Control Systems Group, Department of Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa

In this issue we talk with Ian Craig and Derik le Roux about the activities of the Control Systems Group in the Department of Electrical, Electronic and Computer Engineering (DEECE) at the University of Pretoria (UP), South Africa. Ian is the current Group Head and featured in one of the early IEEE CSM columns on "People in Control" (IEEE CSM, Vol. 27, Issue 5, October 2007). Derik joined the group in 2016 and is currently an Associate Professor in the DEECE.

CSM: Can you provide a brief overview of the UP Control Systems Group?

Our Control Systems Group is one of eight research groups within the DEECE at UP. The activities of the group include undergraduate and postgraduate teaching, research, and community service. At an undergraduate level we are responsible for teaching a 3rd-year course on the fundamentals of control systems to about 250 students, and a 4th-year course on process automation to about 120 students. In addition, we supervise about twenty 4th-year capstone projects each year. Postgraduate teaching includes the presentation of courses on Multivariable and Optimal control. Our research focus is predominantly on knowledge production in the field of applied process control, which is mainly done via the training of Masters and PhD students. As regards community service, group members are heavily involved in the activities of the International Federation of Automatic Control (IFAC) (https://www.ifac-control.org) and the local IFAC National Member Organization, the South African Council for Automation and Control (SACAC) (https://sacac.org.za). We also serve on the editorial board of Control Engineering Practice and regularly review papers for journals and major control conferences.

CSM: Can you define your Group's mission and objectives?

Our mission is to develop advanced control solutions that help industry live lighter on the planet in a sustainable way. Our focus is mainly on the process industries, in particular the minerals processing industry and utilities associated with the petrochemical industry. Our overall objectives are to:

1) Help industry to better achieve their commercial targets by making processes more efficient;
2) Help industry to meet their environmental targets by saving water, energy, and reducing carbon emissions.

These objectives are impacted by environmental, social and governance (ESG) issues which are a priority for executives in the process industries, in particular the mining industry. Automation and advanced process control solutions can play a significant role here as the penetration of these technologies is relatively low, resulting in significant opportunities for running processes more efficiently.

CSM: Can you expand on why advanced process control solutions are suited to improving performance in the process industry?

Plants are often designed from a steady-state point of view that could result in sub-optimal economic performance as operating conditions may change because of time-varying disturbances and operational requirements. Once the plant is designed and working, process control provides a viable avenue for rejecting disturbances and maximizing production and product quality. Economic performance improvements resulting from advanced process control can include improved quality, increased throughput and reduced fuel consumption, emission levels, electricity consumption, quality variability, and consumption of consumables. Advanced process control solutions benefit from the increasing maturity of the Industrial Internet of Things (IIoT) and the increasing appetite for corporations to employ digital transformation strategies across their businesses. Historically, industrial automation and control systems were mostly isolated from corporate networks, running proprietary software on dedicated industrialized hardware. This situation is changing, with more processing plants employing sensors, actuators, and computing platforms that can be connected to local corporate networks and the internet. The result is an abundance of process data that make it possible to better monitor and maintain the base levels of the automation hierarchy on which advanced process controllers (APCs) depend to function properly. APCs are now better supported by, for example: performance monitoring and predictive maintenance of instruments, actuators and other plant assets; control loop performance assessment of local PID control loops; data for updating empirical plant models on which APCs are based; data for verifying fundamental plant models; infrastructure for monitoring APCs remotely which is beneficial as plants in the mining industry often lack sufficient in-house APC expertise.

CSM: Can you provide some examples of what advanced process control solutions your Group has developed for the process industry?

Our Group has developed several industrially verified dynamic plant models used in simulation and APC studies. The approach is to develop models using fundamental principles to capture the main dynamics of the process. To ensure the models remain industrially relevant, the aim is to use variables and parameters which are either measured on-line, or which can be accurately estimated from on-line data. Developed plant models include models for a grinding mill circuit, coal dense medium separation, cooling water systems, gas pipeline networks, a minerals flotation plant, and a tailings retreatment process. Our work shows that APC can contribute significantly to making these processes more efficient while at the same time reducing carbon emissions and water and energy consumption. We used an economic performance assessment method developed by our Group to assess the controller benefits for two recent projects. The first project significantly improved the throughput for an industrial coal processing plant, whereas the second project stabilized throughput and improved water recovery at a tailings re-treatment process. In light of the lack of on-line measurements at mineral processing plants, we conducted several studies to show the minimum level of instrumentation necessary to observe important process variables and parameters. For example, the flotation process is more than a 100-years old, but on-line tracking of performance variables remains a challenge. Although most of our projects are model-based, we recently completed projects in the mineral processing industry using non-model-based techniques such as extremum seeking control and automatic tuning of multivariable controllers.

