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CONTROL APPROACHES TO BIO-ECOLOGICAL SYSTEMS
-MILSTONE REPORT BY CC-IL, IFAC-

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1. INTRODUCTION

As we begin the 21st Century, “Future Directions of Automatic Control” is exploding. Automatic control systems play critical roles in many fields, which means that these theory and technology are now applied to bio-ecological systems such as agriculture and medicine far beyond its initial applications. Further environment problems should be solved based on control applications for the better symbiosis between biology and industry, which may be included in the bio-ecological systems.

At NOLCOS in 2001, Prof. Murray gave the excellent plenary lecture where nano-technology, quantum mechanics, biology and environment were pointed out as the new frontier in control sciences[1)].

It may be noted that bio-ecological systems are considered as one of the most prosperous future directions of automatic control, though the biology mentioned above means not macro biology such as agriculture and medicine but molecular biology.

Our CC is composed of two TCs in agricultural department, one TC in bio-medical department and one TC in environmental science: namely, TC-ILP(Technical Committee on Modelling & Control in Agricultural Processes: A), TC-ILA(Technical Committee on Control Systems for Agriculture: B), TC-ILB(Technical Committee on Modelling & Control of Biomedical Systems: C), and TC-ILE(Technical Committee on Modelling & Control of Environmental Systems: D).

Though each TC has the fundamental concept common through Bio-Ecological Systems, actual problems are quite different in their histories. The first and the second TC have the mission in the agricultural processes and systems, where a lot of applications has been done for these ten years. The third TC has the mission in bio-medical processes having the long history in IFAC. In these TCs, the applications are more important than the concept.

While, the fourth TC was established at San Francisco Congress in 1996. The TC has been discussing the concept and finally organized the workshop in 2001. Therefore, tendency is quite different.

2. CURRENT STATUS

2-1 A: Agricultural Processes

In the agricultural production line there are several different methodologies and processes which requires a rather high energy input at the same time the markets requires a high quality of output products. This is somehow implies all those efforts which is covered by the TC activities. These may be classified according to the applied methodology, technology and application fields.

These issues are somehow appearing among the scientific topics of the workshops and the conferences organized by the TC. However these are slowly changing, but the recently applied most important one can be gathered as follows:

Methodological approaches:

- modelling and simulation methods of dynamical systems and processes in agriculture,
- control, operation and optimization methods,
- modelling issues for agro-industry, e.g. uncertainty, randomness, time-variability, strong external disturbances and lack of predictability,
- artificial intelligence techniques for modelling, control and operation.

Technological approaches:

- photosynthesis of crops under environmental stresses,
- soil-plant atmosphere cycle,
- metabolism of farm animals,
- harvesting systems,
- food processing,
- grading, drying, storage of crops including fruits and vegetables,
- automation e.g. robotics, vehicle guidance, autonomous vehicles,
- internal transport and packaging,
- distribution and marketing automation,
- heating, cooling, lighting, and energy saving.

Application fields according to the discussed methodological and technological approaches:

- greenhouse technology, e.g. climate control hydroponics systems,
- environmental and climate control of greenhouses, warehouses and animal houses.,
- post-harvest, e.g. drying system and control, storage systems control, product quality protection,
- animal husbandry, e.g. climate control, identificationtags, feeder systems, milking robot,
- control issues of precision farming, e.g. site specific operations, positioning, crop protection,
- energy issues, alternative energy resources in agriculture.

2-2 B: Control Systems for Agriculture [2)]

Sustainable agriculture aims at the production of high-quality food and raw materials in sufficient quantity for a wide range of consumers. The rational use of natural resources and preservation of the environment are further objectives of advancement of innovative agricultural technologies. For this reason, control technologies for modern agriculture should be the main part of development and be able to cope with complex agricultural systems and to execute difficult tusks at high efficiencies and with much reduced environmental impact. Much information, intelligence and mechatronics have to be integrated for higher degree of optimization of such complex systems. The facts require the introduction of an information and mechatronics-based agriculture, the so-called “Microprecision agriculture for protected cultivation such as plant factory”

Technological approaches:

- intelligent control technology for greenhouse environment control,
- imaging and NIR technology for non-invasive measurement in bio-instrumentation,
- variable rate control technologies in precision and micro precision farming
- decision support system for microprecision agriculture
- bio-robotics for agro-industry.

Control concepts in technology

- soft control technologies including intelligent controls such as ANN, GA, ES etc.
- control methods derived from bio-systems
- optimization algorithm, Photosynthetic algorithm, DNA algorithm, Leaf cellular automata.

