Curricular development required to support Adaptive Predictive Expert Control projects and business in industry

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Abstract— **This paper has been written to identify the needs and competencies required for new graduate student intake in a small company dedicated to the design and build of process control systems for a variety of applications in a diverse range of industries. While emphasis has been placed on core technical competencies such as IT (Information Technology), electronics, control techniques, industrial process knowledge, project management and perhaps an ability to relate to diverse and unfamiliar industries from a control perspective, there is also an emphasis on the softer cognitive skills such as communication, presentation and being effective in a team. There should be a recognition among students that base skills will change as the industrial environment changes and new technologies emerge. The combination of skills required should lead therefore to a process of continuous improvement, change and life long learning well beyond the content of the course.**

Keywords- Optimisation, adaptive predictive control.

1. INTRODUCTION

ADEX S.L. [1] is a company based in Madrid, Spain, dedicated to developing optimised control solutions for a wide diversity of clients and process industries including energy (coal fired and combined cycle power stations, nuclear and alternative energies), chemical, cement, waste water treatment, and oil/gas refineries. The eponymous product is based on a world patented technology called "Adaptive Predictive Expert Control ADEX" [4,6] which is implemented in practice either as a software product installed on PC (personal computer) linked to the plant via OPC[1], or within an electronic module (see section 4.2) linked digitally to an industrial PLC (programmable logic controller) in turn linked to the plant. The essence of the service is to make process plant operate more efficiently or optimally by improving the precision of the control of continuous process variables such as temperature, pressure, level, or chemical composition. The objective is to reduce variability or oscillations in these parameters in order to save energy, reduce costs and increase production. In the latter case, improving process stability often has a positive effect on equipment reliability and thermal fatigue problems in pipework thereby reducing equipment downtime and so increase production. The core idea of the methodology is that ADEX combines predictive control (anticipating process dynamics) with adaptive control (tracking the process) resulting in more precise control especially when process dynamics change, by updating the predictive model in real time.

Generally in industry, control solutions employ one of two methodologies; application of the traditional PID[2] algorithm which is the main industrial standard, but designed with rudimentary control in mind, or MPC (model predictive control) [2] which has superior performance but where very precise knowledge of the process is required at the outset. The former method, while understood among the majority of control engineers, works satisfactorily when process dynamics are relatively stable and straightforward. The latter can often deliver superior performance over PID, but usually requires much more work in identifying and understanding the process initially to provide a satisfactory solution with the obvious disadvantage of increased design time and cost. Also, if the operation subsequently behaves in a way not addressed in the model design, problems could result due to the lack of adaptability due to using fixed parameters inherent in predictive model design.

ADEX aims to address these problems of cost and lack of adaptability by offering an adaptive, lower cost solution for processess with complex dynamics, and an efficient means of improving plant performance in key parts of the process to deliver clear cost benefits to the operation as a whole. The ability to deliver individual tailored solutions irrespective of the manufacturer of the original control system offers a clear market advantage, particularly compared to the large scale system upgrades usually offered by the mainstream control system suppliers.

The key to ADEX's strategy is therefore the ability to integrate and interface with existing operating plant, or new design projects in a way that minimises intrusion and maximises effectiveness.

Following an introduction in section 1, section 2 provides some background on the nature of the control speciality in industry and section 3 describes ADEX, the company which provides the control services along with some idea of the range of clients and industries. Section 4 provides an outline of ADEX technology, section 5 provides outlines of six job descriptions and section 6 provides information on General aptitudes which are shared among all jobs. Finally, section 7 lists conclusions with acknowledgements listed in section 8.

2. THE NATURE OF THE CONTROL SPECIALITY IN INDUSTRY

This section describes some of the characteristics of the "control" industry environment which students will be expected to enter upon completion of their studies. Many of the issues and opportunities that can arise from improving control in industrial plant have their origins in the engineering design process which will be outlined very briefly here. Design of industrial plant requires firstly an overall concept definition which leads to the specification of performance requirements for all relevant engineering disciplines including Mechanical, Process, Control and Instrumentation (C&I), Electrical and Electronic, Structural, Materials and Piping.

The subsequent detailed design process consists principally of equipment selection and physical layout design along with interfaces. Equipment is often supplied as stand alone working units, some of which are skid mounted for ease of connection to other equipment, and is the responsibility of individual manufacturers. The main engineering contractor responsible for the overall design and assembly of these items performs the tasks of dealing with the interfaces and managing the whole project. This means that detailed control issues are embedded either in equipment modules or in sensors and actuators, while overall control deals with setting process parameter targets, process monitoring (the responsibility of the SCADA[3] supplier), and perhaps detailed control issues at the interfaces between equipment modules. This fragmented approach adversely affects overall plant performance.

