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Industry Expectations and Academic Practice in Control Engineering Education – A South African Survey

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Abstract: This paper presents an overview of the South African control systems landscape. It focuses on control engineering taught at universities and practiced in industry in South Africa and was compiled in the wake of the IFAC world congress 2014 in Cape Town. A background of engineering education in South Africa and control engineering in particular is presented. Two surveys were conducted among control engineering professionals: The first survey covers control engineering courses offered at South African universities at electrical, chemical and mechanical engineering departments. The second survey investigates control engineering in the workplace. A gap analysis maps industry expectations and university offerings.

Keywords: Control engineering; engineering education; South Africa; control industry; control courses.

1. INTRODUCTION

Control engineering stretches over many industries, applications and even engineering disciplines, uniting the classically separated chemical, electrical and mechanical engineering fields. The application of control systems spans the wide range of mechanical, chemical, physical, biological and even economic systems. In this paper we are studying control engineering courses at academic institutions and control engineering industry needs in South Africa, analysing the gap between the two.

1.1 State of the South African Engineering Profession

In 2012, the Royal Academy of Engineering (RAE) conducted a study on engineering in sub-Saharan Africa (Matthews et al., 2012), arguing that engineering capacity is essential to the economic and social development of any country. It found that the region suffers a severe and chronic shortage of engineering skills and that there are insufficient numbers of engineers graduating to meet demands in most sub-Saharan African (SSA) countries.

Compared with other SSA countries South Africa has high quality engineering resources – at academic institutions, as well as at industrial and professional engineering bodies. For example, the South African Council for Automation and Control (SACAC) is the only national member organisation of IFAC in SSA and one of only two national member organisations in all of Africa.

However, there is a shortage of engineering capacity in South Africa, too. A study of the South African Institution of Civil Engineering conducted in 2005 found that in South Africa in the early 2000s the number of engineers emigrating annually matched the number of graduate engineers (Lawless, 2005). The brain-drain continues but since then has somewhat slowed down. The RAE study found that 40% of professional engineers in Sub-Saharan Africa think that the engineering education did not provide the skills that graduates required. A similar study conducted for South Africa alone (Mkele, 2013) reported similar results:

- 43% of more than 700 South African engineers surveyed feel that engineering degree programmes do not train students sufficiently;
- 26% of the respondents saying they may not remain in this country for the foreseeable future;
- The Engineering Council of South Africa (ECSA) found that currently one engineer services over 3 000 people in South Africa compared with 227 in Brazil and 543 in Malaysia.

A recent study on the challenges in engineering education in South Africa found similarly that there is a dire need for engineers (Case, 2006). The reasons are to some extent historical – white minority rule under apartheid only ended in 1994 – but even since the early 2000s there has been only a minor increase in the number of engineering students and graduates.

1.2 Control Engineering Education

Within the last century or so control systems technology has evolved from a basic concept into an engineering discipline that is applied to uncountable problems of automation and taught at universities around the globe. An overview of curricula and a historical perspective of control engineering are given in Kheir et al. (1996). A survey by the IEEE Control Systems Society provides a list of recommendations for control engineering syllabus. A key recommendation is to expose students to more in-depth control courses at an undergraduate level and to introduce control as a mandatory subject (Antsaklis, 1999). A more recent review by Bencomo (2004) gives a literature overview on control engineering education and also highlights the importance of interactivity as well as the role of recent internet-era technology developments in teaching control and how it can be applied.

Some universities have over the years established major control centres where breakthroughs and developments happened. Thus, the description of the course at Lund University by Åström and Lundh (1992), though dated, provides valid guidelines for any control syllabus and we will later draw some comparisons to our study.

1.3 Motivation

The aim of this paper is to take stock of control systems engineering capacity in South Africa, at universities and industrial organisations. We want to highlight the strengths but also point out gaps between how control systems engineering is taught at universities and how it is applied in industry. Do control engineering graduates meet industry standards and needs? What is taught at university level? Is everything that is currently included in a standard university control systems syllabus still relevant? The lessons reach beyond South Africa since control systems engineering is taught in more or less similar fashion at institutions globally.

