Control in the Process Industries

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Introduction

Process control[1] is in many respects a mature technology serving mature industries.[2] It has gone through the emerging phase, the growth phase, and some would argue that it has also gone through the mature phase and is now in decline. The shares of companies operating in industries where process control is widely used, such as the petroleum industry, show typical signs of maturity—high dividend yields and low price-earnings ratios that reflect limited growth prospects.

The maturity of process control technology is also borne out by the decline in research funding for this area over the last decade or so, especially in the U.S. Paradoxically, this decline has occurred precisely because process control research has been so successful in addressing industry concerns. Although PID control been the king of the regulatory control loop for many decades, advanced process control has over the last few decades moved beyond the laboratory to become a standard in several industries. Many vendors now routinely offer advanced solutions such as model predictive control (MPC) technology, with its ability to economically optimize multivariable, constrained processes. Although there is always room to improve upon existing control solutions, it becomes harder to make an argument for research funding if vendors can adequately address most of their customers' control problems.

In contrast to the situation described above, government funding for process control research is readily available in Europe, mostly in the form of industrial-academic collaboration. For example, all German chemical companies have grown their process control departments considerably in recent years. The process control market will remain significant, and process control researchers still have much to offer the process industries. However, researchers will have to get out of their comfort zones for research funding levels to be maintained or increased. For example, there is much room for traditional tools to

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[1] Process control refers to the technologies required to design and implement control systems in the process industries. The goal of process control is to bring about and maintain the conditions of a process at desired or optimal values. Process control technologies include physical and empirical modeling, computer simulation and optimization, automation hardware and software (such as actuators, measuring instruments, implementation platforms, plant communication infrastructure), control structure design, advanced control strategies and related technologies such as process monitoring/diagnosis, and planning/scheduling solutions.

[2] Process industries are those in which raw materials are physically or chemically transformed or where material and energy streams may interact and transform each other. These include continuous, batch, or sequential processes and can refer to process units, whole plants, and enterprises. Specific industries include biological/biochemical/bio-fuels enterprises, cement, chemical, electrochemical, glass/ceramics, heating, ventilation, and air conditioning (HVAC), minerals and metals, petrochemical/refining, pharmaceuticals, power generation, pulp and paper, and water systems. Process components are also prevalent in other industries such as automotive, green buildings, microelectronics, and nuclear power.

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be applied in nontraditional industries such as the biological/biochemical and pharmaceutical industries. Conversely, traditional industries increasingly require agile and dynamic enterprise-wide solutions. Comfort zones are stretched, as forays into nontraditional fields and enterprise-wide solutions both require domain knowledge that often does not form part of the traditional training of a process control researcher. For those willing to make the effort the potential rewards are huge. In nontraditional industries, one can find plenty of low-hanging fruit where simply applying basic control tools can have substantial impact. Similarly, the economic benefit of control at the enterprise level could dwarf that obtained from improved unit process control.

Successful Applications of Control

The impact of process control can be viewed from two main vantage points: technical and economic. The main technical impact occurs in cases where operation would not be possible without control, such as when control is required to stabilize an unstable process. Few such examples currently exist in process control (for example, level and anti-slug control), but the number may increase with the advance of process intensification efforts. For stable processes, the technical impact of process control is to improve dynamic response and reject disturbances. Once the basic control infrastructure is in place, advanced process control is one of the technologies most often used for improving economic performance. The ideal situation, however, is where the plant is designed to be easy to control, for example, by providing for adequate actuator authority to deal with dynamic disturbances. Unfortunately, plants are often designed taking primarily a steady-state view. Once the plant is designed and working, process control provides the means for maximizing production and product quality.

> *Advanced control is one of the technologies most often used for improving the economic performance of a process plant.*

The economic performance improvements resulting from advanced process control are often divided into various subcategories and expressed in term of percentages. For example, improvements achieved in various industries by a major vendor are:

Increased throughput	3-5%
Reduced fuel consumption	3-5%
Reduced emission levels	3-5%
Reduced electricity consumption	3-5%
Reduced quality variability	10-20%
Reduced refractory consumption	10-20%

Single-loop PID control structures based on hierarchical time decomposition (cascades) still dominate most process control applications. PID controllers are successful because they work reasonably well in most applications. They are generally implemented without the need for a process model and are relatively easy to tune according to well-established tuning rules, either manually or automatically, using software supplied by all the major vendors of process control platforms. The main impact of PID control is technical.

