1. **Title: On-line Optimization: Extremum seeking control and its applications**

2. **Names and Affiliations of Speakers**

Prof. Iven Mareels, Associate Professor Chris Manzie and Dr. Ying Tan

Melbourne School of Engineering,

The University of Melbourne

3. **Abstract (one or two paragraphs)**

Extremum seeking control (ESC) is a real time optimization method for steady-state optimization of engineered systems. It is an enabling technology that is used in a range of important applications, such as power generation, irrigation, optical communication, environmental monitoring and economics. The main objective of this tutorial is to present the fundamentals of extremum seeking control to systems and control researchers who may not be familiar with the concept. This tutorial will describe several streams of ESC from around the world and will provide participants with an overview of the current state-of-the-art in ESC from the basic ESC theory through to current design practice, example applications, and ongoing research directions.

4. **Intended Audience (one paragraph): Describe the background assumed of tutorial attendees. Tutorials may range from basic for attendees new to the field to advanced topics for experts.**

The expected audience includes engineers, scientists, postgraduate students, and academics.

5. **Description: A statement (no more than 3 pages) giving clear motivation for the topic to be presented at ASCC and a comprehensive outline of the proposed content.**

Design of engineered systems whose operation is in some sense optimal is increasingly important due to the range of socio-economic and environmental problems we are facing at

the dawn of the 21st century. Increased demand for energy and other limited resources, climate change and an increased competition in the global market exert pressure on engineered systems to be more efficient, cheaper, cleaner and of better overall quality than existing systems. Optimal control engineering is an enabling technology that provides methods for the systematic design of engineered systems that exhibit optimal behaviour, such as maximal productivity, best efficiency, minimal cost and best quality.

While still attracting considerable research attention, optimal control methods can be regarded as classical and in certain areas, such as linear quadratic control, they are very well developed and understood. An underlying assumption in the classical control literature is that both the plant model and the cost to optimize are known to the engineer designing the system. However, many engineering systems do not satisfy this basic assumption and, hence, classical optimization methods are often not directly applicable.

Extremum seeking control (ESC) is an optimal control approach that deals with situations when the plant model and/or the cost to optimize are not available to the designer but the plant input and output signals may be measured. Using only these available signals, an extremum seeking controller dynamically searches for the optimizing inputs in real time. The idea of extremum seeking dates back in 1950's. However, the understanding of how extremum seeking systems should be designed and how they work was relatively modest until the early 2000's. Since then engineers have implemented ESC in biochemical reactors, ABS control in automotive brakes, variable cam timing, electromechanical valves, axial compressors, mobile robots, mobile sensor networks, optical fibre amplifiers, the Frascati Tokamak Upgrade, bluff-body drag reduction, human exercise machines, tidal turbine engines and thermoacoustic instability. All these applications indicate the power of ESC in real applications.

This tutorial will consist of three sessions. Each session will be around one hour.

Session 1 (50 mins): Introductory Session (by Prof. Iven Mareels)

The Introduction Session focuses on the basic principles of ESC, in particularly the adaptive ESC. A simplest possible ESC will be presented into details. The attendee will come to understand

- The basic problem formulation of ESC;
- The link of ESC to optimization algorithms;
- The performance of ESC;
- The design trade-off of ESC;

Session 2 (50mins) – Overview of Recent Advances (by Dr. Ying Tan)

This section introduces some recent developed frameworks which make systematic analysis and design of ESC possible. These frameworks include

- A unifying framework of adaptive ESC based on estimation of derivatives;
- A systematic approach to ESC based on parameter estimation;
- A global sampled-data based ESC framework.

With the knowledge of these design frameworks, it is possible to combine an algorithm from a large class of discrete or continuous (on-line) optimization algorithms with appropriate estimators to design various ESCs. This provides a much needed design flexibility as the designer can tailor the ESC to the problem at hand.

Session 3 (50 mins) Applications of ESC (Associate Professor Chris Manzie)

This section will introduce real world examples that motivate the need for extremum seeking solutions, and discuss aspects of practical application of extremum seeking to SISO and MISO problems including combustion and powertrain control, through to large scale systems.

We will have half an hour for dialogue, diagnosis and brainstorm thinking. Attendees are encouraged to bring and present for discussion, their own research experience, and problems encountered in applying ESC to various applications.

6. **Materials: A description (one or two paragraphs) of materials to be provided to attendees on the conference website – course slides, annotated bibliography, code snippets etc. NOTE: the materials themselves do not need to be provided in the proposal.**

The attendee will find course slides and annotated bibliography on the conference website.

7. **Bio-sketches: A half-page bio-sketch of each tutorial presenter must also be included**.

**BIOGRAPHY of Professor <u>Iven Mareels</u>**

Iven Mareels is Professor of Electrical and Electronic Engineering and Dean of the Melbourne School of Engineering. He is a leading expert in the area of control engineering, with seminal contributions to adaptive control and ESC. Professor Mareels is a Vice-President of the International Federation of Automatic Control (IFAC) and Chair of the IFAC Technical Board (2008-2014). He is a Fellow of the IEEE, Fellow of the Australian Academy of Technological Sciences and a Fellow of the Flemish Royal Belgian Academy of Sciences and Humanities. He was the Chair of the National Committee for Automation Control and Instrumentation, Engineers Australia, (2004 - 2009), and Chair of the Australian Research Council College of Experts for Mathematics, Information and Communication Sciences, 2002 - 2004. He is co-authored 5 books, and in excess of 130 journal papers/book chapers, and about 250 conference papers.

**BIOGRAPHY of Dr. <u>Ying Tan</u>**

Dr. Ying Tan received her Bachelor from Tianjin University, China in 1995. In 1998, she joined the National University of Singapore and finished her PhD study in 2002. She joined McMaster University in 2002 as a postdoctoral fellow in the Department of Chemical

Engineering. She has started her work in the Department of Electrical and Electronic Engineering, the University of Melbourne since 2004. Currently Dr. Ying Tan is Future Fellow (2010--2013), which is a research position funded by the Australian Research Council. Her research interests are in intelligent systems, nonlinear control systems, extremum seeking control, sampled-data distributed parameter systems and formation control. Dr. Ying Tan is IEEE Senior member and a Steering Committee member of the Asian Control Association (ACA).

**BIOGRAPHY of Associate Prof. Chris Manzie**

Chris Manzie received the B.S. degree in physics and the B.E. degree (with honors) in electrical and electronic engineering and the Ph.D. degree from the University of Melbourne, Melbourne, Australia, in 1996 and 2001, respectively. Since 2003, he has been affiliated with the Department of Mechanical Engineering, University of Melbourne, where he is currently an Associate Professor and an Australian Research Council Future Fellow. He was a Visiting Scholar with the University of California, San Diego in 2007, and a Visiteur Scientifique at IFP Energies Nouvelles, Paris in 2012. He has industry collaborations with companies including Ford Australia, BAE Systems, ANCA Motion and Virtual Sailing. His research interests lie in applications of model-based and extremum-seeking control in fields including mechatronics and energy systems. Associate Professor Manzie is a member of the IEEE and IFAC Technical Committees on Automotive Control.