Introduction: Some challenges for adaptive and innovative systems in the next future

Dimitri Lefebvre
GREAH – University Le Havre,
25 rue Philippe Lebon,
76058 Le Havre, France
E-mail: dimitri.lefebvre@univ-lehavre.fr

Biographical notes: Dimitri Lefebvre graduated from the Ecole Centrale of Lille (France) in 1992. He received his PhD in Automatic Control and Computer Science from the University of Sciences and Technologies, Lille in 1994 and HAB from the University of Franche Comté, Belfort, France in 2000. Since 2001, he has been a Professor in the Institute of Technology and Faculty of Sciences, University Le Havre, France. He is with the GREAH (Electric and Automatic Engineering Research Group). His current research interests include learning processes, adaptive control, fault detection and diagnosis, and applications to electrical engineering.

1 Introduction

One of the most efficient ways to investigate new directions and to find innovative solutions to unsolved problems is certainly to encourage the crossover between several research domains. This interdisciplinary approach will be a guideline for the International Journal of Adaptive and Innovative Systems that will promote intelligent system development and management bringing together the technologies, the people and the processes. The selected contributions provide cross learning between various business, economics and logistical, as well as scientific and technological disciplines comprising energy and resource industries, environmental and ecological systems, computer and automation sciences, risk and engineering management, human and material organisations. A lot of unsolved problems exist in all these research areas. Some examples of challenging issues are presented in this introductive paper according to a non-exhaustive selection of domains.

2 Renewable energy

Our world has been powered primarily by carbon fuels for more than two centuries, with some demands met by nuclear power plants over the last five decades. Nowadays, electrical energy remains an essential factor for the development of the human societies. The increasing environment concerns in recent years about global warming and the harmful effects of carbon emissions have created a new demand for clean and sustainable energy sources, such as wind, sea, sun, biomass and geothermal power (Da Rosa, 2005). The limited reserves of fuel oils and their unstable prices also have significantly
increased the interest in renewable energy sources. For this reason, the design of hybrid power systems, also named systems of multiple sources of energy, has received considerable attention in the last decade (Chedid et al., 1998). Hybrid power systems may constitute the most economical solution in many applications. In addition, they may result in lower environmental pollution and provide a more reliable supply of electricity through the combination of several energy sources. In many situations, they can be considered as pollution-free sources of abundant power. Additionally, they generate power near consumers; hence, they eliminate the need of running high voltage transmission lines through rural and urban landscapes.

**Figure 1** Topology of a multisource renewable energy system

In this context, many hybrid energy systems frequently combine solar, wind and other energy sources (taking advantage of their complementary nature) with a lead-acid battery bank (to overcome periods of scarce generation) (Patel, 2006). These electrical systems are composed by two or more sources of renewable energy (or eventually not renewable) in order to generate electrical power. Figure 1 provides an example of hybrid energy system with four sources (Mboup et al., 2008). One of the main advantages of hybrid energy systems is the possibility to prefer the available local resources that could guarantee high quality levels and reliability of the service, with reduction of costs for investment and operation.

The development of hybrid energy systems will be one of the most existing challenges for the next decades. To be efficient, these systems must be designed to adapt themselves to the environmental and economic situations. Promising challenges concern at first improvements in the design of batteries to store and save energy. Recently, several researches (Chedid et al., 1998; Valenciaga and Puleston, 2005; Lemos Pereira, 2000) have also focused on the control of hybrid power sources and propose solutions to manage and coordinate the operations of the hybrid energy systems based on the measurement of the main significant system variables (solar radiations, wind turbine shaft speed, etc.). These methods are mainly designed as a combination of several local controllers and require the use of additive sensors to be efficient. Many works are in progress to improve and simplify the control design of hybrid energy systems. A systemic
approach with the use of artificial intelligence and the overall use of adaptive control schemes will be studied. In particular, control systems with smart sensors, hierarchical control schemes and supervision systems that include control and diagnosis in a framework are investigated (Figure 2) (Guérin and Lefebvre, 2008). Lastly, reliability is also an important question to deal with hybrid energy systems, as long as such kind of systems are at first useful in isolated places where maintenance and reparations are difficult and expensive operations. The development and success of hybrid energy systems will be strongly related to the reliability performance of the new equipments.

Figure 2   Supervisory control design for a two sources hybrid energy system

3 Logistic and transportation

From the end of the Second World War, the circulation of people and exchange of products has increased more and more. In the same time, the cities and traffic networks have expended, so that, they represent today half of the superficies of the main urban areas. But this development is still not enough to fulfil all the requirements concerning human and product transportations. As a consequence, many challenges remain, concerning logistic, traffic forecasting, regulation and monitoring. These challenges require adaptive and innovative solutions.