Advanced control that optimizes PID loop setpoints is usually required to make a significant economic impact. The most successful advanced process control technology has been MPC. In the petrochemical industry, for example, MPC is often combined with online optimization of the setpoints on the basis of large, rigorous nonlinear stationary plant models. This practice is known as real-time optimization (RTO). One major vendor has reported more than 1,000 MPC implementations, and since its commercialization in the early 1980s MPC has become a standard in various industries.

Since the 1980s, model predictive control has become a standard in various industries.

Other high-impact process control success stories include inferential sensing using, for example, Kalman filtering; process modeling and identification tools for the estimation of process variables that are too difficult/expensive or impossible to measure online; automatic fault detection and diagnosis and statistical performance monitoring using multivariate statistical methods—very important where the number of control loops per control engineer has escalated rapidly over the last two decades; modeling and process simulation tools for rapid prototyping; and systems methodologies and analysis tools to deal with highly complex processes.

An industry breakdown of successful process control applications is given below. Some of the application highlights and their impact are:

- Industrial energy control for CO_2 footprint reduction (for example, $4M in savings for one particular application).
- Refining and petrochemicals (typical cost reductions of 10-20%).
- Steel rolling mill tension control (for example, €100K savings just in plant building costs).
- Boiler startup optimization using nonlinear MPC (reported to save around 15% of energy at each startup in numerous installations).

Pharmaceuticals

Standard feedback control (such as PID control) and multivariable statistical methods have been applied in most steps of the pharmaceutical manufacturing process, but not routinely and usually not using more advanced methods. Applications of multivariable statistics have seen huge growth in the pharmaceutical industry, and the growth of feedback control applications has been extensive, but starting from a low level.

Robust nonlinear feedback control has been applied in the crystallization of pharmaceuticals in many companies and has been well documented in the literature. Financial, safety, and environmental quantification of impact is difficult because companies are purposely secretive about this information.

Mining, Minerals, and Metals

Several control technologies besides PID have been experimented with in the metals industry. Some are now considered established technologies with significant advantages over classical PID control, such as:

- MPC: automatic flatness control, temperature control based on finite-element heating models.
- Optimal Linear Quadratic Gaussian (LQG) control: tension control based on online section measurements, hot strip mill combined control of looper and stand.

- Kalman filtering: automatic gauge control (AGC), automatic camber control.
- Neural-networks-based control: waterbox control for steel microstructure identification as a function of casting properties and rolling temperature.

Although it is difficult to quantify the impact of these applications in general terms, some examples provide some insight:

- Tension control in a rolling mill for long products: Advanced multivariable control exploiting section-measuring devices, beyond performance and dimensional quality effects, allows for a much more compact mill, saving more than €100K just in building costs for the plant.
- Control of a reheating furnace: Advanced control results in a 5% reduction in gas usage (a typical plant produces 500,000 t/year with a gas consumption of approximately 65 Nm^3/t).
- A copper concentrator scheduling solution running successfully since 2005 has reportedly increased throughput by 1-2%.
- The application of automated plantwide process monitoring schemes on a mineral processing concentrator circuit has decreased response times from as much as six weeks to a maximum of three days. This has led to substantial savings in terms of reducing product losses.

Chemical/Petrochemical

Key to the success of advanced control technologies in large-scale continuous processes such as petroleum refining is the ability to “model” and “optimize” (online or offline) the process and then build suitable MPC strategies around this optimized model. Typical studies lead to improvements on all fronts, including cost reductions of 10-20%, increased safety margins, and reduction of emissions (up to 70%) under varying conditions (guaranteed operability envelopes).

Advanced control seems to have the greatest impact in refining and petrochemicals because the margins can be low and every last bit of performance has to be squeezed out. Less advanced control has been applied upstream on oil platforms because there the driver is throughput.

Long-term applications of MPC in the chemical and petrochemical industry include crude towers, other distillation columns, gas separations, fluid catalytic cracking units, hydrocrackers, and polymerization reactors. The economic savings have been in the hundreds of millions of dollars. Other process control technologies that have been employed successfully are RTO, multivariate statistical process control (SPC), controller performance assessment and monitoring, plantwide loop oscillation detection, closed-loop identification, and soft sensors.

Extended Kalman filters are used extensively to construct observers that monitor and control batch processes, especially polymerizations.

Other

MPC applications are expanding from chemical/refining plants to industrial energy and public power generation utilities. One example is a new Advanced Energy Solutions product developed by Honeywell and applied in plants in Europe, Africa, and Asia.