Challenges for technologie

- new technologies that can contribute to the advent of the bio-informatics discipline
- technological breakthrough in bio-production industry
- contribution to medical communities through therapeutic use of plants
- development of environmental technologies using wide varieties of plant materials
- human-plant interface for amenity

2-3 C: Modelling & Control of Biomedical Systems

The current scope of the TC can be summarized in its opening sentence as covering the application of systems and control concepts, methodology and techniques to medicine, biology and health care.

This is a broad statement. However, it is one which is relevant both to the activities of the past as well as embracing all that is likely to be relevant to the next ten or more years.

Breadth of Coverage

-all levels in this biomedical setting from the sub-cellular and cellular levels of the living entity, to the organ and whole living organism.

-equally it extends beyond this to the medical encounter between patient and clinician, up to the health care delivery unit (e.g. intensive care unit) and beyond to public health policy and management.

Challenges of the Biomedical Domain

-a key facet of the biomedical domain is the high degree of complexity that it affords in many of its applications (across all levels from the cellular to the health care organization). As such, much activity has involved demonstrating the applicability of existing control methods and techniques to this challenging domain, using biomedical examples to demonstrate limitations of existing methods and techniques. This latter highlights areas where methodological advance has been needed

2-4 D: Modeling and Control of Environmental Systems

Environmental issue is one of significantly important subjects to be solved in a global scale for attaining sustainable developments in the new century. A major feature of environmental issues is that studies on environments are interdisciplinary and should deal with complex and heterogeneous systems which include chemical, physical and biological phenomena and further socio-economical activities. Individual technologies have recently been much developed independently in various areas. The purpose of the TC is to explore and create new original methodologies for analysis and design for the environmental improvement from the systems control point of view.

New modeling methodologies

-to construct an integrated model structure consisting of a variety of heterogeneous subsystems,

-to give an estimate of environmental variables by using only small number of data,

-to realize a data-based nonlinear modeling in combination of physical modeling,

-to perform impact assessment of policy options by using the integrated model,

-to deliberate adequate scenario for decision making under some uncertainties.

3. FORECASTS

3-1 A: Agricultural Processes

The fast changing of the field of the application and the used technologies covered by the TC activities will not change quickly. In spite of this fact, likely new applications will come to the focus of interest in the sense of modelling and control. Even more emphasis is, however, expected on the quality and safety issues of the end-product in the different applied technologies. This will make some motivation on the new technologies to be applied. The man-machine interaction will grow up as well.

Concerning to the control methodological approaches in the near future it is expected to deal with the methods as: robust control, adaptive control, image processing, real time control, uncertainty handling, non-linear identification methods, intelligent control. Concerning to control systems it is expected development related to soft sensors, biosensors and crop monitoring.

3-2 B: Control Systems for Agriculture

For the precision and microprecision agriculture, communication networking of production units has become an important feature of agricultural production and can be expected to continue to grow. Farm operations can be communicate with weather services, traders, contractors, suppliers, biological services, consultants, and many other organizations. In these applications, the internet already plays a key role. For on-farm communication, which is mainly used for online or inline applications on or among tractors and implements in the field and all controllable elements in the plant factory, a specific communication system, some communication bus system will have to be developed in the future.

Several algorithms of bio-computing have been developed and implemented providing graphical user interfaces to existing databases. Bio-computing might lead to a better understanding of life and the molecular causes of certain diseases. This sounds very far from control system of

agriculture. The current approaches in Bio-computing are very helpful only in identifying patterns and functions of proteins and genes. Even they are still far from being perfect. However, the concept and approach are very useful to find another dimension of naturally created optimization process which might be useful to handle the complex bio-production systems.

The followings are the new areas, new applications and new problems:

-Bio-informatics,

-Amenity and human life quality,

-Food safety,

-Agricultural environmental impact.

Our technology will become more important because our technology will be more involved in providing with appropriate and practical solutions needed to overcome existing and coming up problems in the complex life support systems such as agricultural system, food system, green environmental system and so forth.

3-3 C: Modelling & Control of Biomedical Systems

Some re-focusing of the activity is now occurring as a result of the world-wide focus on medical/health informatics as an important component of the re-engineering of health care and its delivery. However, medical/health informatics can be defined within a clear control context. In essence, health care delivery is based on the clinical encounter between the patient (as the controlled system), and one or more members of the clinical team (as the controller). It should be noted, however, that in the case of managing their chronic disease the patient may also take on elements of the role of the controller. In this context examples of the clinical encounter can range from a primary care consultation to an episode of care in a coronary care unit. Within this patient/clinician control loop, data obtained from the patient need to be processed and interpreted. This needs to be done in the particular clinical context, in order to provide information to the clinician for the purpose of decision making/deciding upon control action.

