficiency, capability and run-time system transparency. Although the underlying concepts of runtime control software architecture for mechatronic systems have been firmly established, significant reforms on taught structure with regard to simulation tools are necessary since simulation has become a common tool for all sorts of design and validation activities.

Hardware-in-the-loop (HILS) [25] is a simulation concept, which put hardware in a software loop in order to test the behavior of the product or process. In a HILS the embedded software runs on the real hardware that will eventually build into the product. HILS can be applied for the design of robotic systems, mechanisms, airplanes, missiles, unmanned aerial vehicles, and so on [26]. In order to radically improve the effectiveness and integrability, it is also the system level off-line design, configuration, diagnostics tools and software that much inclusion remains to be done.

Microinstrumentation prospective

Microinstrumentation equipments are essentially useful where higher QoS (Quality of Service) such as sensitivity, selectivity, resolution, fidelity, etc. are desired. Miniaturization improves portability and speed. The principle of operation of such tools and equipment, although it requires application of fundamental science, coherent and synergistic technological integration are of paramount importance. A typical microspectrometer can take less space and measure, analyze and provide precise controlled signals in both large, medium and small scale processing in chemical, food, drug delivery systems, to name a few. Miniaturization can help the control engineer to measure and analyze the physical, chemical and biological parameters in the applications where space and weight are the measure problems. Examples are nuclear reactors, space shuttle, etc. The other application fields are: spectroscopy, surface analysis, tribology, topography, microfluidics, microtomography, electronic imaging, etc. Some recently developed microinstrumentation equipments are micro-oscilloscopes, microvoltmeter, microradar, etc.

Computronics prospective

Electronics and computer science and engineering have long been fundamental to control. Since, the scope of both the fields are vast, development of a unified computronics syllabus for all sorts of control application is essentially desirable. This topical subject will allow the students to gather the fundamental requirements of applied computer electronics in the domain of control. The main issue lies with the control conformant *computronics standardization*. Traditional computronics platforms are mutually exclusive for which the integration always carries the redundant physical as well as logical configurations thereby increasing space, cost and time constraints. Well-structured computronics curricula can facilitate configurability, interoperability and interchangeability improving the control integrability and minimizing the appearance of physical and logical redundant candidates.

MEMS prospective

The progress in microfabrication technologies is transforming the field of solid-state into microelectromechanical systems. The small-sized systems require less reagent resulting in faster, accurate and less expensive operation. The relative merit for MEM systems lies in the fact that these components are fabricated by batch manufacturing methods similar to microelectronics techniques, fulfilling the added advantage of miniaturization, performance and integrability. MEMS devices consume smaller resources and have good response times, faster analysis and diagnosis, better statistical results and certainty, improved and flexible automation possibilities, decreased risks and costs.

Since most of the physical phenomenons in a control domain are to be measured and controlled precisely in a timely predictive manner so as to meet the real-time limitations and PASTS, respectively, miniaturized components will certainly address the desired necessities. Moreover, prognostic measurement (index of the system performance) in terms of sensor-, actuator-, loop- and system validation can also be achieved through an MEMS integrated design approach. In conjunction with mechatronics study MEMS can become supportive for designing and controlling the micromechanisms such as micromanipulator, microhandling equipments, micrograppers, microrobot, etc., used for clinical, industrial and space applications.

Convergent network prospective

The proprietary design of CoN by DN and CN appears to be irrational. The necessity of a unified CoN system is due to the reasons that the underlying communication principle for bulk data and control data are very different. The study on CoN will establish a sound technological skill as far as remote monitoring and control, advanced supervisory control and data acquisition (SCADA), home automation and control, building automation and control (intelligent building), etc. are concerned (Fig. 7). The four-layered (Fig. 7b) factory-wide automation and control functions can be faithfully addressed by the CoN without