Control engineers will therefore be contributing either at a detailed equipment function level within the equipment supplier base, or at an overall module interface or supervisory level. The specification of control requirements usually lies within the process engineering discipline and defines parameter performance in terms of desired temperatures, pressures, flow rates, liquid levels etc.

For ADEX control engineers involved in both new design projects and optimisation of existing plant, the challenge is to provide effective solutions given very different process environments, often with limited access to control modules built into equipment for reasons of confidentiality or warranty issues.
The design of facilities and the selection of appropriate equipment for process plant mentioned above involves much use of standard engineering tables for sizing and matching to performance specifications covering most engineering disciplines. The tables are designed to be applicable to most operating circumstances, and offer protection against individual engineering error, reduce checking and validation cycles, provide simpler and more reliable quality assurance and harness existing industrial experience as far as possible. Examples include pipe sizing, equipment selection, material selection (for chemically aggressive environments), support for structural support decisions etc. It is only when control precision is business critical, or the process is extremely complex that innovative control solutions are applied in design. The emphasis is therefore on meeting specification and safety standards rather than optimal performance and this mitigates against improved control.

Indeed, budgets are usually tight and the main aim of projects is to complete work as quickly and as cheaply as possible. The bidding process for winning such projects usually leads to competitors removing all but bare essentials and the minimisation of risk from the bid package. This focus on standardisation in design has affected control technologies adversely, particularly as "optimization" is seldom a design requirement since this benefits operating cost (OPEX) as opposed to "CAPEX" or capital cost, the main criteria used for bid selection. While there are sometimes requirements for competitors to bid on "NPV", (e.g. The Schiehallion oil and gas project of Shell [3]), this is a comparative rarity unless the contract is also a lifelong one combining design, build and operation for a single contractor.

3. ADEX THE COMPANY

ADEX S.L, based in Madrid, Spain, was formed in 2005 with the aim of introducing Adaptive Predictive Expert Control technology to process industries both in Spain and abroad. This technology, based on an early (1976) patent by Professor Juan Martin Sanchez, and which, in its current form, enjoys worldwide patents [6], represents a major step forward in industrial control methodology which hitherto has been dominated by the PID algorithm. The company employs 12 engineers in total. The flexible nature of ADEX technology, based on its ability to adapt to continuous process dynamic changes, has made it applicable to a wide range of industries

The following is a list of some typical projects carried out by ADEX. This illustrates the need for diverse engineering skills and knowledge required for projects.

	Steam temperature control in steam turbine for combined cycle plant, Barranco de Tirajana
	Development of control logic for FP7 Flexiburn multi-fuel, oxy-combustion, CO_2 capture project.
	Steam temperature control in attemperation process at the Cockenzie coal fired power station, near Edinburgh, Scotland

[3] SCADA Supervisory Control and Data Acquisition

repsolypf.com	Process optimisation by means of temperature, pressure and level control in a naphtha splitter
repsolypf.com	Sulphur recovery control to minimize H_2S emissions from tail gas at Puertollano and La Coruña refineries.
PEMEX	Sulphur recovery control to minimize H_2S emissions from tail gas at 5 units of the plant at the Héctor R. Lara Sosa refinery in Mexico.
g	Control separation of oil, gas and water.
arcelor	Temperature control in steel making furnace
ASTURIANA DE ZINC	Update of the pH control system in waste water treatment plant at the lixiviation department at the Asturiana de Zinc plant.
MAX	Control functions in MYRRHA - Accelerator eXperiment, research and development program
CRS4 Project	Control of transmutaton reactors including theproton accelerator. CDT, Paris.
ESAMUR	Control and optimization of the biological stage in waste water plant. ADEX controls the nitrification-denitrification sequences.
acciona	Mantain O_2 concentration levels in waste water plant to improve biological efficiency and reduce energy costs at 'La Gavia' waste water treatment plant, Madrid.
SCOTTISHPOWER	Mantain O_2 concentration levels in waste water plant to improve biological efficiency and reduce energy costs at Daldowie waste water treatment plant, Glasgow, Scotland.
UNED	Intelligent building climate control.
Holcim	Control and optimization of the grate cooler in the cement works of Holcim España in Yeles and in Gador, (Almeria).
Tudela Veguin	Control and optimization of the mills in the Tudela Veguin cement works, La Robla

4. ADEX TECHNOLOGY

4.1 METHODOLOGY CONCEPTS

Adaptive Predictive Expert (ADEX) Control methodology has the following three characteristics: (i) anticipates process evolution using a model of the process to apply predictive control; (ii) adjusts the model parameters in real time using an adaptive mechanism in such a way that the prediction error converges towards zero, and (iii) incorporates available process knowledge into the controller operation.
ADEX methodology thus integrates Adaptive Predictive Control (APC) [5] and Expert Control [4] in order to provide a control solution able to apply expert control when available and adaptive predictive control when appropriate, thereby optimizing the global process operation. ADEX combines APC with Expert control using domains of operation defined for each of them in an integrated setup. The evolution of process variables determines whether APC or Expert control should be applied to the process [4].