Smith predictors, MPCs, Kalman filters, fuzzy logic controllers, and nonlinear control in the form of state feedback linearization have been implemented in the glass and ceramic industries. The first immediate and obvious impact was process variability reduction. In two cases where the financial impact had to be calculated, the cost reduction was a few million dollars.

LQG, robust, and H_∞ control trials have been performed in experimental fusion main plasma control (in the international ITER project).

Standard feedback control (such as PID control) has been applied routinely in electrochemical processes, such as lithium-ion batteries, for many years. More advanced methods for feedback control and for integrated design and control still need to be employed.

Applications of multivariable decoupling control solutions have become standard in many pulp and paper mills. Plantwide model-based optimization of paper mills has also been reported. In an application of robust multivariable control design to the cross-direction control of paper machines, an approximately 80% reduction in control tuning time and up to 50% higher performance have been reported.

Model-based control and optimization solutions in cement production have provided significant savings in more than 300 installations worldwide.

Additional emerging industries for the process control community include renewable energy, some types of biological processes, molecular and nanotechnology, and megascale processes.

Investment in advanced process control (APC) in industries where it has not been used previously could proceed as follows. Controller performance monitoring tools could be used as a door opener for APC by showing that the reality is not as good as plant managers believe or claim. Once installed, only a few highly successful APC installations would be required to potentially open up a whole industry for APC, which could then go on to become an industry standard. Sound economic performance assessment methods play a key role in justifying investment in APC, especially in groundbreaking implementations.

Market Sizes and Investment

Modern process industries cannot operate without process control. The process control market size is therefore a percentage of the process industries' market size. To understand the significance of this percentage, consider that the investment in instrumentation and control of a greenfields project is about 5-8% of the overall plant. In addition, a significant install base of regulatory and advanced controllers must be maintained to achieve production targets. The remaining component making up the total process control market size is the implementation of new (advanced) controllers on existing plants.

One way of estimating the process control market size would be to examine the turnover of the major process control vendors. A difficulty with this approach is that these vendors often also serve non-process industry markets but report turnover figures at the holding company level. The process control market size should therefore be estimated by stripping out the non-process industry contributions if reported separately.

A recent estimate of the world market for process control can be obtained from a report published in 2009 by the European Union [1]. According to this report, the 2007 world market for "Monitoring and Control" was about €188B, with Europe's share estimated at €62B. The 2007 world market for process-control-related industries was about €26B, with Europe's share estimated at €10B. Of the world market for the process industries, €5B was for equipment, €4B for software, and €17B for services. Growth was projected at 6.9% per annum.

Research Funding and Employment Summary

Government

Government funding for process control has been low, especially in the U.S. The exception has been in applications to new industries such as semiconductors or fuel cells, but such programs are usually of limited duration. The low governmental funding level is a bit surprising in light of the relatively high industrial interest and importance.

The European Union (EU) has set aside €10M/year specifically for control research; about 33% of this figure is for process control. Approximately ten times this amount is available for process control research through other EU grant programs. Government funding is available in Europe, and particularly in Germany, mostly in schemes with industrial-academic collaboration (industry's share is partly supported; the academic partners are fully subsidized).

In the UK, convincing funding councils to give any priority to industrial process control is difficult because most research funding is geared toward topical issues such as systems biology or CO_2 capture. The situation is different in Sweden (for example, the new Process Industries Centers at Lund and Linköping) and in Canada, especially in Alberta, where sustainability and responsible use of tar sands are very pressing concerns.

Employment

Of concern is that a decline in process control research funding at universities, as is happening in the U.S., inevitably leads to a decline in the hiring of academic staff and hence also graduate students working in this field. This in turn leads to a decline in the number of APC advocates in the process industries. Due to lack of knowledge about what APC can achieve, many plants are likely to operate suboptimally. Conversely, it takes only a few highly successful and well-publicized implementations for APC to become an industry standard, as has occurred in the cement industry.

Pharmaceuticals

Pharmaceutical companies are investing heavily in modeling and control technology within their companies but are only employing and supporting a small number of control engineers in academia. Investment in control has been increasing and is expected to continue to do so.

The market size for the pharmaceutical industry is many billions of dollars, and the growth rate for the industry has been between 10% and 20% per year. Thus, pharmaceuticals is a large potential market for control technologies. Progress has long been hindered by the need for recertification if changes in the control regime were made—once a production process for a medicinal product was validated and licensed, it was effectively "locked"—but this has come to an end as a result of the process analytical technologies (PAT) initiative of the U.S. Food and Drug Administration (FDA).