Medical/health informatics is in essence the adoption of information and communications technologies (ICT) to the enhance the operation of this control loop. It should also be noted that that this ICT-enhanced patient/clinician loop is set within a wider health management environment which can in turn be modelled from a control system perspective. It is the development and application of methods for the processing and interpretation of medical data for use in a decision making/control context which is becoming increasingly evident within the overall scope of the TC; a trend which is likely to continue over the coming decade.

Activities During the Next Decade

As is evident by the breadth of its scope, the on-going activities of BIOMED are likely to involve the application of a very wide range of control concepts, methodology and methods and techniques. The approaches adopted will be matched to the requirements of the specific application. However, it is suggested that the following may feature prominently over the next few years:

Modelling at the cellular level and in pharmacological applications:

-the adoption of advanced methods of stochastic modelling

Modelling methodology

-further developments in relation to identification and validation methodology

Model-based interpretation of medical images

-for example, in relation to Positron Emission Tomography (PET)

Control applications in the high-dependency medical environment

-adoption of neuro-fuzzy and related approaches, for instance in intensive care and similar environments

Intelligent analysis of medical data

-adoption of data mining methodologies, ANNs and structural time series methods

Physiological signal analysis

-higher order statistical methods in the interpretation of electro-physiological signals

Knowledge management in the medical domain

-application of temporal reasoning and other intelligent and model-based approaches

Modelling of patient scheduling, resource allocation and clinical outcomes

-adoption of a range of loop-relationship approaches, including Petri nets

3-4 D: Modeling and Control of Environmental

Systems

Modeling

Modeling is one of the most important procedures for cope with environmental problems. One should clarify a purpose and target for modeling, since an environmental system consists of a variety of phenomena and subsystems. Normally, the purposes for environmental modelling are summarized as follows:

-Modeling of environmental systems and explicit statement of environmental issues: Global environmental system is an integrated system which consists of atmospheric, water, solid, biological, ecological, human and socio-economical subsystems. Environmental problem and target should be explicitly described logically, qualitatively or quantitatively by using the integrated model.

-Prediction and estimation of important environmental variables by using the constructed composite model to use efficiently in environmental strategies and managements:

-Assessment of influences and impacts for environmental changes: How the changes of input variables and/or environmental variables influence mutually the variables of climate system, ecological systems, socio-economic activities, human lifestyle and others, how to construct loss functions which fit into the objective and model, and how to select an optimum strategy from the policy options by using the constructed models.

-Adequate decision making: Policy deliberation based on the assessment models.

Environmental Management

Environmental and risk management system should function so that goals for their environmental improvements and safety can be attained. A variety of systems approaches are available in analysis and synthesis of the management systems. Advanced information techniques and intelligent tools are now essentially needed to complete the data-base for the life cycle assessment, choose a suitable scenario from the options, make decisions by using soft data as well as hard data under uncertainty, design safety-guaranteed social system. New systems approaches should further be developed to treat with difficult problem with pluralism and heterogeneous aspects of the environmental issues.

Challenging Control Themes in Industries

In the past ten years, industries have made efforts to save energy, improve efficiency of energy use, reduce CO2 emission, and promote recycling and life cycle assessment. There are still many issues to be challenged from systems control points of view in the researches and developments in industry toward environmental targets. Only some of topics are summarized below:

-Iron and steel industry, upper and lower processes such as blast furnace, melting furnace, electric furnace, strip mill consume large quantity of energy as well as discharge large waste energy. Therefore they developed efficient energy use and transformation devices, and new method for reuse of waste energy by adopting flow analysis of mass and energy. However, problems of saving energy and use of waste should be considered as a optimal design of energy network or an integrated system design for combining related systems including energy system outside the steel company, which can be regarded as an optimal control system design. Moreover, optimal control system design should also be developed in efficient and stable combustion control, efficient transformation to power, waste energy recycling system, and so on.

-Chemical plants also have large energy consumption such as naphtha-ethylene plant, so the energy saving is one of the most important theme. Total system design for a plant is needed to realize an optimal system considering productivity, energy saving and resources saving, and stabilize the operation and avoid bottlenecks. In control of paper production plant, they made efforts in saving energy as well as recycling materials.