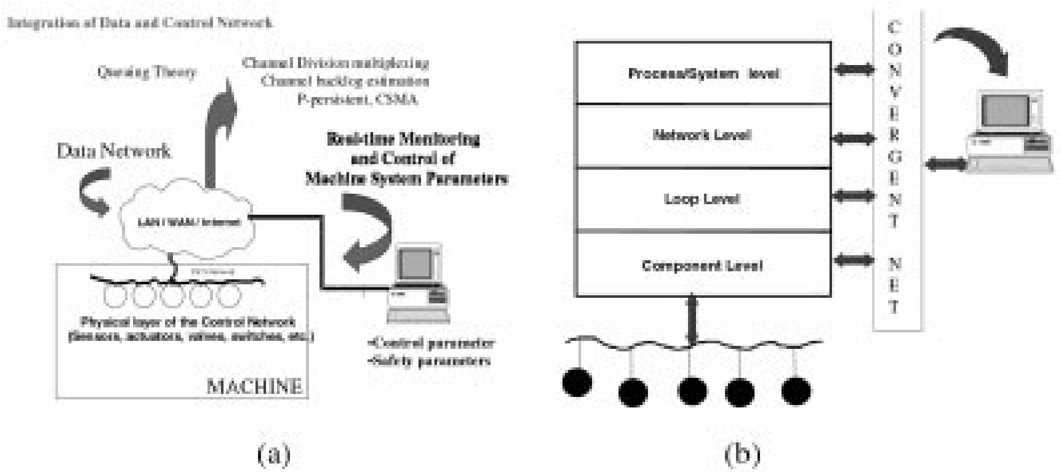

Fig. 7. (a) Traditional CoN; (b) advanced CoN implementation.

the need for traditional customized interfacings as shown in Fig. 7a.

Control photonics prospective

The impact of photonic technology in control systems is considered to be significant. AO components and devices are emerging although already implemented in small scale. Automation and control systems are progressively switching over to accommodate AO systems due to the fact that the traditional components and devices (sensors and communication parts) are susceptible to signal attenuation, power consumption, noise interference, life cycle cost of installation and maintenance, etc. Control systems will be equipped with optical components and devices adopting a wide range of implementation scenarios. For instance, they can provide the major element of the superhighway to facilitate new services such as broadband remote monitoring and control (BRMC). Necessary measures should be taken at this early stage of this emerging technology by introducing control photonics as the topical subject in control engineering education.

Green control prospective

Intrinsic safety standards and environmental concerns are two important factors, which have taken considerable attention. Consumer pressure, legislation, standards, the need to maintain competitive advantage and the desire to be a good corporate citizen have forced designers and manufacturers to consider the environmental impact (EI) in their products. Green control, a methodology for the assessment of EI, suggests the recording of LCI of a control platform. Since, the methodology considers: where to use the waste products once its present state is over, ii) what part of the components are to re-cycled once its present state is over, and iii) how to remanufacture another component from the remaining part, it is believed that energy and resource can be best utilized in order to achieve sustainability [19, 21]. Tracking the life-cycle data will facilitate efficient life-cycle estimation of products/machines/systems for new options to be designed. An analogy to the concept of recording LCI can be made from the 'black box' flight recorders for aircraft. The methodology makes it possible to implement 3R concepts and analysis techniques and projects how LCI can best be tailored to particular control product/machine/system. The significant implied benefits are i) development of smart control product, ii) design for environment (DfE), iii) utilization of energy and resource, and iv) component/machine evolution (Fig. 8).

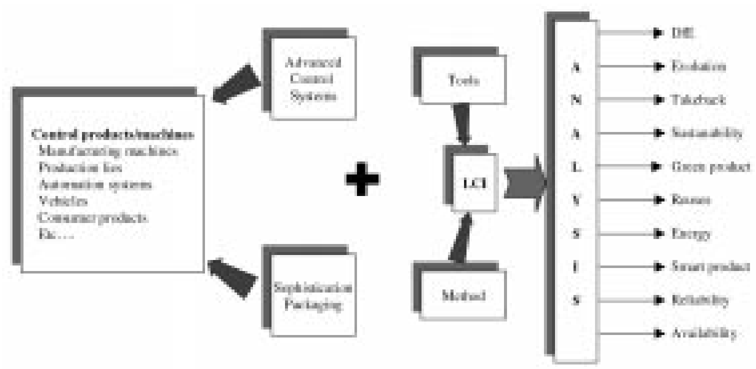

Fig. 8. Life cycle information as an index to green control.