CSM: How does your postgraduate teaching supplement your research efforts?

Our postgraduate courses are aimed at providing students with a better understanding of the multivariable nature of plants, and how to design and evaluate controllers for such plants. The Optimal control course makes use of the "Optimal Control Systems" textbook by Subbaram Naidu. The course presents the optimal control problem from the perspective of calculus of variations and introduces fundamental principles such as the linear quadratic problem, Riccati equations, and Pontryagin's principle. We take care to ensure students appreciate the interaction between optimization and the numerical integration of differential equations. By the end of the course, students should be proficient to design and implement a constrained linear model predictive controller. For the multivariable control course we use the "Multivariable Feedback Control" textbook by Sigurd Skogestad and Ian Postlethwaite. The course includes a number of take-home assignments and an exam in which the students have to design an H_∞ controller for a relatively complicated plant and perform a μ-analysis on the resulting closed-loop. This course helps students to appreciate the multivariable nature of processes and expose them to a number of linear systems tools that are used to analyze such systems. This course has received positive feedback from practicing APC engineers, even though these control design methods are not necessarily used much in the process industries. We also have two research oriented courses that students use to investigate and develop research topics.

CSM: Can you tell us a bit more about the undergraduate teaching done by your Group?

Our introductory control course is presented to all third-year students in our department, where we basically cover chapters 1 to 12 in the textbook "Control Systems Engineering" by Norman Nise. This is followed by a fourth-year course on process automation – for this course we use the textbook by Dale Seborg *et al.* titled "Process dynamics and control". Both textbooks are supplemented by comprehensive course notes and video lectures that we made during the COVID-19 pandemic. These courses also have a significant practical component. For example, in the introductory control course students build their own plant (a circuit of two adjacent power transistors) with temperature sensors and pulse width modulation actuators. The idea is to control the temperature of the one transistor with the other acting as a disturbance. The plant is identified using system identification techniques, and a PID controller is designed for the resulting model. The PID controller is then implemented on a microcontroller and tested on the real plant. We follow a similar process with the automation course laboratories, but here we use industrial PLC and SCADA systems typically used in plant automation.

CSM: Can you tell us a bit more about the final-year capstone projects supervised by your Group?

We supervise about 20 project students which equates to 10% of the total number of project students in the DEECE. Each project is supervised and completed on an individual basis, and the difficulty level of all 200 odd projects are calibrated and evaluated by one project lecturer. Students develop a project proposal that includes a project description, technical challenges, a functional analysis, and system requirements and specifications that are used to measure the success of the project during the exam. Students have to develop a budget, an implementation plan, and procure/manufacture (typically 3D print) all their own hardware, and build the project in a dedicated laboratory. The exam consists of a comprehensive report and a hardware demonstration. Recent projects in our Group include a robot that can draw a picture presented to it by a user, and a quadcopter that can catch a ball, a pool-playing robot, and autonomous vehicle following using radio controlled cars.

CSM: We noticed that you published an article on HIV/AIDS modelling and control in CSM a number of years ago (IEEE CSM, February 2005, pp. 80-83). Do you cover any infectious diseases concepts in your control courses?