-In electric power plant, efficiency of power generation should be improved. A combined cycle power generation system now can attain about 50% efficiency. Total system design for highly efficient co-generation systems is also a very challenging theme. Environmental management should give a future plan for the new energy sources, moreover, in order to reduce CO2 emission, new clean energy sources should be developed, such as solar power, windmill power, geothermal plant, oceanic power. Since natural energy tends to fluctuate, one of the problems is how to attain stable power supply

since natural energy tends to fluctuate and how to improve its efficiency by using control techniques.

-Fuel cell is expected to be an alternative power generation system in a variety of applications such as vehicles and ordinary power supply. Although present research interests are in the development of polymer electrolyte fuel cells from the view points of downsized and long-lived device with high cost performance, the fuel cell is one of the small scale chemical plant. Modeling and control approaches contribute to the optimal design of the fuel cell plant especially in many applications. LCA for the fuel cell is also an important subject.

-Through the effort of improvements in the last twenty years, car industries not only successfully cleared regulations for air-pollution by exhaust gas but also reduced fuel consumption, which can be attained by computer control devices. Recently development of hybrid or electric cars is expected as a powerful strategy to CO2 mitigation in the new century. However, it strongly depends on the success of the compact size of fuel cells as well as optimal design of control systems for actuators. New sensor-less induction motor control techniques and algorithms essentially needed in achievement of high torque efficiency in combination of battery. It is also an optimal design of integrated system including chemical reaction system and actuator drive system.

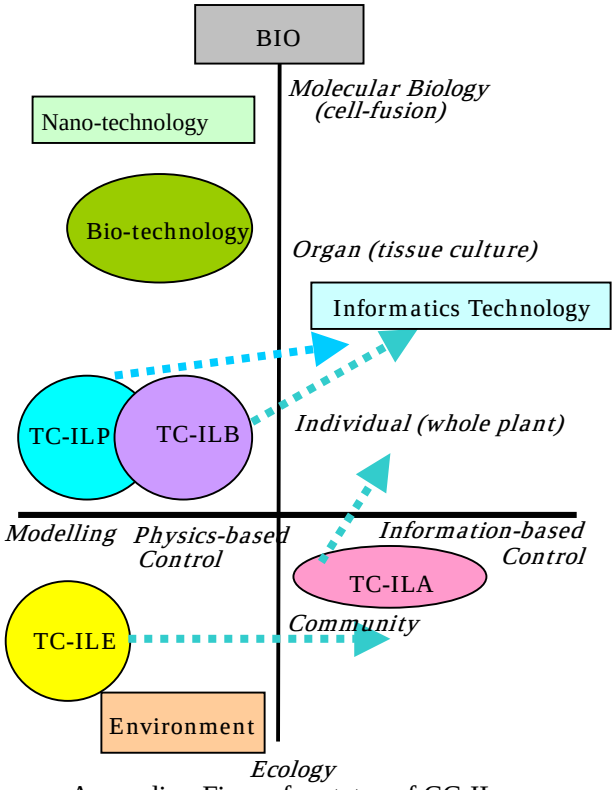
-Waste management and treatment is also one of the important subjects to reduce pollution to environment and promote recycling. Refuse incineration plant plays an important role in treatments of the ordinary and industrial wastes. Reduction of pollution by the exhaust gases and improved efficiency per provided electric energy are very important subject to be solved. From a control point of view, automatic combustion control is significant to reduce both CO-related dioxins and NOx concentrations in exhausted gas discharged from a municipal refuse incinerator. Modeling and control of waste gasification and ash melting plant is a newly expected waste treatment of dioxin.

-For water quality control, the design of a sewage plant is one of the important issues for clear the water quality regulation of the total quantity of nitrogen and phosphorus from the plant waste to river. A precise and detailed mathematical model is essentially needed to estimate the water quality and quantity, for instance, a model describing changes of water quantity in a process from the rainfall to the sewage plant, a model describing decomposition of organic substances by bacteria and removal process of phosphorus. The purpose of the mathematical modeling is to estimate and predict the time change of water quality and quantity, to design a sewage treatment plant control system, to realize an on-line control and tuning algorithm based on the model, and so on. However, an efficient methodology for such modeling is not yet attained, since it involve bacteria reaction, nonlinear and spatially wide process.

REFERENCE

1) Richard M. Murray : Panel on Future Directions in Control and Dynamical Systems Report, (2001)

2) Yasushi Hashimoto, Haruhiko Murase, Tetsuo Morimoto and Toru Torii : Intelligent Systems for Agriculture in Japan, IEEE Control Systems Magazine 21(5), 71-85, (2001)



Appendix : Figure for status of CC-IL