The Adaptive Predictive (AP) domains are those in which the dynamic cause-effect relationship between the input and output process variables can be identified in real time by means of a time-varying model driven by an adaptive mechanism. In these domains, APC can be applied, and the process operation is thus optimized.
ADEX enables the application of expert control in certain domains of operation where manual control can provide a more robust and efficient control than APC. Operator experience is used to develop the rules imitating manual control intelligence that will drive the process output from the expert domain towards the AP domains.

4.2 ADEX CONTROLLER MODULE

The ADEX Controller Module (ADEX CM) has been developed to bring ADEX technology closer to PLC control level and offer a more robust industrial solution.

The ADEX CM robust solution requires the control strategy to be written on the PLC control program that includes ADEX controller graphical operators, but the corresponding code to execute these controllers is installed inside the ADEX CM, which essentially is a fully protected enclosed coprocessor with digital links to the PLC. The controllers in the ADEX CM can be executed by the program in the PLC as determined by the corresponding ADEX controller operators.

The ADEX CM, in addition to containing the coprocessor that executes the ADEX controllers, also contains functions necessary for power, communications with the PLC which are via RS-232 or RS-485 and support to a USB link for configuration purposes as shown in Figures 2, 3 and 4.

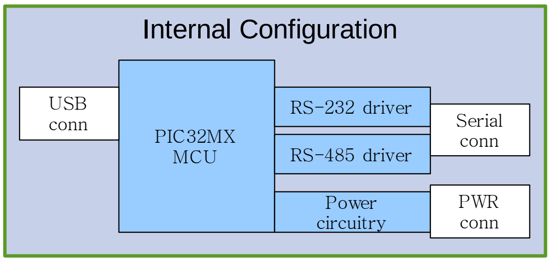

Figure 2: Block diagram showing internal configuration of ADEX CM

Figure 3: Photograph showing ADEX CM in plant

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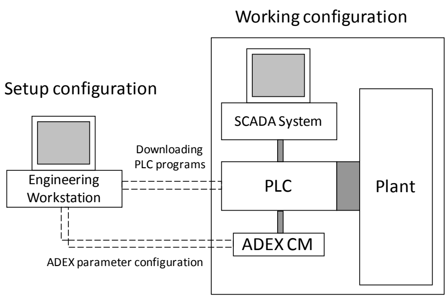

Figure 4: Diagram showing the set up and working configurations for the ADEX CM

Figure 4 shows both the working and setup configuration of the ADEX CM. To the right of the figure, the working configuration shows that the ADEX CM is connected only to the PLC which is connected both to the plant (actuators and sensors) and to the SCADA system which displays variables graphically. At the outset, or whenever required, an engineering workstation can be connected in order for an engineer to configure the ADEX CM parameters, or program the PLC control logic to include the control strategy. In the case of Cockenzie (see section 3), the PLC and SCADA system were already part of plant operation so the addition of ADEX involved using all the same equipment and indeed PLC functions, with the only addition of the ADEX CM.

5. JOB DESCRIPTIONS

For the purposes of this exercise, six jobs have been defined covering the main technical areas required by ADEX. It is recognized that the students will not come with much, if any, industrial experience, so the requirements have been refined accordingly. Although the engineer is referred to throughout the text as 'he' this means 'he' or 'she'. These jobs are:

- Control Engineers I and II
- Process Engineer
- Electronics Engineer
- IT Specialist
- Operations Analyst

This particular blend of disciplines has been selected in order to provide the width of knowledge necessary to carry out ADEX projects reflecting the needs of industry as described in section 2. The blend is also selected in the expectation that there will be a degree of overlap between the team members in terms of their knowledge, but at the same time, the differences will provide a blend of approaches which will enrich the quality of the final results. This section describes something of the emphases and overlaps between these disciplines.