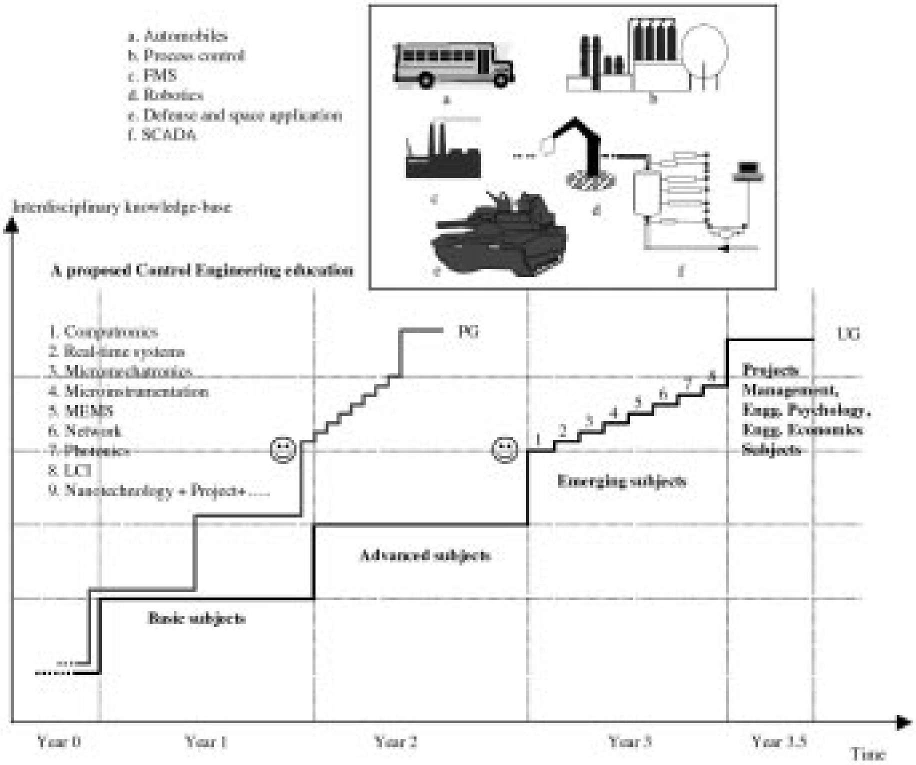

Fig. 9. A proposed interdisciplinary control engineering education.

Nanotechnology prospective

While interest in a variety of possible applications, nanotechnology has accelerated research and development, but a key obstacle to development remains the need for cost-effective large-scale production methods. Much of current research focuses on potential applications of carbon nanotubes. Carbon nanotubes are considered as the ultra-fine devices of the future and can offer significant advantages over many existing materials due to their exceptional mechanical, electronic and chemical properties. Although, the research still is at its rudimentary stage, the control domain will considerably gain out of this since nanotubes can be utilized as electronics devices, super-capacitors, lithium ion batteries, field emission displays, fuel cells, actuators, chemical and biological sensors, electron sources, etc. The nanoscale devices and equipments can give added benefits in terms of a better greener environment, miniaturization, efficiency, resource consciousness, and so on.

DISCUSSION

Interdisciplinary study (IS) was established in the seventies to provide alternative programs and courses at the UG and PG levels. IS requires the completion of an area of concentration, which unlike conventional majors does not contain a list of required and elective courses. Traditionally, appropriate courses are chosen from departments throughout the institute/university as well as from the IS course offerings. All IS programs have been tailored to fit the needs of an individual scholar but in a broader sense the benefits goes to the production place. However, this conservative approach has many drawbacks in term of co-ordination, lack of knowledge of the subject seekers, multiple physical interaction as far as administration is concerned, sequence of course offerings, and so on. In fact, new multi-disciplinary subjects have been attracting manufacturers, developers and system integrators. Therefore, there has been a momentum to open ID departments, in order to overcome many of these shortcomings encountered in traditional methods of teaching through IS. Combined action and cooperation increases effectiveness and productivity. The productivity of an industry can increase up to 40% by employing engineers with interdisciplinary knowledge at the basic level [27]. Adoption of modern and matured technology with improved capability is paramount in order to meet competitive challenges.