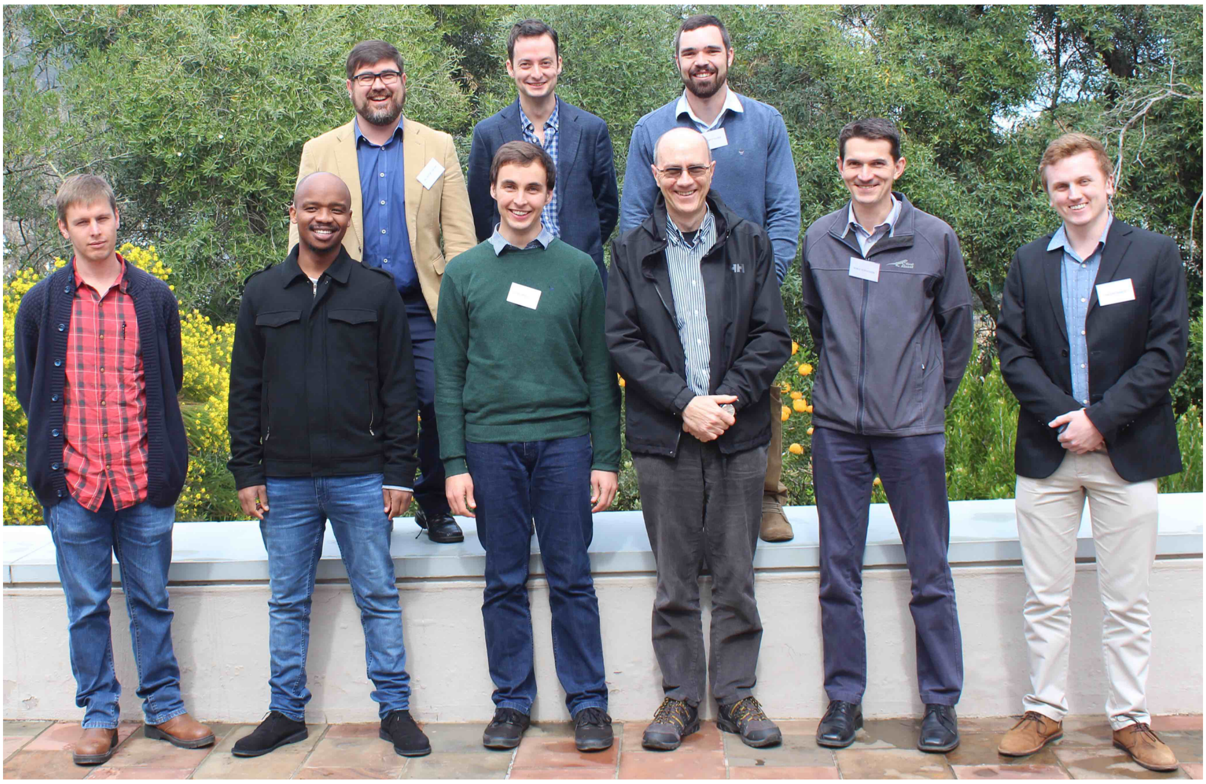
The textbook by Norman Nise covers the HIV/AIDS model that we used in each chapter in the form of a "Progressive Analysis and Design Problem". For example, Problem 68 in Chapter 2 describes our nonlinear HIV/AIDS state-space model which is linearized in Problem 31 in Chapter 3. Students who complete this course have therefore been exposed to the modelling of infectious diseases. The follow-up automation course has a significant component on obtaining plant models for control purposes. Models for sensors, actuators and processes are obtained from data and/or first principles, including the use of the principle of conservation of a quantity. The latter is used, for example, in the automation course to model the dynamics of a thermocouple. The principle-of-conservation approach is also used to model the disease dynamics of HIV/AIDS, a model by now familiar to students. When COVID-19 was dominating the headlines, it was decided to introduce COVID-19 modelling into the control systems curriculum in the form of a SEIQRDP COVID-19 model that we used to study optimized lockdown strategies. This model uses the same principle-of-conservation approach and students appreciated the fact that the material that they covered in the automation course can be applied to better understand the COVID-19 pandemic that they were experiencing.

CSM: Can you expand on the community service activities of your Group?

As far as local activities are concerned, Ian is a past president of SACAC and has served on its executive committee for almost 30 years. Derik has served as the Honorary Secretary and Treasurer of SACAC for the past nine years. Four of the Group members and alumni have served as Presidents of SACAC, in addition to the current President, Loutjie Coetzee. Internationally, our Group is very active in IFAC. Ian is a past president of this organization and is the current Publication Management Board Chair. Derik is a member of the current IFAC Technical Board and the Publications Board. Group members and alumni are also actively involved in the IFAC Technical Committees related to process control. In addition, Ian is a past Editor-in-Chief of Control Engineering Practice, with Derik being on the Early Career Advisory Board of this journal.

Photos

Group members attending the 2014 IFAC World Congress in Cape Town, South Africa



Group members attending the 2019 IFAC Mining, Minerals and Metals Symposium in Stellenbosch, South Africa

Group members as part of the South African delegation at the 2023 IFAC World Congress in Yokohama, Japan.

Ian and Derik attending the 2023 outgoing IFAC Council meeting in Yokohama, Japan.