Mining, Minerals, and Metals

Companies investing in applied control research is a key factor in the global competitiveness scenario. For example, some companies producing turnkey steel-making plants invest more than 8% of their overall budget in research, with control technology representing 30% of the research budget. Sensing devices, mathematical models, prediction systems, and simulation environments account for most of this investment. A conservative estimate of the process control market size in the steel-making domain is €1B.

As for funding agencies, the example of Regione Friuli Venezia Giulia in Italy is worth noting. In the last six years, the commission funded eight research projects in the steel-making domain where control and automation were the main subjects, with total funding of more than €1.5M.

An increasing number of mining companies are seeing process control as a strategic investment, particularly as a means of becoming more energy-efficient and improving their returns on investment in capital equipment. In the platinum industry, for example, both Anglo Platinum and Lonmin have recently increased their investment in research and development in plant automation and process control substantially. These investments are likely to grow, provided they can realize tangible benefits for these companies over the relatively short term.

Other

Little investment has been made in advanced control research for electrochemical processes such as lithium-ion batteries, and very little funding has been available for academic researchers in this area. Given the size of the industry, the investment could grow rapidly if a control engineer found a “killer application” of advanced control that resulted in a major improvement in economics. The potential market for control for new electrochemical products is huge. Some countries are trying to obtain up to 30% of their total energy needs through renewable energy, and that cannot happen unless advances are made in solar cell manufacture and battery designs (to handle the increased need for load balancing when wind and solar power are used).

The IChemE held an industry-academia event in 2008 that addressed some issues raised here. An abbreviated event report is available [2].

Future Challenges

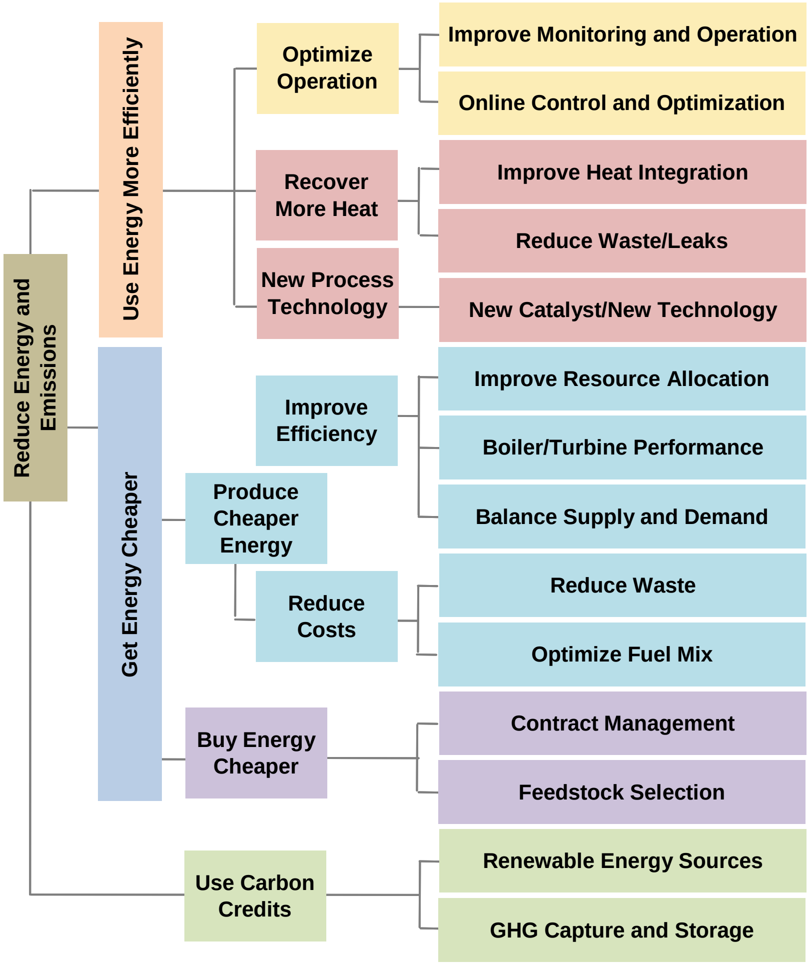
Energy Efficiency in Industrial Processes

Mitigating climate change is perhaps *the* grand challenge of the 21st century as highlighted by the 2009 Copenhagen climate change summit. The process industries are major users of energy as well as major emitters of greenhouse gases (GHG). Improving energy efficiency in industrial processes will be key to reducing GHG emissions and will become the major focus of the process industries. The manufacturing optimization and energy consumption reduction that will be required can open new doors to control.