Braae et al. (1996) provided an overview of the academic institutions teaching control engineering in the 1990s, as part of a series describing control engineering education in various countries. We give an update of the information on academic institutions but also expand the scope by including information on syllabus and contrasting it to industrial needs.

In this paper, results of two surveys are presented. First, a survey of all control engineering courses in South Africa gives an overview of control engineering education. How many hours is control taught at what institutions? Second, a survey of industry needs answered by the most important South African control engineering companies is presented. The paper is organised as follows. We first present and discuss the results of the academic survey in Section 2 followed by the results of the industrial survey in Section 3, including a comparison of the two studies in a gap analysis. We discuss the implications of the gap arising between academic offerings and industrial needs.

2 SURVEY OF CONTROL ENGINEERING COURSES IN SOUTH AFRICA

In this section we present the results of an online survey that was distributed to all control engineering lecturers in South Africa. To place the results into context we will briefly describe the engineering education system in South Africa. An in depth study of the current issues and trends in engineering education in South Africa are given in Case (2006) and a response describing engineering paradigms in South Africa is given in Case and Jawitz (2003).

The accreditation body in South Africa is the Engineering Council South Africa (ECSA) which carries out accreditation on behalf of Council of Higher Education (CHE). ECSA distinguishes between 'engineering' degrees and 'technology' degrees where engineering degrees are taught at university level and technology degrees are at what used to be called 'Technikons' which are comparable to the German system of 'Fachhochschule' or the former UK 'Polytechnic'.

The focus of the survey is on university or 'engineering' degrees. Engineering degrees are taught at undergraduate and postgraduate level. The undergraduate degree is the four year Bachelor of Engineering (BEng) degree, at some universities it is a Bachelor of Science (BSc) degree. The postgraduate courses are one or two year and are called Honours (BEng Hons) or Master of Engineering (MEng). The 'technology' degrees are National Diplomas (NDip) and Bachelor of Technology (BTech). Engineering and technology degrees are parallel education paths.

South African universities were re-structured in the years between 2001 and 2004 (Barnes, 2009). Before the end of Apartheid in 1994, South Africa supported 36 higher education institutions which were financially unsustainable. In the early 2000s, many of these institutions were merged based on location with the result that most universities mentioned in this paper comprise several campuses. However, control engineering at 'engineering' level is – without exception – taught at only one campus at each institution. Today, there are eight universities teaching control at engineering level.

Students are admitted to university after finishing high school ('matric'). The prospective student must apply to each university individually. There is no central admission or allocation system. The choice of university for students may depend on the tuition fees which range from US$3000-US$4500 per year. The academic year for all classes starts in February, the South African summer, and ends in November. The academic year is split into two semesters.

2.1 Survey description

The survey captures all control engineering courses in South Africa. A list of courses was compiled before sending out the survey in June 2013, based on university yearbooks and verified by members of the South African Council for Automation and Control (SACAC). In total, there are approximately 40 control engineering courses taught by about 20 lecturers. There are about 20 more control lecturers teaching control technology at BTech and NDip level.

The survey was implemented as a Google form and the link was distributed by email to all control engineering lecturers. The survey questions covered three aspects:

- Students taught: Which engineering discipline, how many and at what level;

- Course teaching method: Laboratories, guest lectures, site visits, text books used, course description and comments;
- Course syllabus: A list of checkboxes containing distinct topics such as 'root locus' was provided for conformity of the answers.

The survey was sent out to all lecturers and the return rate for the undergraduate degrees was 80% while the response rate for the postgraduate courses was 90%.

2.2 Survey results

Fig. 1 shows a map of South Africa indicating the location of the universities at which control engineering is taught. The bars next to the university location show the expected number of graduate in 2013 for the different engineering disciplines for which control engineering is a mandatory component: electrical, mechanical and chemical engineering. Most mechanical engineering students are taught control by electrical engineering lecturers.

Note that there are three universities in the geographically small province 'Gauteng': two in Johannesburg – University of the Witwatersrand (Wits) and University of Johannesburg (UJ) – and one in Pretoria, the University of Pretoria (UP). Despite its size, Gauteng is the most populous province (12.3 million people) and generates 7% of the GDP of Africa.

