UDRC Themed Meeting on Quantum Signal Processing

As part of the UDRC phase III, our next themed meeting will be on Quantum Signal Processing for Defence and held on Wednesday 3rd May 2023, at Heriot-Watt University, Edinburgh. This event is intended for academic researchers, industrial partners and Dstl staff to learn about and discuss current trends in Quantum Signal Processing. The program will consist of a series of talks covering a range of theory and applications to current defence /security problems, followed by a discussion session.

Timings: Wednesday 3rd May 2023

Location: MultiFlex Rm, Robotarium, Heriot-Watt University

Registration: https://edinburgh.onlinesurveys.ac.uk/quantumsignalprocessing

Organisers: Dr Yoann Altmann (y.altmann@hw.ac.uk); Prof Steve McLaughlin (s.mclaughlin@hw.ac.uk)

Time	Topic	Name
9.20 - 11.00	**Session 1**	
9.30-10.00	On-chip and off-chip processing for high-speed, super-resolution LIDAR	Istvan Gyongy (University of Edinburgh)
10.00 - 10.30	Turning SPAD Arrays into Depth-based Neuromorphic Cameras	Dan Yao (Heriot-Watt University)
10.30-11.00	Advances in hair-thin 3D endoscopy	Simon Mekhail (University of Glasgow)
11.00 - 11.30	**Break**	
11.30-12.00	**Session 2**	
11.30-12.00	Bayesian inference for quantum sensing and quantum model learning	Cristian Bonato (Heriot-Watt University)
12:00 – 12:30	Neuromorphic sensing and processing for defence	Gaetano Di Catarina (University of Strathclyde)
12.30 - 13.30	**Lunch Break**	
13.30 - 14.30	**Session 3**	
13.30- 14.30	Timing is everything: model-based and learning-based reconstruction methods for event-driven cameras	Pier Luigi Dragotti (Imperial College London)
14.30 - 15.00	**Break**	
15:00 - 16.30	**Session 4**	
15:00 – 16:00	Counting Electrons and Accounting for Ions in Focused Beam Microscopy	Vivek Goyal, Boston University
16:00 – 16.30	Discussion and closing remarks	

The University Defence Research Collaboration in Signal Processing in the information Age is funded by EPSRC and Dstl.

Speaker: Pier Luigi Dragotti

Title: Timing is everything: model-based and learning-based reconstruction methods for event-driven cameras

Abstract: Traditional signal processing is based on the idea that an analogue waveform should be converted in digital form by recording its amplitude information at specific time instants. Nearly all data acquisition, processing and communication methods have progressed by relying on this fundamental sampling paradigm. Interestingly, we know that the brain operates differently and represents signals using networks of spiking neurons where the timing of the spikes encodes the signal's information. This form of processing by spikes is more efficient and is inspiring a new generation of event-based audio-visual sensing and processing architectures.

In this talk, we investigate time encoding as an alternative method to classical sampling, and address the problem of reconstructing classes of sparse non-bandlimited signals from time-based samples. We consider a sampling mechanism based on first filtering the input, before obtaining the timing information using a time encoding machine. Leveraging specific properties of these filters, we derive sufficient conditions and propose novel algorithms for perfect reconstruction of classes of sparse signals.

We then extend our analysis to multi-dimensional signals and present a model for an alternative event-driven camera which also inspires a neural network architecture for the reconstruction of intensity videos from events.

Bio: Pier Luigi Dragotti is Professor of Signal Processing in the Electrical and Electronic Engineering Department at Imperial College London and a Fellow of the IEEE. He received the Laurea Degree (summa cum laude) in Electronic Engineering from the University Federico II, Naples, Italy, in 1997; the Master degree in Communications Systems from the Swiss Federal Institute of Technology of Lausanne (EPFL), Switzerland in 1998; and the PhD degree from EPFL in 2002. He has held several visiting positions including at Stanford University, Stanford, CA in 1996, at Bell Labs, Lucent Technologies, Murray Hill, NJ in 2000, and at Massachusetts Institute of Technology (MIT) in 2011. Dragotti was Editor-in-Chief of the IEEE Transactions on Signal Processing, from January 2018 to December 2020; Technical Co-Chair for the European Signal Processing Conference in 2012 and Associate Editor of the IEEE Transactions on Image Processing from 2006 to 2009. In 2011 he was awarded the ERC starting investigator award (consolidator stream) for the project RecoSamp. His research interests include sampling theory and its applications, computational imaging and data-driven signal processing with applications in art investigation and in neuroscience.

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Speaker: Vivek Goyal

Title: Counting Electrons and Accounting for Ions in Focused Beam Microscopy

Abstract: A particle beam microscope uses a focused beam of ions or electrons to cause the emission of secondary electrons (SEs) from a sample. A micrograph is formed from the SEs detected during the dwell time of the beam at each raster scan location. It seems innocuous to analogize the microscope with an ordinary digital camera, but with serialized pixel-by-pixel data collection. This is valid in some ways, but it precludes maximum information extraction.