Energy efficiency has always been an important consideration in advanced process control and is often explicitly included in optimization and control objective functions. The nexus with GHG emissions has further elevated its importance. More holistic perspectives on energy use and emissions reduction in industrial processes are being sought. As one example, Fig. 1 depicts a classification of automation and process technology measures primarily focused on refineries. Control and related technologies are well represented.

Very-Large-Scale Integrated Process Control (VLSIPC)

The use of economic-performance-optimizing MPCs (in contrast to setpoint tracking) is considered a strong trend for the future. Such control, known as dynamic real-time optimization (D-RTO), is applied to process and energy systems that are typically modeled by a large number of nonlinear differential-algebraic equations. D-RTO can be viewed as a variant of nonlinear MPC with an economic objective. Such integrated optimization-based control systems will be implemented in a complicated multiloop, hierarchical, and decentralized architecture to cope effectively with the network character of such systems. To implement VLSIPC systems successfully, the process control community must take a broader view. Its target should be the economic performance of a technical system that is implemented by the plant, the monitoring and automation system, and the human operators and decision makers in the face of process and model uncertainty.



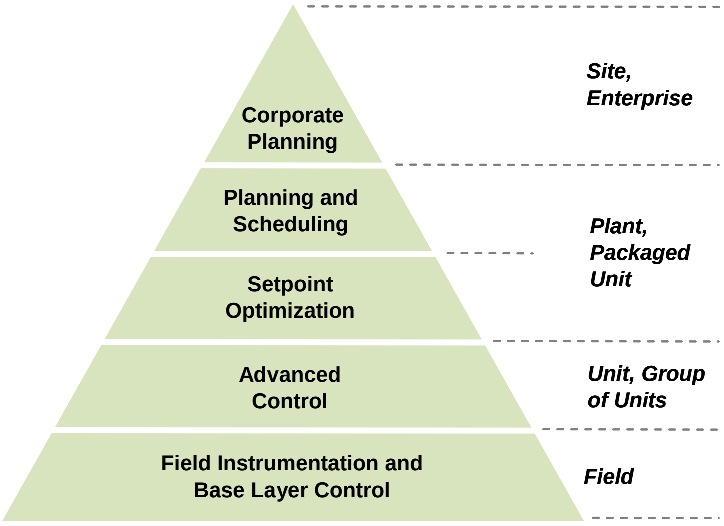
Source: Brendan Sheehan, Honeywell Process Solutions

Figure 1. An analysis of measures for reducing energy and emissions in refineries. Advanced optimization, control, and monitoring technologies are crucial in several cases.

The ISA S95 and ISA S88 standards provide a framework that makes it easier to integrate enterprise resource planning (ERP) systems, manufacturing execution systems (MESs), and distributed control systems (DCSs), paving the way for automating entire businesses. Such systems will be better able to deal with increasing volatility in production, energy, and raw material availability/requests/pricing by helping to make the business more agile. The integration of areas that are currently operated quite independently, such as operation and maintenance, scheduling and control, and energy management and production, is becoming a distinct possibility. A related challenge is to design such integrated systems to be easy to maintain through, for example, monitoring solutions that provide meaningful and easy-to-understand recommendations.

Classical approaches to DCS design and deployment (including all the layers from instrumentation and regulatory control to the advanced layer covering APC/RTO and the business layer covering MES and ERP; see Fig. 2) have reached their limits. Deploying and maintaining the next-generation DCS solutions that can respond to a volatile economic environment in real time will require that most of the activities be automated. Current solutions, however, are still static. DCS management tools for consistent cross-layer real-time responsiveness to changes in, for example, process topology and the business plan should become part of the system.

Related theoretical and practical challenges are methods for structuring automation solutions into layers and decentralized control tasks in order to solve large-scale online optimization and control problems in the presence of plant-model mismatch. Tools are required for multiscale modeling and control systems design, processes with many orders of magnitude ranges in time and spatial scales, “controlling” the sensor-to-enterprise-to-supply-chain, and integrating process control, design, and operations.



Source: Wolfgang Marquardt, RWTH Aachen

Figure 2. Layers in a process enterprise. Cross-layer integrated control solutions are needed.

