AiPT
Aston Institute of Photonic Technologies

MILE

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Final Report
Project duration – 2 Years

Project period -

01-11-2017 – 31/10/2019

PART A

Aston University

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Project Full Title	Machine Learning Techniques for Stabilisation of Mode-Locked Lasers
Host institution	Aston University
Scientist in charge	Sergey Sergeyev
Start date of the project	01/11/2017
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Periodic report no.	1
Period covered by the report	01-11-2017 – 31-10-2018
Project website address (if any)	

Declaration

I, Otti D'Huys, hereby declare that

- Both Part A and Part B of this Report and its related appendices have been approved by the Scientist in-charge, Sergey Sergeyev, and any other relevant party (for e.g. secondment academic/non-academic organisation).

- The contents of the publishable summary (Section 1 of Part A) do not contain any confidential data, and have been approved by the Scientist in Charge and any other relevant party ((for e.g. secondment academic/non-academic organisation) involved in the generation of the Results.

Signed,

Otti D'Huys

Birmingham, 1 May 2020

1. Summary for publication

1.1 Summary of the context and overall objectives of the project

This section must be of suitable quality to enable direct publication by the MULTIPLY Management Team. It should be easy to read i.e. written in a language easily understandable by a broader public, thereby promoting the dissemination and supporting the exploitation of EU funded results. It should preferably not exceed 7480 characters (equivalent to two pages of a text document).

PLEASE NOTE – As this summary will be made publically available, this part must not contain any confidential data.

The summary for publication must be drafted as a "stand-alone" text. No references should be made to other parts of the report. References can be made only to publicly available information.

Beside the summary, diagrams or photographs illustrating and promoting the work of the project can be provided.

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Networks of interacting elements are omnipresent in nature, ranging from gene regulatory networks and neuronal networks in a physiological context to transportation and communication networks in the engineering of a modern city. Thus, the understanding of how networks systems coordinate to optimise their functionality represents a fundamental question in fields from neuroscience and medicine to physics and engineering.

In this project, we studied neuromorphic photonic networks – networks of photonic elements inspired the brain. The main rationale is that the dynamics of the laser population mimics the dynamic of a population of neurons to some extent. In contrast to in vivo experiments with brain cells, photonic or electronic experiments have a long lifetime, are more stable and easier to control. In this sense, a photonic implementation of a neural population has the advantages of photonic setups – relatively cheap compared to living tissue, and well controllable – and still provides experimental conditions that deviate from too (simple, symmetric) mathematical models. Secondly, a photonic implementation of neural dynamics might give rise to novel implementations of brain-inspired computing systems as a possible application.

In a secondment at INPHYNI (Nice, France), an interdisciplinary collaboration between Dr. S. Barland (INPHYNI), who is experimental physicist and does the experiments, Dr. R. Veltz (INRIA), a mathematician who provides the background in mathematical neuroscience, and myself as theoretical physicist analysing the model, we have studied the dynamics of a population of incoherently coupled semiconductor lasers. As it allows to couple several 100 lasers, it is among the first experimental realisations of a large population. Our results allow insight in the population dynamics: our (ongoing) results aim to show, experimentally and theoretically, that the coherency of the population is mediated by spontaneous emission noise, and we investigate the optimal interplay between noise level and experimental parameters to induce synchronisation between the photonic neurons.

In a supporting line of research, stochastic effects in network dynamics have been studied in a more general, abstract and fundamental context: Most real-life networks, in the brain, but also often in an optical context exhibit a time delay: it takes a finite time for information to travel between network nodes. Such a coupling delay can have profound effects on the network behaviour, but is however not always taken into account in models due to the mathematical complexity. Over the last decade theory has been developed for deterministic, long and constant delays. However, most real life networks, in a biological or optical are not deterministic and the delay times are not constant, but both the network nodes and the delays show stochastic variations. Although stochastic variations can have a far-reaching effect in the network output, as we found in the optical neuromorphic experiment, but their role remains largely unexplored.

In collaboration with a team from the Institute of Applied Physics (Nizhny Novgorod, Russia), we develop a mathematical framework for the analysis of networks of generic neuromorphic elements, with interaction delays and subject to noise, studying their stability to stochastic perturbations, memory capacity and suitability for applications of neuromorphic computing. So far, we have shown, in an electronic neuromorphic oscillator and theoretically, the fundamentally different role of perturbations applied to network nodes and network links to network robustness.

Not only are real life systems subject to noise, many networks themselves are not constant in time: in neuronal and physiological networks the connectivity itself changes over time as well as the interaction time between network elements. The dynamics of such networks in motion is still poorly understood, and interaction times are not taken into account in most models. In collaboration with a team from UNED (Unversidad Nacional de Educacion a Distancia, Madrid, Spain), we have contributed to a mathematical description of the collective dynamics of such variable networks.