Interdisciplinary opportunities at the UG and PG level should embody source of concepts and techniques, which have recently been applied in practical situations. Figure 9 illustrates a proposed interdisciplinary control engineering education arising out of presentation and discussion. It is true that knowledge can be acquired passively. But, students have to ripen their academic skills by actively learning from the valuable lessons. The control engineering being now, as an interdisciplinary field will provide these lessons as far as control of *system of systems* [28] are concerned.

CONCLUSIONS

This paper presents a citation for emerging control-conformant interdisciplinary topical subjects. Some of the important emerging topical subjects such as RTSs, mechatronics, MEMS, computronics, microinstrumentation, convergent networks, control photonics, green control and nanotechnology have been elucidated keeping in view the scope and impact, especially in the control domain. It is concluded that the following benefits can be achieved from the respective topical subjects:

- RTS; visualization, embedded control and co-design issues.
- Mechatronics: synergistic integration of mechanical, electronics and control and HILS.
- Microinstrumentation: sensitive, selective, resolution, responsive, portability, speed, low weight, space, etc.
- Computronics: configurability, interoperability, interchangeability, integrability, embedded technology and redundancy.
- MEMS: small, responsive, better resolution to PASTS and system validation.
- CoN: factory-wide BRMC, NOO, DCS, SCADA.
- Control photonics: less interference, low life cycle cost, immune to noise, etc.
- Green control: DfE, evolution, eco-label, 3R, desire to be good citizen.
- Nanotechnology: miniaturization, sustainable, more greener environment.

REFERENCES

1. http://www2.gist.ac.kr
2. http://www.robotic.dlr.de/control
3. N. P. Mahalik. *Mechatronics: Principle, Concepts and Application,* McGraw-Hill International Edition, Higher Education (2004), ISSN 007-048374-4.
4. Jaochim Holtz, Sensorless control of induction motor drives, *Proc. IEEE,* **90**(8), Aug 2002, pp 1359–1394.
5. http://en.wikipedia.org/wiki/Real-time
6. Stuart Bennett, *Real-time Computer Control,* Pearson Education (2003).
7. F. Harasima and M. Tomizuka, Mechatronics: what is it, why and how, *IEEE Trans. Mechatronics,* **1**(1), March 1996.
8. N. P. Mahalik and S. K. Lee, *Integrated Advanced Design Strategies for High-Speed Spindle Systems; Application of Fieldbus Technology in Mechatronic Systems,* Springer-Verlag (2003) pp 549–583.
9. Richard A. Crocombe, MEMS technology moves process spectroscopy into a new dimension, *Spectroscopy Europe*, Axsun Technologies, Inc, 1 Furtune Drive, USA.
10. D. N. Pagonis, G. Kaltsas and A. G. Nassiopoulou, Fabrication and testing of an integrated thermal flow sensor employing thermal isolation by a porous silicon membrane over an air cavity, *J. Micromechanics and Microengineering,* Institute of Physics, **14**, 2004, pp. 793–797.
11. http://www.dbanks.demon.co.uk/ueng/surfum.html
12. http://www.cfdrc.com/research/mems/rfmems.html
13. J. Q. Broughton, F. F. Abraham, N. Bernstein and E. Kaxiras, Concurrent coupling of length scales: methodology and application, *Physical Review B,* **60**(4), 1999, pp. 2391–2403.
14. M. Zhou, Y. K. Shyy and H. L. Thomas, Topology optimization with manufacturing constraints, in G. Cheng, Y. Gu, S. Liu and Y. Wang (eds.), *Proc. Fourth World Congress of Structural and Multidisciplinary Optimization (WCSMO-4),* June 4–8, 2001, Dalian, China.
15. K. K. Tan and K. Z. Tang, Control of fieldbus-based systems via the Internet, *Fieldbus Technology; Industrial Network Standard for Real-time Distributed Control,* Springer Verlag, Germany (2003), ISSN 3540401830, 590 pages.
16. *Proc. Int. Photonics Technology Conference,* 11–14 September, 2001, Kwangju, Korea.
17. D. T. Neilson, *Optical Fibre Communication Conference*, March 2000, OSA Technical Digest Series, Vol. 4, pp. 202–204.
18. D. T. Moore, The Current Status of Photonics Technology, *Int. Photonics Technology Conference 2001,* 11–14 September, Kwangju, Korea, 2001.
19. Philip Moore, J. Pu, Changwen Xie, Matthew Simon and Graham Bee, Life cycle data acquisition methods and devices, *Mechatronics 2000 Conference*, Atlanta, Georgia, USA, September 6–8, 2000.
20. B. P. Weidema, Increasing credibility of LCA, *Int. J. Life Cycle Assessment,* **5**(2), 2000, editorial column.
21. N. P. Mahalik, Ph.D. Thesis, Component Validation and Life Cycle Data Acquisition for Distributed Machine Control Systems, De Montfort University, UK, 1998.
22. http://www.nanotech.unsw.edu.au/
23. Jun Li, Peter H. Feiler, Impact analysis in real-time control systems, *IEEE Int. Conf. Software Maintenance,* August 30–September 03, 1999**,** Oxford, England, p. 443.
24. J. Pu and P. R. Moore, Component/image-based design of distributed manufacturing machine control system, *Proc. Int. Conf. Recent Advances in Mechatronics,* ICRAM-1995, Vol. 2, Turkey.
25. Martin Gomez, Hardware-in-the-loop simulation, 11/30/01, 08:21:52 AM EST, http://www.embedded.com/story/OEG20011129S0054
26. N. P. Mahalik and S. K. Lee, Design and development of system level software tool for DCS simulation, *Int. J. Advances in Engineering Software,* **34**(7), July 2003, Elsevier Science, pp. 451–465.