The first two jobs, Control Engineers I and II, have a control engineering bias obviously, but with a different emphasis. Control Engineer I provides expertise on control method and on control strategy to be employed in a particular application including definitions and adjustments of control parameters using, among others, the ADEX Development platform ADEX COP [7]. The main activity for Control Engineer II is the production of software simulation models of processes in order to help determine/understand process dynamics, parameter interactions and control strategy from a process perspective. Here, the area of overlap between Control Engineers I and II is the control strategy. Once the process simulation model is verified, possibly using the existing controls in place if the process already exists, a new ADEX control strategy can be tested using ADEX controllers in order to demonstrate any improvement and so justify replacing the existing controllers.
Control Engineer II is unlikely to have knowledge of the range of processes which ADEX deals with, but in certain industrial areas (currently various types of power stations and alternative energy sources such as wind and wave power), there would be benefit in employing a person with more detailed knowledge of these industries. Other industrial examples include chemical and pharmaceuticals. Often, it is the clients of ADEX who provide that expertise. The overlap between Control Engineer II and the Process Engineer would clearly be in the area of process definition with the Control Engineer II concentrating on process modelling issues while the Process Engineer concentrates on actual process dynamics. It is likely that the Process Engineer will have a slightly more practical interest while the Control Engineer II will have more of a mathematical approach.

The Electronic engineer is required as some of the ADEX solutions need to be physically integrated into plant. Some applications can work satisfactorily with ADEX control being provided via OPC where all of the ADEX operations are contained and deployed using PC based software and so do not require Electronics Engineering input. The ADEX CM module, described in section 4.2, is an example of a control module whose design required considerable electronic engineering work and team coooperation with IT programmers and control specialists. It is likely that ADEX will require to design and produce more such modules for different applications and industrial environments.

The IT (Information Technology) specialist provides the structured and disciplined programming expertise required by the group. It is very likely that all members of the engineering team are able to program, but not necessarily with the degree of quality and maintainability required for trouble-free performance. Programming may be required on industrial PLC's and on PC's in addition to the ADEX CM control module. Other areas of programming requirement could be adjustments and additions to SCADA screens for graphical output of process parameter values over time. There will also be a programming requirement for user interfaces to ADEX strategies on PC or on the ADEX CM.

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Finally, the Operations Analyst is added to provide a view of overall plant function, including economics, designed to address the specific role of ADEX products and services in an optimization context. This person will be able to help make proposals and define opportunities for improvement within industrial plant including non-control factors which will influence success. These factors may include equipment updates without which improved control alone may not deliver the desired results. Project success will also depend on how these engineers interact in a project environment.

It should also be mentioned that ADEX is organised into two technical departments: Applications and Systems. In general, Applications deals directly with clients and focuses on projects, while Systems provides the necessary tools and background work required to support ADEX projects.

The following is a brief description of each job. It can be assumed that all positions will require very good knowledge of ADEX methodology as a base, although further training will obviously be provided.

Control Engineer I – Works on control applications reporting to the Applications manager. Provides specific expertise on control methods and algorithms and is responsible for generating control applications using either the ADEX COP development platform or configuring the ADEX parameters within an ADEX controller module. He will also be generating control strategies as well as adjusting the parameters of ADEX controllers. In the event of the application requiring a backup controller on PLC, he will also be required to produce a backup PID controller. Qualification requirement will be an Electrical or Electronics degree containing a good background in general industrial subjects.

Control Engineer II – Main responsibility is the generation of software simulation models of plant in the event that either the process is inaccessible, new/ innovative, possesses a dynamic which can only be studied in a simulated environment or, for safety or cost reasons, requires simulation as a precursor to real plant trials. The creation of a credible simulation model requires a broad and deep understanding of the process in question, specific control issues, and equipment performance. Some processes may be very specialised, since ADEX tends to be involved in processes which are not necessarily susceptible to standard control techniques. This person will likely be qualified to MSc or PhD level. He will be familiar with MatLab Simulink but will probably have to use or at least interface with other simulation packages. He will be responsible to the Systems Manager.

Process Engineer – This is a general title for engineers who are likely to have specific interests in one or more process industry sectors. Generally, these engineers work within a limited number of process areas which require particular specialist knowledge, but since ADEX is involved in a number of different industries, it is required to have an engineering group capable of understanding processes such as those in power generation, waste water treatment, de-salination, alternative energies, aerospace, various chemical processes (including distillation columns), welding processes, oil and gas production including refineries plus others which may offer business opportunities in future. The process engineer will be required to have at least enough knowledge to be able to have an intelligible conversation with the client, managers, site engineers and operators as well as be able to translate process requirements into control solutions either alone or in conjunction with the control engineer assigned to the project team. The qualification will likely be to degree level and either be of a general industrial nature, or applied chemistry. The electrical and electronic engineers also receive some background of a general engineering nature. For a recent graduate selection point of view, the issue will be about adaptability and basic knowledge to allow fast entry into understanding unfamiliar processes irrespective of the type of engineering qualification.