Fig. 1 indicates the control courses taught at undergraduate level. Only some universities offer postgraduate courses in control engineering: University of Pretoria, Wits, Stellenbosch University and the University of Cape Town. In other institutions, postgraduate students may focus on control engineering as part of their research project but no postgraduate courses are provided. Postgraduate courses are comparatively small – ranging from five students to 16 students at the University of Pretoria, mechanical engineering.

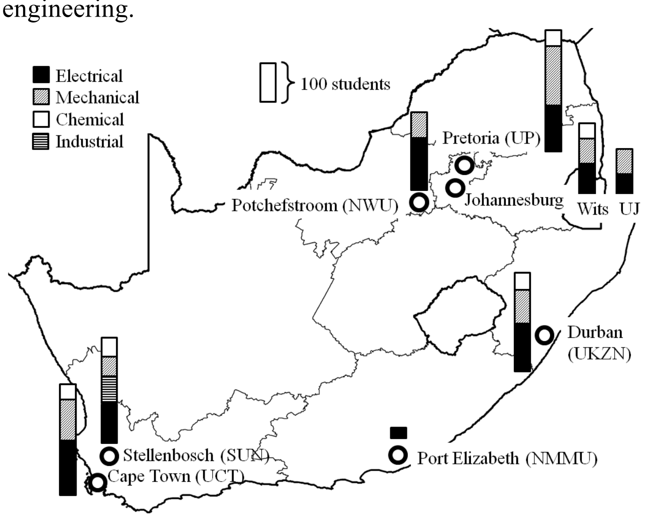

Fig. 1. Number of control engineering graduate students in 2013. UCT – University of Cape Town; SUN – Stellenbosch University; NMMU – Nelson Mandela Metropolitan University; NWU – North West University; UKZN – University of KwaZulu Natal; UP – University of Pretoria; Wits – University of the Witwatersrand; UJ – University of Johannesburg.

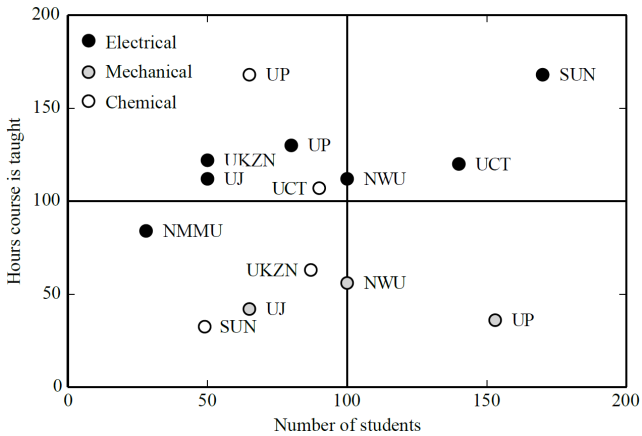

Fig. 2. Number of students and exposure of undergraduate control engineering courses. (University abb. see Fig. 1).

Fig. 2 shows a more detailed view of the courses offered by plotting the number of students taught and number of hours that the courses are taught in total, including lab sessions and case studies. The figure provided is the minimum that each undergraduate student is exposed since all the courses listed are mandatory. This view may be interpreted as a quality measure of the course: fewer students and more hours teaching control gives the lecturer greater leverage and the students more exposure to control. So courses in the top left quadrant will potentially be more attractive. From Fig. 2 it can also be noted that electrical engineering students are more exposed to control engineering than mechanical students and that class sizes in general are smaller for chemical engineering students.

In the following, we discuss common control topics taught at universities and speciality areas at certain institutions and draw comparisons to a control curriculum survey that was conducted by the IEEE Control System Society in 2009 (Cook and Samad, 2009). Secondly, a compilation of textbooks used in control engineering education is presented.

2.2.1 Course contents

In the survey, a list of course contents were given to the control course lecturers to ask whether the course was covered. The results are presented in an overview comparison with industry in Sec. 3. All control courses have their own flavour. The under-graduate courses at North West University and Stellenbosch University (SUN), electrical engineering, focus on classical control theory. A number of courses focus on process control – SUN engineering, University of Johannesburg, electrical engineering, as well as University of Pretoria, chemical and electrical engineering.