In the domain of logistic, producers and transporters are seeking more effective ways to market their products. They tend to improve the supply chains in order to reduce costs and investments. One of the most important issues in agile supply chains is responsive logistics. Responsive logistics aims to coordinate effective flows of products in the supply chains in order to adapt quick response to market demand. As a consequence, many challenging issues concern responsive logistics: improved flexibility; reduced supply cost; reduced stock holding costs; removal of stock rooms; control of inbound materials; integration of functions from purchasing to sales; and increased control of the supply chain. Logistics forecasting is also a key part of responsive logistics (Agarwal et al., 2006). Most firms cannot simply wait for the demand to emerge and then react to it.
Instead, they must anticipate and plan for future demand so that they can react immediately to customer orders as they occur. The improvement of supply chains efficiency and effectiveness is also closely connected with matching supply and demand. Matching supply and demand requires the reduction of uncertainty within supply chains, so as to facilitate a more predictable logistics demand. However, in many markets, it is becoming impossible to remove or ignore sources of turbulence and volatility. Hence, supply chain managers must accept uncertainty, but still need to develop a strategy that enables them to match supply and demand at an acceptable cost. The ability to achieve this has been termed supply chain agility (White et al., 2005). Efficient tools to understand and also to drive supply chain agility must be developed in the next future and represent a challenging issue for geographic, economics, mathematics and computer sciences.

In the domain of traffic control, many investigations must be considered as long as pollution and environmental issues are concerned. Long term traffic networks control design is dependent on the public policy and new roads construction. The construction and maintenance costs of a road network can be financed in part through public funding and in part by imposing tolls on some of its roads (Ferrari, 2002). If the tolling stops or changes suddenly after some time, traffic volume will be redistributed in the freeway network. Some traffic volume will shift to the free freeway causing unbalanced distribution of traffic volume in the whole freeway network. This phenomenon is named transportation market failure (Levine and Inam, 2004). When there is no toll charge, higher values of potential demand might cause congestion and queuing at bottleneck links of the road network. Queuing delay at saturated links may grow, leading to a queuing equilibrium where travel demand and travel cost match each other (Yang and Bell, 1997). Therefore, constituting a set of new toll standard and toll policy is significant for obtaining reasonable traffic assignment in the network and further increasing the social benefits. As a consequence, road pricing is being advocated as an efficient means of managing traffic demand and of meeting other objectives, such as reducing the environmental impact of road traffic and improving public transport.

Another response to traffic congestion and pollution is to build new roads, but some people argue that these new roads do not reduce congestion but instead induce additional traffic (Uchiyama et al., 2006). The induced traffic demand from increased infrastructure supply over time typically coincides with an increase in population and a higher per capita income in the study area. To isolate the effects of the different variables is a complicated task. There is also a danger of oversimplification in answering this complex problem. This occurs quite frequently during the discussions of traffic growth. The induced traffic usually indicates new traffic volume brought by the construction or rebuilding of highways that promote the development of regional economy (Goodwin, 1996; Mokhtarian et al., 2002). The induced traffic volume has significant meaning in economic evaluation of projects, selection of road technical standards and transportation management of new opening roads, and therefore, draws the attentions of researchers to the relevant research areas.

Short term control design is developed according to message, guidance systems and also traffic lights. The traffic regulation based on the control of the crossing lights requires the investigation of mathematical models, and is an important challenge that must be considered in order to reduce traffic congestion and to improve the transportation of human and products. For this purpose, the traffic flow is often considered as a heterogeneous system. It takes a continuous form in motorway circulation and a discrete
one in intersection ways. On one hand, the continuous form of traffic flow is mainly modelled from a macroscopic point of view, which has been inspired from the hydrodynamic theory (Lighthill and Whitham, 1955; Papageorgiou, 1997). In this case, the traffic flow is described by global variables as the flow rate, the flow density and the flow average velocity. On the other hand, the discrete form of traffic flow is modelled from a microscopic point of view that focuses on the individual vehicles behaviours in roads. This approach describes the traffic in a finer way: vehicles are individually represented by considering the interactions between them. Generally, this theory represents each vehicle by its acceleration, its velocity and its position in road. Several models exist: car following models (Gazis et al., 1961) and cellular automata models (Nagel, 1982) are famous examples. Based on such mathematical models, several solutions are investigated for traffic regulation. Many simulators have been developed: ‘SCOOT’ (Hansen et al., 2000); ‘OPAC’ (Gartner et al., 1991); ‘CRONOS’ (Boillot et al., 2000) are some examples. Control design based on the hybrid nature of traffic (Di Febrarro et al., 2004) has also been investigated and further researches must be encouraged in this domain. Figure 3 shows a hybrid Petri net model developed for the analysis and control of traffic flow in urban areas (Tolba et al., 2005).