Electronics Engineer – Due to the nature of the ADEX product, and driven by the need to integrate solutions into existing client operations hardware and/ or existing designs, there is an increasing requirement to build controllers and control strategies into a hardware environment that is compatible with those already in place or with newer hi-tech processes. These hardware solutions are growing in sophistication and give rise to the need for electronics engineers who can harness the latest in industrial communications technologies which could currently include Ethernet, Modbus, RS232, RS485, Profibus, Profinet, Ethernet/ IP etc. He would be expected to be able to program micro controllers and design FPGA applications. Overall, this engineer will have to be conversant and expert in the hardware and systems environment of the industries where ADEX is involved, and as more applications and products are developed, a wide range of electronic products will emerge built specially or adapted to suit. He will be in possession of an electronics / electrical degree.

IT specialist – This person, similar to the electronics engineer, will be responsible for developing internal (to ADEX) software and providing specialist assistance to the process of integrating ADEX solutions in client industry environments. He will have expertise of programming in C, Linux, able to program a range of industrial PLC's, and should be able to assemble or adapt SCADA screens which normally have to be altered to accommodate extra ADEX information. Knowledge and discipline in working to the appropriate industry quality standards would also be a pre-requisite. It is likely this person will also be qualified to degree level in an IT related subject, but consideration could be given to persons with great expertise who may not be fully qualified.

Operations Analyst –This job has been added in recognition of the need for optimisation products, albeit electronic ones, to be firmly founded in plant economics. The term "operations analyst", in this context, emerged from the oil industry, and was focused primarily in the area of improving plant-wide efficiency, reducing costs by reviewing work practices, minimising energy consumption, de-bottlenecking production processes, ensuring maintenance and risk based inspection were both optimised (i.e. minimising unplanned failures as much as possible at minimum cost). Since one of the largest challenges in any production facility is avoiding down time as far as possible, equipment performance should operate as close as possible to design, and part of that is determined by the efficiency of the control system. The control system can be adversely affected by faulty valves or sensors, pump wear, and deterioration of rotating equipment in general. This discipline therefore will perform a number of roles depending on the point of view of the client. A total optimization service can be offered which embeds the control part, and so ensure that the whole system of actuators, process and sensors will deliver the desired optimization. It could be that the reforms required are so great that the benefits will not be sufficient to cover costs. The advantage of this holistic approach is that this can be determined at the outset at minimum cost to the client. Other engineering activities such as valve change out, can either be subcontracted by ADEX or left to the client to manage separately. The Operations Analyst's prime contribution would be cost benefit analysis, identifying improvements and cost consequences which permit attractive proposals to be made by ADEX with risks clearly defined and permitting a different type of relationship with the client; more of a partnership. The base skills required, apart from general engineering, would be ability to analyse operations logs, maintenance and inspection records, be able to understand, analyse and interpret reliability data, fault registers, extract and classify production outages (from operations logs) and be able to assess the impact of control on equipment and vice versa.

6. GENERAL APTITUDES

This section deals with general aptitudes and attitudes of the students and although some things are naturally inherent to individual personality, there are many attributes which can be taught and could therefore be reasonably included in an education/ training program by way of preparation for industry. The combination of skills and disciplines outlined above are intended to form the basis of a team which can work together to provide a total service to clients in the area of control optimization or rather, plant optimization using stable and precise control as a base line starting point. It is likely that all of the candidates will have a wide range of capabilities and interests, and the intention in drawing up this combination is not intended to be rigid but to provide guidelines as to the range of skills required and the likely source of these skills in a standard curriculum as was found in the UNED web site.
Based on this, the key success factor will be the ability of the team to work together, and the following is a list of the most useful characteristics:

- Ability to learn new techniques.
- Ability to work in a team of diverse individuals with complementary skills.
- Presentation skills. Able to project ideas succinctly.
- Report writing and English language skills.
- Creative, problem solving. Able to view problems from different angles.
- Personal work organisation, initiative.
- Ability to relate at a personal level with various industry responsibility levels and to communicate appropriately from plant manager to shift supervisor down to operator and other support staff.

7. CONCLUSIONS

This paper has outlined some of ADEX's business environment and described some key technical areas where engineers, based on a review of University Curricula from the UNED, could be expected to fill roles within the company. It is not expected initially, that recent graduates would work unsupervised, but given the required level of technical competence in the areas indicated in section 5, Job Descriptions, and taking into account the personal attributes listed in section 6, General Aptitudes, and given an adequate level of supervision, engineers could within a year or two, gain sufficient skills to be able to progress in the company.

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