An interesting finding is that certain topics appear to be more relevant for chemical engineers, namely sensors and measurement systems, actuators as well as advanced control strategies such as multivariate control and interaction, cascade control loops, Smith predictors, ratio controllers, split range and DMC. Electrical engineers tend to focus more on state space control and digital control as well as phase lead and lag compensator design and nonlinear models.

Table 1. Textbooks used in South Africa for control engineering education.

Burns, R.	Advanced control engineering	General
Dorf, R.C. and Bishop, R.H.	Modern control systems	General
Franklin, G.F., Powell, J.D., Emami-Naeini, A.	Feedback control of dynamic systems	General
Friedland, B.	Control system design: An introduction to state-space methods	General
Gopal, M.	Digital control engineering	General
Kirk, D.E.	Optimal control theory	Process control
Kuo, B.C., Golnaraghi, F.	Automatic control systems	Mechatronics
Luyben, W.L.	Process modelling, simulation and control for chemical engineers	Process control
Marlin, T.E.	Process control: Designing processes and control systems for dynamic performance	Process control
Nise, N.	Control systems engineering	Mechanical engineering
Ogata, K.	Modern control engineering	General
Phillips, C.L. and Nagle, H.T.	Digital control system analysis and design	General
Roffel, B., Betlem, B.	Process dynamics and control	Process control
Seborg, D.E., Mellichamp, D.A., Edgar, T.F.	Process dynamics and control	Process control
Skogestad, S., Postlethwaite, I.	Multivariable feedback control	Process control

Control engineering, like all engineering disciplines, is creative and practical. Engineers ‘build’, ‘create’ or ‘design’. Consequently, laboratory session that provide hands-on experiences are essential. In South Africa, the lab sessions are predominantly conducted in Matlab (90%). Other implementation environments such as Python, Octave, Mathematica and C also play a role. Some departments provide physical hardware that represents the system to be control, such as a ball-and-beam system.

2.2.2 Text books

The frequently cited and well researched review on control systems engineering education (Kheir et al., 1996) gives an indication of which textbooks were used in control courses around the world almost two decades ago. The academic survey conducted for this paper found that most of the textbooks are updated versions of the textbooks listed in Kheir et al., see Table 1.

At some universities the cost of textbooks plays an important role since students come from previously disadvantaged backgrounds and are struggling to make ends meet while studying. A future effort among control systems lecturers could be to standardise the textbook used to bring down the cost or make textbook like lecturing material freely available.

2.3 Discussion

Control courses at South African universities follow very much the same syllabus, textbooks and laboratory sessions as other universities internationally. An emphasis on process control in a number of courses can be noted. There is a clear distinction between electrical and chemical engineering departments. Mechanical engineers in general are less exposed to control engineering.

The force behind control engineering education in South Africa is weak in comparison to other countries. At Lund in 1992, there were 280 electrical engineering students alone and about 100 chemical and mechanical students each (Åström and Lundh, 1992). There were six full control professors in the department alone while there may be one or two at any South African university, added by lecturers and senior lecturers. In fact, there are about the same number of full professors in South Africa. The low numbers of control engineers in closest proximity means that there is a strong need for collaboration – cross-country, international and with industry.

3. SURVEY OF CONTROL ENGINEERING INDUSTRY IN SOUTH AFRICA

Control engineers worldwide are employed in a variety of industry sectors. Even though South Africa is the largest economy in Africa, only some of these industry sectors are significantly established, mainly process and manufacturing industries and defence. Apartheid promoted certain engineering disciplines, in particular military and defence (Case, 2006). This is still reflected in the work of universities and government supported research institutions such as the CSIR (Council for Scientific and Industrial Research) which employs 3,000 engineers and scientists.

South Africa is a resource rich country with large occurrences of gold, platinum, coal, iron and other minerals (Yager, 2008). There is a great potential for process control engineers to automate and improve the many production processes. In addition to mineral resources, the warm climate allows the growth and harvest of large forests and thus supports a significant pulp and paper industry with SAPPI and Mondi as key global companies. Oil and gas refineries can be found along the coast line. However, 60% of the exports are natural resources with very little value added.