Such a traffic network can be regulated according to the control design of the lights on each crossing. Automata, Petri nets and other discrete event tools can be investigated for that purpose (Tolba et al., 2005).

Figure 3 Petri net model of a traffic network in urban area (see online version for colours)

4 Technological risk management and fault diagnosis

The management of the technological risks aims at protecting the persons and the equipments throughout the life cycle of industrial processes. For a good management, these processes have to be known in terms of physical or behavioural modelling. This knowledge leads to the development of optimal and adaptive control and strategies of
diagnosis for online monitoring and supervision. Among the existing tools, many investigations, concern signal processing methods and higher statistics approaches that can be associated to artificial intelligence algorithms in order to improve the performance of fault detection and diagnosis methods (increasing the detection rate, decreasing the false alarm rate and the delay to detection). Such studies must go on.

Fault diagnosis and control design usually require a model of the system that is investigated. In that case, fault are detected and isolated according to the difference observed from the measured signals to the expected ones provided by the model (Figure 4). A linear or non-linear model of the plant can be based on the physics of the plant. Statistical pattern recognition techniques that include neural networks are generally used for classification of the fault because they are general non-linear function approximators. The function approximation is achieved by using an appropriate network built up from artificial neurons which are connected in an appropriate pattern (including feedback and feedforward connections) by appropriate weights. However, the exact architecture of a neural network is not known in advance, it is usually obtained after a trial and error procedure. To overcome this methodological weakness, the structure of the neural network (number of neurons and their pattern of connectivity), as well as the value of the network parameters (weights attached to connections), should be developed using robust and adaptive identification procedures.

Figure 4  Diagnosis based on residual generation (see online version for colours)

No matter what type of model is chosen for diagnostic and control purposes, the most general methods are population based on advanced stochastic optimisation techniques: evolutionary strategies with deterministic selection, evolutionary algorithms with probabilistic selection, and particle swarm optimisation are methods that have significantly outperformed local search algorithms and are promising alternatives to usual techniques. They do not rely on assumptions such as differentiability, continuity or unimodality. They are capable of handling problems with non-linear constraints, multiple objectives and time varying components, and they have shown superior performance in numerous real world problems. The success of population based techniques lies in their capability of generating new candidate solutions far from existing solutions by exploiting
Introduction: Some challenges for adaptive and innovative systems

The parallel nature of the population-based search. However, it is important to use advanced algorithms employing diversity and stagnation measures to get the most out of these algorithms.

Another way to detect fault and to decrease technological risks is to use adaptive filtering, sequential methods to detect changes and higher order statistical methods (namely expectation maximisation and independent component analysis techniques). Adaptive filters are an important class of self-adjusting digital filters where the coefficients of the filter vary in time according to some predefined criterion. Those filters are therefore ideally suited to adaptively reduce or cancel the interfering noise in the monitored signals. System identification is another task performed by adaptive filters in various engineering applications. In many cases, the system is time varying and it is therefore of little use to design a control system based on the fixed plant model. Instead, an adaptive modelling or adaptive system identification where system model is constantly updated with new observations will be used to track the plant changes. Early fault detection, which reduces the possibility of catastrophic damage, becomes possible by detecting the change of characteristic features of the signal. A practical example of such approach combines filters bank technique, for extracting frequency and energy characteristic features, and sequential methods like the dynamic cumulative sum method, which is a recursive calculation of the logarithm of the likelihood ratio between two local segments. Figure 5 illustrates the application of such methods (Mustapha et al., 2008).

Figure 5 (Right) original signal and decomposition into three channels using a filters bank; (left) dynamic cumulative sum; (top) original signal resulting from decomposition; (middle) DCS function; (bottom) detection function (see online version for colours)

An alternative approach to system modelling can be considered through the use of statistical expectation-maximisation algorithms. Expectation-maximisation alternates between performing an expectation step, which computes an expectation of the likelihood by including the latent variables as if they were observed, and maximisation step, which computes the maximum likelihood estimates of the parameters by maximising the expected likelihood found on the expectation step. The parameters found on the maximisation step are then used to begin another expectation step, and the process is repeated. In this way, any parameterised plant model can be accurately estimated using the expectation-maximisation algorithm. Final step in this fault detection process would
then be the fitting of the acquired data to estimated model. The independent component analysis technique is also an emerging statistical and computational technique for revealing hidden factors that underlie sets of random variables, measurements or signals. In recent years, this technique has drawn considerable attention in various research fields. Independent component analysis is related to principal component analysis technique usually used in fault detection schemes but in many ways, independent component analysis is a much more powerful technique, capable of finding the underlying factors or sources when classic methods fail completely. The use of independent component analysis has to be investigated for the analysis of monitored signals and detection of new events that can indicate the possible pre-fault and fault conditions in the system. The basic idea behind this approach is to use the independent component analysis to extract dominant independent components from operating process data and to combine them with statistical process monitoring techniques. Support vector machine classification algorithms can also be associated to analyse extracted components or their power spectrum density estimates to obtain enhanced knowledge of the monitored system condition and eventually perform fault identification.