One example of a “mega” industrial process that requires the development of larger, more complex control systems and solutions is the Shell Pearl gas-to-liquids (GTL) project in Qatar [3]. This integrated project comprises two offshore platforms, each with 11 production wells, two multiphase pipelines, and an onshore processing complex. When complete, Pearl will produce multiple finished products, including enough fuel to fill over 160,000 cars a day and enough synthetic base oil each year to make lubricants for more than 225 million cars. The control system for Pearl is correspondingly large. The control room comprises almost 1,000 control cabinets hosting 179 servers, programmed with 12 million lines of software code. Almost 6,000 km of control wiring extends throughout the plant. Advanced control solutions will need to be correspondingly larger scale and more complex. For such mega projects, the total number of sensors and actuators will be in the hundreds of thousands.

Other Application Challenges

New possibilities for control exist in areas where manual control is still heavily used. One possible application is drilling for natural gas or oil, which is extremely costly, especially when done offshore.

A promising application related to energy savings and carbon emissions reduction is climate control in buildings. Although this application is not strictly speaking process control, members of the process control community perhaps possess the most relevant knowledge.

Most processes in the electrochemical industries offer promising opportunities for a control engineer to make an impact. An example would be lithium-ion batteries, which have huge built-in inefficiencies that limit their widespread application in the automotive industry unless government subsidies are available. Other examples would be micro fuel cells and high-efficiency solar cells, where a major limitation has been the inability to manufacture reliable products (low yield). The potential impact of control in these areas could be significant.

Several problems exist in the steel-making domain where the use of advanced control methodologies may have a significant impact, such as looperless tension control in rolling mills for long products and electric arc furnace model-based control.

Process intensification efforts, such as Eastman Chemical collapsing an entire chemical plant into one highly integrated process unit, could introduce intentional unsteady-state operation, providing a research opportunity for the process control community.

Opportunities for Research

The application challenges discussed above provide excellent opportunities for research. Some of these research needs are discussed below.

Generating Good Process Models at Low Cost

This pursuit may sound like an oxymoron, but many consider it to be the holy grail of control—especially in the process industries where fundamental models are often extremely complex and expensive to obtain. A method of developing good low-cost process models could open up a host of new applications for APC. New plants are increasingly using training simulators that include faithful models which are valid over large operation ranges. Deriving "low-cost" control-relevant models from these simulated models is a distinct possibility.

Controller Design for Models Described by Nonlinear Partial Differential Equations (PDEs) and Integro-Partial Differential Algebraic Equations (IPDAEs)

A key theoretical challenge in nearly all process industries is the lack of nonconservative methods for the design of robust controllers for models described by nonlinear PDEs and IPDAEs. Although the finite-time case has been largely solved in recent years, at least for processes with reliable numerical simulation schemes, the infinite-time case is wide open. Much progress has been made in robust control analysis and design for infinite-time linear PDEs, but the amount of conservatism in terms of performance suboptimality and robustness margins has not been thoroughly characterized for many classes of control design methods.

The steel-making domain requires very complicated and detailed models that describe complex physical phenomena, such as steel tandem rolling. The behavior of the dimensions during rolling depends in a very complex way on many aspects/parameters of the process. Mill models typically merge PDEs with look-up tables and nonlinear algebraic relationships. The many approximations that are currently introduced to control the process clearly limit what can be achieved in the control phase. The impossibility of tuning the physical models using indirect information such as forces and torques makes the models unsuitable, and operators tune the controller by trial-and-error.

Control Structure Adaptation

An optimal control strategy structure based on the process model and available inputs and outputs should be employed at all times. Determining the optimal structure for a control strategy is currently part of the "art" of process control, based mostly on experience. Tools are required for solution configuration, a higher level of autonomy, and automated recovery from faults (such as loss of manipulated variables). Control structure adaptation has been used with significant impact in aerospace (reconfigurable flight control with redundancy of control surfaces/actuators). The role of similar investigations in process control must be explored.

New Sensing Technologies

Video cameras and related image-processing techniques look very promising, and applications have been reported by industries that have traditionally lacked online sensors, such as food processing, minerals processing, and pulp and paper. Video sensors can be used for both fault detection and real-time quality control.

Other Remarks

This section focuses on barriers to the application of APC in the process industries.

Technical Barriers

The process control infrastructure in a plant is often insufficient for the implementation of APC. Examples could include insufficient CPU capacity and lack of measured variables, actuators, and actuator authority. Process limitations include too many unknown parameters or a process that is too nonlinear for a “standard” APC solution to be applied.