Control engineers are employed by a variety of companies, ranging from large multinationals, such as SASOL, to medium-sized businesses and small consulting firms. Often, expert knowledge is imported from overseas due to the shortage of skilled engineers. For example, BMW as well as Volkswagen have production plants in South Africa, but the development and research is undertaken at headquarters in Germany. Many control engineering multinationals, such as ABB, Endress+Hauser, Festo, Honeywell, Rockwell and Siemens have their local headquarter in the province of Gauteng which is the economic heart of sub-Saharan Africa.

In the following sections we describe the survey sent out to industry and present and discuss the results. To our knowledge, there is no overview of the control engineering industry in South Africa, carried out by either academic institutions or industrial research bodies. In fact, a 2013 initiative by the Engineering Council of South Africa (ECSA) and the Departments of Higher Education and Training (DHET) and Economic Development (DED) call for a general engineering skill survey in general since "there is no reliable set of statistics guiding our decisions on engineering skills development.".

3.1 Survey description

The survey was implemented as a Google form and the link was distributed by email. The survey was distributed to 55 individuals within identified companies; 20 responses were received. The survey consisted of 21 questions covering the following topics:

- Size and type of the organisation: How many employees does the company have? What industry does it operate in? Is it a control system user or supplier?
- Number of control experts employed: How many control engineering and control technology graduates are employed?
- Expectations of growth in staff numbers: How many control engineers is the company expected to hire in the near future?
- Attitudes towards the quality of control education offered in South Africa: How satisfied is industry with the quality of control engineering graduates? What skills are graduates expected to have?

3.2 Survey results

Out of the 20 responses received, ten of the answers were from organisations with less than 100 employees; the number of control engineers employed ranged from 1 to 200. Eight of these responses were from end users, while six were from suppliers or consultants. Key findings of the survey are:

- 84% of respondents stated that control and automation is very important to their business, and
- 80% of respondents expected to be hiring more control engineers in the near future.
- On average respondents expected to double staff numbers in the near future.

The degree of support reported by industry for educational institutions is encouraging, with 60% of respondents reporting they support one or more institution; 50% of organisations support more than one university. Fig. 3 shows the result of the question: how satisfied are you with the quality of graduate engineering and technology control engineers? The answers are positive especially in the light of the survey cited in Mkele (2013).

Practically all respondents stated that engineering and technology graduates require a number of years of training before they are useful. 55% of those surveyed agree that the engineering curricula meet the needs of industry, while 45% feel the same about the technology curricula.

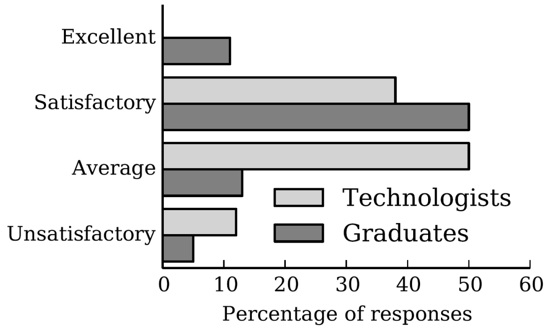

Fig. 3. Industry perception of control engineering graduates.

An essential part of the survey was to ask the respondents about curriculum topics that should be included in a typical control engineering syllabus. Fig. 4 shows the results of this question and compares this with the content taught in South African control courses as described in Section 2. The graph distinguishes between post and undergraduate courses.

An immediate observation of this comparison is that control courses focus on the mathematical background such as system modelling, identification and control theory, while industry expect that the student knows about more practical issues, such as instrumentation, PID tuning and troubleshooting as well as automation architecture. A topic that seems to be 'over-taught' is state space control theory that is part of many under- and postgraduate courses.

A comparison as shown in Fig. 4 begs the question whether industry should dictate what is taught at university. Most engineers will work in industry and an important role of universities is to prepare for the workplace. The RAE report on engineering capacity in sub-Saharan Africa (Matthews et al., 2012) recommends that universities routinely review and update engineering curricula to meet industry needs. Fig. 4 may indicate that control engineering lecturers should consult industry to make sure that the contents taught prepare the students optimally for a successful career in control systems.

Respondents were asked what software control engineers used in their work environment and what software should be taught as part of the engineering curriculum. The most notable requirement is proficiency in the MS Office software in particular Excel. In terms of programming, Matlab is the preferred language and C or C# are also frequently used. Other software tools required are Database/SQL, CAD, G2, Aspentech, Python and Visio.