5 Biological and artificial intelligences

In the field of robotic, computer and automation sciences, many challenges exist that concern the combined use of biological and artificial intelligences. Artificial intelligence is usually inspired from biological intelligence. Neural networks, evolutionary algorithm, fuzzy logic are famous examples of (simple) mathematical reasoning inspired from biological intelligence. Such tools are of particular interest as long as they present a very high adaptability depending on the environment. Many domains can be investigated with such tools: complex systems analysis and control, adaptive systems theory and practice, knowledge based systems technologies, information technologies, process sensing and control, real time learning and machine behaviours, smart systems and structures, and so on. The problem of plant wide systems control design is considered as an interesting example.

Among the non-linear complex processes, the control engineers are confronted with, plant wide non-linear chemical or biological systems are frequently described. These processes consist of a large number of different units (reactors, separators, strippers, cooling systems, and so on). Such plants are strongly non-linear, multivariable and delayed systems. Moreover, numerous installations are open-loop unstable. Plant wide control means, the control of the overall system and it generally implies the decomposition of the process into some sub-processes or units and a selection of pertinent measured and controlled variables. The global control scheme usually accepted consists of a cascade control strategy divided into two or three successive stages according to Figure 6 (Lefebvre et al., 2008). Such global strategies were introduced 30 years ago (Grant Fisher, 1983; Morari, 1983) but continue to provide unsolved control problems. The objective of the first stage is the steady state stabilisation. Consequently, it is essential to perfectly analyse steady state conditions before developing any particular strategy. The first difficulty to be overcome for the multivariable processes is a judicious choice of some measured and manipulated variables. This stage consists of single input – single output loops providing set points trough a stabilising algorithm, thanks to local controllers like proportional plus integral or proportional plus integral plus derivative
regulators. The second stage is implemented for disturbances rejection. Controllers tuned for Stage 1 only reject some disturbances. Numerous other disturbances that act on the dynamics can not be compensated by low level controllers and require additive loops. Stage 2 generally consists of a decentralised control in which the plant is divided into sub-units. The first step is the selection of a set of reliable measured and manipulated variables sensitive to the disturbances. The control strategies associate a single feedback loop to each sub-unit. Finally, tuning these loops, the engineers focus their attention on the stability of the model in the presence of disturbances. The higher control level (i.e., Stage 3) is implemented to ensure the global control of the plant. Several problems can be considered: safety and/or environmental issues; production rate optimisation; physical constraints on the process. This stage essentially results on composition and flow control considering some economic aspects.

Since the last two decades, researchers and engineers have proved that for plant wide control of industrial processes, non-linear models associated with adaptive control algorithms are suitable. This choice is a direct consequence of the necessity to get stable and robust performance for systems whose dynamics are not perfectly known and disturbed by many unpredictable perturbations. Exciting challenges concern the use of neural networks and other artificial intelligence tools to develop innovative and adaptive control for such complex systems (Åkesson and Toivonen, 2006; Ge et al., 2002).

**Figure 6** Cascaded control strategy for plant-wide processes

Indirect control network control schemes applied to the control design of chemical processes like the Tennessee Eastman challenge process is an illustrative example (Figure 7) (Zerkaoui et al., 2007). A set of selected variables (temperature, pressure in reactor, levels in separator and in stripper units) is used in order to drive the outputs of the system (volume and quality of the final product).
6 Concluding remarks

From computer science to biology, from energy to natural resources, from traffic to human organisations and material infrastructures, from economics to logistics, the fields of applications for adaptive systems are large and promising. Many unsolved problems and open issues remain. Solutions will be found in the next future based on the investigation of complementary approaches. As a consequence, interdisciplinary and crossover between sciences and techniques are the bases to develop new results and to investigate future applications.

In this first issue of *International Journal of Adaptive and Innovative Systems*, other examples of crossovers between methods and applications will be developed. Artificial intelligence with neural networks and genetic algorithms is used to optimise physical factors in bio-chemical processes (article from Pakshirajan and Manda). Genetic algorithms are also combined with discrete event production simulators for the optimal design of flexible transfer lines in manufacturing systems (article from Qudeiri et al.). Adaptive search procedures to produce global optimum solutions for problems of huge state spaces are discussed according to genetic algorithms (article from Siva Sathyaa et al.). Artificial intelligence also includes robotics: human-robot cooperation is investigated.
according to the interactions between unmanned robots and their environment (article from Zieba et al.). Finally complex information systems are developed for adaptive multimedia and web services (article from Kanellopoulos) and also for self organised networks of service-based components (article from Greer et al.).

References