27. N. P. Mahalik and S. K. Lee, Three upcoming interdisciplinary technological disciplines: mechatronics, photonics and computronics, *J. Scientific and Industrial Research,* **61**(11), Nov. 2002, pp. 927–939.
28. http://www.lboro.ac.uk/prospectus/pg/systems/ase/index.htm

N. P. Mahalik, an invited Professor in the department of Mechatronics, Gwangju Institute of Science and Technology (GIST), South Korea, received his B.Sc. Eng. (Electronics), M.Eng. (Communication), and Ph.D. (Machine Control) in the year 1989, 1993 and 1998 respectively. He has experiences in authoring and editing research books for technical education. To his credit, Dr Mahalik has received the prestigious NOS (1994) and Brain-Korea-21 fellowship (2001) award from the Indian and Korean government, respectively, for pursuing research especially in the field of interdisciplinary areas. His research area has been 'Micromechatronics'. More than 50 research articles and reports have been published.

J. Ryu is a Professor in the department of Mechatronics, GIST. He received his B.S. (1982), MS (1984) and Ph.D. (1991) degree from Seoul National University, Korea Advanced Inst. of Sci. & Tech and University of Iowa (USA), respectively in Mechanical Engineering. He has received best education award, president award and have been teaching advanced control, dynamics, automation, virtual environment and haptics. The research field includes parallel manipulator kinematics/dynamics/control/optimal design, haptic device for VR interface, computer haptics/VR dynamic simulation, vehicle dynamics/control, hardware-in-the-loop simulation. Prof Ryu is a member of ASME, KSME, KSAE, IEEE. More than 120 research articles and reports have been published.

B. H. Ahn, a senior Professor in the department of Mechatronics, GIST. Director of the System Integration Laboratory with additional administrative position as Vice-President at the institutional level. After serving in the Air Force Tactical Flight Wing as Pilot and subsequently as Chief during 1966-1981, Prof. Ahn preferred to join in the academic field since then. Prof. Ahn, received his Ph.D. in Industrial Engineering in the year 1980 and have achieved many distinctions, awards, publications and patents to his credit. He is the auditor of the Society of Korea Industrial Engineering, member, Society of Korea Human Factors Engineering; member, Board of Directors, Society of Korea CALS/EC. His research interest includes, data acquisition/fusion for intelligent transport systems; industrial application of information technology; microtelemanipulation; air traffic control, systems management and reliability analysis. More than 120 research articles and reports have been published.

Kieson Kim. Professor Kim is the Director of the IT Professorship Scheme. His research interests are in Digital communication theory and applications, Multimedia communication signal processing and its VLSI implementation, Telemetry system equipment and measurement and Digital MODEM development for broadband assess.