Obtaining good process models for control remains a significant challenge, especially for processes with high complexity and dimensionality. A significant gap still exists between the capabilities and tools for developing high-fidelity models (in dynamic simulation tools, for example) and the ability to derive “intelligent” advanced model-based controllers from such models in a seamless way. Modeling of processes that contain huge numbers of solid particles in the presence of a liquid, as found in the pharmaceutical industry, are usually much more challenging to model and control than processes that only involve liquids and gases. Such models require a deep understanding of transport phenomena, physical chemistry, and nonlinear PDEs.

Other technical barriers include the lack of robustness/adaptability of control solutions, APC solutions that are difficult to engineer and maintain, difficulty in justifying/measuring economic improvements, poor infrastructure in developing countries, and long distances between the site and the technical office.

Workforce Barriers

The workforce is divided into process control engineers who design, commission, and maintain APC systems and process engineers and operators who are the users of process control solutions.

Barriers for the application of APC among process control engineers include lack of domain knowledge and the inability of most to apply the latest control technology. Domain knowledge is often lacking in the control community, which limits the ability to generate high-impact applications of feedback control theory. Rigorous process modeling relies to a great extent on domain knowledge, which requires process control researchers to get out of their comfort zones. Stationary simulations, which are of limited use for controller design, are commonly used in process design, with dynamic modeling and simulation only done if needed. This practice leads to a lack of skilled personnel.

Only a very limited portion of the control community is able to apply the latest control technology, partly because the level of rigor in technical education is continually decreasing. Applications of model-based control require multidisciplinary skills (control and domain knowledge) and are still a mixture of both art and science. Despite the difficulty of replacing required expertise with tools, most process control vendors invest heavily in tool development, and these tools are becoming a major differentiator among the APC solution providers (Honeywell, ASPEN, and others). Completing huge software engineering projects that adhere to a high standard seems to be a limiting factor in getting applications implemented. The problem is partly due to human resource factors, as when skilled personnel leave and carry away knowledge of the details in their heads.

Barriers for the application of APC among process engineers and operators include lack of advanced control knowledge. The lack of advanced control knowledge among plant personnel is pervasive and results in suboptimal operation and maintenance of APC solutions. The reasons are manifold and include the retirement of skilled staff, high staff turnover, and the employment of new "unskilled" replacement staff. This problem can partly be addressed by making advanced control solutions easier to engineer, operate, and maintain, and by process sites allowing remote monitoring and maintenance by centrally located skilled staff. Industry could live with 95% optimality but not with five different optimization tools in one plant.

Education and knowledge transfer for process control personnel are important for sustaining the success of control applications and for identifying new opportunities for control. The introduction of template solutions with grey-box ID-based tools facilitates knowledge transfer from the development team to the application engineers. New opportunities for traditional APC solutions can be found in upstream processes in the pharmaceutical industry, namely, the organic chemical reactors and separators prevalent in the chemical industry, and process engineers with sufficient control knowledge will be able to identify such opportunities.

Cultural Barriers

Many control engineers incorrectly perceive that their control toolbox is generic enough that the best control design involves simply selecting the right tool from the toolbox. This misperception often leads to a control solution looking for an application, instead of the reverse. Generic control tools usually cannot be applied to the most challenging control problems (it could be argued that this lack of ability to apply generic tools is what defines challenging control problems). In that case, a deep understanding of processes is required to produce a control design method that is robust and reliable for all members of a particular class of process. This cultural problem can be seen in control engineers no matter what their engineering discipline, even though they are supposed to be experts in the processes of their discipline.

Another cultural problem is that many control engineers in academia typically do not formulate feedback control algorithms with the degree of robustness to uncertainties and insensitivity to disturbances needed for implementation in the pharmaceutical and biomedical industries. A hiccup in their processes can result in injuries, casualties, and hundreds of millions of dollars in recalls, lawsuits, and process redesigns. A feedback control algorithm that performs well only 99.99% of the time or requires occasional manual retuning to function 100% of the time is useless in those industries.

Control is still widely viewed as a "service" activity rather than a "core" activity and thus is often not fully appreciated by management. Having a few good reference implementations of advanced control makes selling new projects much easier. Economic justification is crucial for new applications of advanced control.

Cultural differences exist all over the world. In Europe, plants run well already and the awareness of optimization is widespread. However, no investment will be made without good justification. In greenfields plants, it is easier to "add" advanced solutions as long as there is sufficient justification for doing so. Again, having good references makes it much easier to convince clients to implement advanced control.