3.3 Discussion

In 2009, Cook and Samad published a survey on the international academic and industrial control engineering landscape. Surprisingly, the perception by industry of the quality of South African control engineers is very much in line with the findings of Cook and Samad. Possibly, South African industry has an even better perception: International

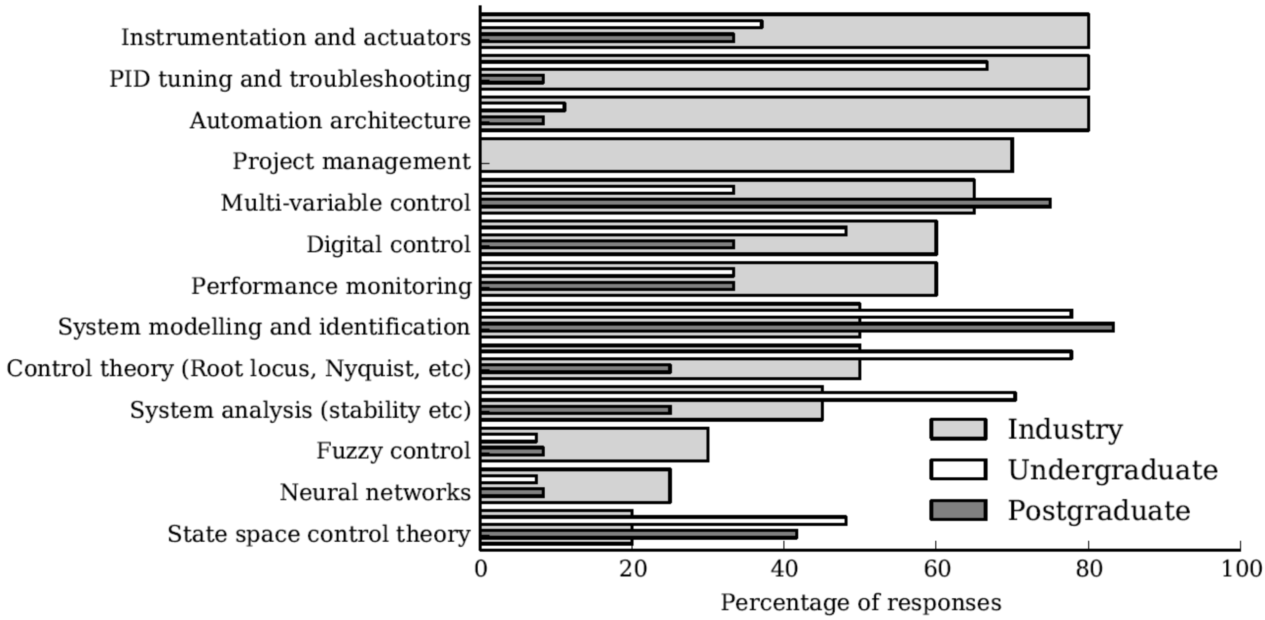

Fig. 4. Control engineering topics expected by industry and taught at South African undergraduate and postgraduate level.

industry thought that only 4.6% of graduates where excellent, compared with more than 10% in South Africa.

However, there is appears to be a gap between what industry wants and what is taught. The syllabus on average seems to be focusing on methods rather than application issues, such as instrumentation or automation architecture. This may be an international trend as the control courses follow very much the standard syllabus taught internationally (Cook and Samad, 2009). This hypothesis is supported by a recent ISA guideline to define an undergraduate engineering degree in automation (Rhinehart, 2007). Despite this taskforce and ISA initiative, there is still no automation degree in the US.

4. CONCLUSIONS

Control engineering and engineering in general is in high demand in South Africa. There is a skills shortage but also a thriving community at academic institutions, professional bodies and industry that aims at filling the gap. Due to the scarcity of skills control engineers have to work close together and build bridges across physical locations, disciplines and between academia and industry. A recommendation for universities is that the control engineering syllabus should be reviewed on an on-going basis by industrial experts. In the long-term, an increase in engineering capacity is required to step up the added value to raw materials. Because of the wealth of resources the control engineering application potential in South Africa remains largely untapped.

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