In a sequence of recent works, we have shown that time resolution within each pixel dwell time enables significant imaging improvements without changes to the basic microscope hardware. The key idea is that source shot noise, meaning the randomness of the number of incident particles, can be mitigated when finer time resolution is available. Images of pixel-to-pixel SE yield variation can be formed more accurately from a time-resolved vector of measurements at each pixel. Novel estimators computed from time-resolved measurements have low sensitivity to the beam current value, creating a natural robustness. Furthermore, random fluctuations in beam current can also be accurately estimated from the time-resolved data. In addition to yielding further improvements in the standard SE yield micrographs, this could be used to improve the control of focused ion beam milling. We believe that the inherent averaging over source shot noise in conventional uses of particle beam microscopes has limited the uses of these microscopes and even the choices of incident particles. More speculative possibilities may also be discussed.

Bio: Vivek Goyal received his doctoral degree in electrical engineering from the University of California, Berkeley. He was a Member of Technical Staff at Bell Laboratories, a Senior Research Engineer for Digital Fountain, and the Esther and Harold E. Edgerton Associate Professor of Electrical Engineering at MIT. He was an adviser to 3dim Tech, winner of the 2013 MIT $100K Entrepreneurship Competition Launch Contest Grand Prize, and consequently with Google/Alphabet Nest Labs 2014-2016. He is now a Professor and Associate Chair of Doctoral Programs in the Department of Electrical and Computer Engineering at Boston University. Dr. Goyal is a Fellow of the AAAS, IEEE and Optica, and he and his students have been awarded ten IEEE paper awards and eight thesis awards. He is a co-author of Foundations of Signal Processing (Cambridge University Press, 2014).

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Speaker: Istvan Gyongy

Title: On-chip and off-chip processing for high-speed, super-resolution LIDAR

Abstract:

Over the last few years, the use of single-photon avalanche diode (SPAD) sensors has become widespread in applications such as smartphones and robotics. SPADs have also become a key technology in automotive LIDAR, promising low-cost, accurate and robust 3D sensing. We review some of the underpinning embedded processing that enables high-speed, long-range operation even under high ambient levels. We also discuss off-chip neural network processing to enhance and interpret depth data.

Bio:

Istvan Gyongy received M.Eng. and Ph.D. degrees from the University of Oxford, in 2003 and 2008, respectively. Following a period in industry, where he worked on processors for smartphones and a cloud-connected activity tracking system for dairy farms, he joined The University of Edinburgh. He is currently a Lecturer and is developing single-photon avalanche diode (SPAD) cameras and exploring applications in 3-D capture and the life sciences.

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Speaker: Dan Yao

Title: Turning SPAD arrays into depth-based neuromorphic cameras

Abstract:

Event cameras, also known as neuromorphic cameras, detect the change of light intensity to generate streams of asynchronous "events", which encode the time, location (i.e. pixel coordinates), and polarity (i.e. pixel sign) of each pixel. Compared to conventional cameras, this type of bio-inspired sensors features the attractive properties of high temporal resolution, high dynamic range, and low power consumption, making them extremely useful in solving dynamic vision problems. In quantum imaging, Single-Photon Avalanche Diode (SPAD) arrays have long been the workhorse of many quantum optics experiments, due to their single photon level sensitivity and high frame rate. In quantum dynamic imaging, when using SPAD arrays to capture high speed sequences of binary frames, there exists potential redundant information over the frames. To achieve fast information extraction for quantum imaging, in this talk, I will present a new algorithmic framework to turn the high frame rate SPAD arrays into neuromorphic cameras. The working principle of neuromorphic cameras will be adopted to exploit the information changes carrying by SPAD arrays, with greater flexibility and additional target estimates. Specifically, the proposed algorithm is not limited to only detect the light intensity changes as the neuromorphic cameras, but also allows for the detection of target depth changes in 3D imaging. Thus, the outputs of the algorithm will be the streams of events in the form of "intensity-change events" and "depth-change events". I will present some preliminary and promising results for obtained with simulated and real SPAD arrays.

Bio: Dr. Dan Yao is a Research Associate at Heriot-Watt University, working within the SIPLab group with Prof. Stephen McLaughlin and Dr. Yoann Altmann. She has been working on approximate Bayesian inference since her PhD, and mainly focused on solving image inverse problem using scalable approximate Bayesian methods, with the ability to offer uncertainty quantification. Her current research interests are to explore efficient Bayesian uncertainty quantification methods for Quantum imaging, such as neuromorphic imaging, and single photon avalanche diode arrays (SPAD) based image problems.

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Speaker: Simon Mekhail

Title: Advances in hair-thin 3D endoscopy

Abstract:

While traditional endoscopy uses either, small cameras with implant footprints of a few millimetres, or multicore fibres where many cores each transmit a single pixel of scene in a large bundle, we explore imaging using a single multimode fibre the width of a hair. This imaging system uses specific mixing of the fibre modes with fast spatial shaping of the input field to generate a raster scanning spot at the end of the fibre. Though this was first demonstrated a decade ago, we have recently carved new avenues into single fibre endoscopy exploring three exciting new frontiers, time of flight 3D imaging, imaging in a dynamically bent fibre, and imaging using a compact self-contained portable setup.