A significant disconnect often exists between academia and industry. Unfortunately, control at many universities has become more of an applied mathematics subject than an engineering subject. Students are often not prepared to get into the workforce and solve real control problems. Conversely, process control users often regard universities as specialized APC vendors and require a quick project turn-around that is not conducive to fundamental research. However, research activities in process control need to be more focused on addressing industrial problems rather than pure theoretical advances.

Regulatory Barriers

Stricter regulations play a key role in tightening product quality specifications, which normally lead to increasing demand for APC. Conversely, when a clear roadmap for the necessary legal and economic environment is lacking (for example, for CO_2 footprint reduction, energy efficiency, and life-cycle considerations), companies are often not compelled to invest in advanced control. Regulations that are too strict can, however, hinder progress, as was the case in the pharmaceutical industry before introduction of the PAT initiative by the U.S. FDA.

Conclusions

The process industries have historically been a major beneficiary of advanced control solutions. PID auto-tuners, model predictive control, and real-time optimization have all had a substantial impact on the cost, efficiency, and safety of process plant operations. Ironically, though, the success of these technologies is leading (or in some cases has led) to a perception of commoditization. If off-the-shelf solutions are now available, why is more R&D investment required?

In fact, process control remains a vital area of research with substantial opportunities for future impact:

- Although advanced control has been widely adopted in some process industry sectors, many other sectors are just starting to deploy such solutions—as evidenced by some of the applications noted in this section. All process industries have their individual characteristics, so methodologies and techniques must be tailored.

- Advances in control applications are driven not only by advances in control theory. Control solutions are enabled by other technologies, and developments in these areas open up new opportunities. Thus, new sensors (video cameras are a good example), wireless communications, broadband access to the Internet, and increasingly more powerful processors all present new opportunities for impact with control theories and algorithms.

- Control has gradually moved up the plant automation hierarchy from field solutions (PID), to multivariable systems, to higher level optimization. But opportunities for control do not stop there. Little work has been done in the area of integration with planning and scheduling, and especially with enterprise applications. Furthermore, the development of mega projects and the concept of a plant as a node in a larger supply-chain network suggest new horizons for the field.

Finally, while control scientists and engineers must continue to strive to overcome barriers, both technical and otherwise, increasing societal and industry demands for energy efficiency, reduced GHG emissions, more competitive operations, and greater automation and closed-loop responsiveness all promise increasing demand for advanced control and related technologies in the process industries.

Selected recommendations for research in control for the process industries:

- Methodologies, including algorithms, to develop control-relevant process models at low cost would open up application opportunities that are currently not cost-effective for advanced control.
- Determining the structure of a control strategy is an art today and needs to be developed to a science; rigorous control structure adaptation techniques are also needed.
- With increasing integration of process plants and their upstream and downstream connections, new research opportunities have emerged in wrapping closed-loop optimization and control loops around enterprises and supply chains.

References

[1] J. Pereira (ed.). Monitoring and Control: Today's Market and Its Evolution till 2020. Luxembourg: Office for Official Publications of the European Communities, 2009.

[2] Institution of Chemical Engineers, “The Chemical Engineer,” p. 55, Feb. 2009.

[3] “Pearl GTL – An overview” [Online], 6 September 2010. Available at http://www.shell.com/home/content/aboutshell/our_strategy/major_projects_2/pearl/overview/.

Related Content

The Impact of Control Technology report also includes more than 40 flyers describing specific “success stories” and “grand challenges” in control engineering and science, covering a variety of application domains. The ones below are closely related to the topic of this section.

Success Stories

- Advanced Control for the Cement Industry – *E. Gallestey*
- Advanced Energy Solutions for Power Plants – *V. Havlena*
- Advanced Tension Control in Steel Rolling Mills – *T. Parisini and L. Ciani*
- Auto-tuners for PID Controllers – *K.J. Åström and T. Hägglund*
- Cross-Direction Control of Paper Machines – *G. Stewart*
- Ethylene Plantwide Control and Optimization – *J. Lu and R. Nath*
- Performance Monitoring for Mineral Processing – *C. Aldrich*

Grand Challenges

- Process Manufacturing Networks – *W. Marquardt and K. Frankl*
- Supply Chain as a Control Problem – *K.D. Smith et al.*

These flyers—and all other report content—are available at http://ieeecss.org/main/IoCT-report.