Bio:

Simon Peter Mekhail started his academic career with a degree in biomedical engineering with honours from the University of Auckland in New Zealand before moving to the Okinawa Institute of Science and Technology in Japan to pursue a PhD in applied physics for neuroscience and experimental physics. His work there included fibre endoscopy for brain implants and extended to the use of tapered nano-fibres for cold atom experiments. He moved to the University of Glasgow in 2020 working on quantum and low light imaging and the fibre endoscopy he will be presenting about in this meeting.

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Speaker: Cristian Bonato

Title: Bayesian inference for quantum sensing and quantum model learning

Abstract:

The development of techniques for the characterization of quantum states and their dynamics is crucial for applications in quantum communication, computing, sensing and simulation. In quantum sensing, for example, physical parameters of interest can be measured, with quantum-limited sensitivity and high spatial resolution, by optimizing information extraction from a quantum sensor. Here we present our progress on the application of Bayesian inference for the characterization of quantum systems. In a first set of experiments, we apply sequential Bayesian estimation to improve the performance of a quantum sensor based on a single electronic spin. Our protocols, implemented on a fast micro-controller, adaptively choose optimal experimental settings in real-time to estimate decoherence timescales and static magnetic fields. We show that online adaptive approaches can provide a speed-up by a factor up to one order of magnitude compared to their non-adaptive counterparts, and discuss the expected impact on quantum sensing. In a second set of experiments, we focus on automated reconstruction of the model for an unknown system of quantum emitters based on the arrival times of the emitted photons. We employ a Markov-chain Monte Carlo (MCMC) approach to infer the distribution of multiple parameters. We also introduce an algorithm to reconstruct a Lindblad master equation that describes the system. We benchmark our algorithms on a system of two resonant self-assembled InGaAs quantum dots in the cooperative emission regime.

Bio: Cristian Bonato is a Professor at Heriot-Watt University, where he co-leads the Quantum Photonics Laboratory. He currently holds an EPSRC Early-Career fellowship (2019-2024) and is the Principal Investigator for Heriot-Watt's Quantum Magnetometry Facility. He has been awarded a MSc in Physics (2004) and a PhD in Electrical Engineering (2008), both from the University of Padua (Italy). Before joining Heriot-Watt as Assistant Professor in 2016, he has worked as a post-doctoral researcher at the Leiden Institute of Physics (with Dirk Bouwmeester on semiconductor cavity-QED) and at the Technical University of Delft (with Ronald Hanson on spin control with nitrogen vacancy centres in diamond).

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Speaker: Gaetano Di Catarina

Title: Neuromorphic sensing and processing for defence

Abstract:

Artificial Intelligence (AI) is currently at the forefront of technological development in many sectors, like manufacturing, services, space, and defence. Deep Learning (DL), as the latest incarnation of AI, is used ubiquitously and it is slowly replacing more conventional signal processing algorithms and approaches.

However, despite the considerable advances in recent years, DL requires significant hardware acceleration and resources to be effective, as it is rather computationally expensive. In typical defence applications, this is indeed a problem; moreover, miniaturisation of electronic devices requires small form-factor processing units, with reduced SWaP (Size,Weight and Power) profile.

Therefore, a different processing paradigm is needed to address both issues. In this context, an attractive alternative is given by Neuromorphic (NM) Engineering, seen as the analog/digital implementation of biologically brain-inspired neural networks. NM systems propagate spikes as means of processing data, with the information being encoded in the timing and rate of spikes generated by each neuron of a so-called spiking neural network (SNN). NM implies also a rethinking of the sensing, as data needs to be generated in spiking format, to be effectively and efficiently processed through SNNs.

On this premise, the key advantages of SNNs are less computational power required, more efficient and faster processing, much lower power consumption. Indeed, NM has the potential to be game changing in the defence and security domain, across multiple sensing modalities and field applications.

Bio:

Dr Gaetano Di Caterina is currently Senior Lecturer, and the Leonardo Lecturer, in the Electronic and Electrical Engineering Department at the University of Strathclyde, where he is Director of the Neuromorphic Sensor Signal Processing (NSSP) Lab, within the Centre for Signal and Image Processing (CeSIP) group. Dr Di Caterina has a background in signal, image and video processing, he is Course Director of the MSc in Machine Learning and Deep Learning at Strathclyde, and has published works on Machine Learning, Deep Learning, Neuromorphic technologies and Signal Processing at several international conferences and in academic journals. Recent research projects include funding from DASA/DSTL, AFOSR/AFRL, ESA and Leonardo UK. (https://pureportal.strath.ac.uk/en/persons/gaetano-di-caterina)

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