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IRES TRACK II: US-UK international student research in robust control of quantum networks

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Motivation

- Big **gap** between **classical control** and **quantum systems**
- Quantum **technology requires control**, esp. robust control, but *existing tools* from classical control often ***not** applicable* to quantum systems
- **New talents** familiar with *both classical control* and *quantum physics* urgently *needed to develop new solutions*
- **Engineering students** with control focus have *limited opportunity* to learn about *quantum systems*
- **Physics students** with quantum focus *generally lack education* in classical *control & optimization*
- **Narrow focus** on individual PhD topics major limiting factor
- **International collaboration** highly beneficial

Aim 1: Intersection of classical control and quantum systems optimization, machine learning, modelling, simulations & experiments

Quantum control vs classical control

Open-loop vs feedback, linear systems vs nonlinear systems
Modelling **quantum systems**, dynamics and control, control problems
Introduction to spin networks, energy landscape shaping, reservoir engineering

Classical robust control and **challenges** in application to quantum systems
Robustness and decoherence: quantum vs classical robust performance

Machine learning and optimisation techniques
Bayesian techniques of model identification and parameter estimation

Efficient and effective coding, parallel and HPC issues (clusters, GPUs, etc)

Emergence of **classicality under decoherence**
Quantum thermodynamics and control

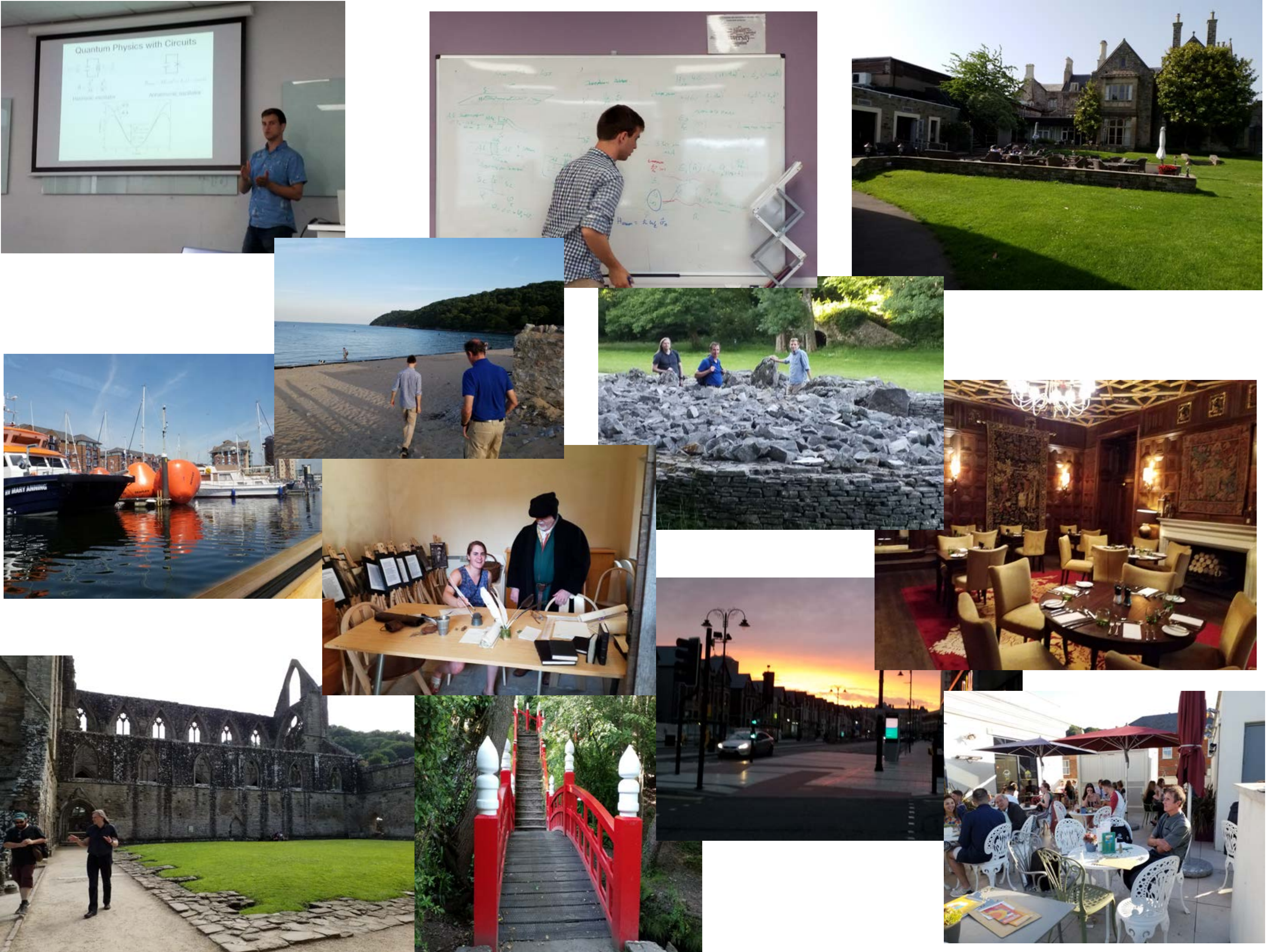
Challenges: Extremely wide range of topics and methodologies needed
Students with vastly different background needed as well

Aim 2: Engage students via a range of activities

Combination of tutorials, advanced topics, guest lectures, students presentations, mini-projects, discussions and lots of ***social activities***

06/24 Mo eve	Welcome dinner
06/25 Tu eve	Walking tour of the city
06/26 We pm	Cardiff Castle
06/27 Th pm	Dinner
06/28 Fr pm	Welsh Heritage Centre
06/30 Su am	Tintern Abbey
07/01 Mo eve	Swansea Marina and Dinner
07/02 Tu pm	Tawe River Cruise
07/03 We pm	Craigynos Castle and National Showcaves
07/06-07/07	Wales Air Show http://www.walesnationalairshow.com/

Much of the interaction happened informally at social events!


Quantum Physics with Circuits

Did we achieve our aims?

- **Students did benefit from**
  - ✓ Interactions/collaboration with other students
  - ✓ Inspiration from lively scientific discussions
  - ✓ Sense of community created
- **Scientific outcomes**
  - ✓ Discussions have catalyzed new research
  - ✓ Several research papers
  - ✓ *Survey paper* – joint effort led by students

Robust Quantum Control in Closed and Open Systems: Theory and Practice

C.A. Weidner, E.A. Reed, J. Monroe, B. Sheller, E. Maas, E.A. Jonckheere, F.C. Langbein, S.G. Schirmer

Abstract—**Robust control of quantum systems is an increasingly relevant field of study amidst the second quantum revolution, but there remains a gap between quantum physics and robust control. To develop general theories of robust quantum control, this gap must be minimized, as general quantum systems are not amenable to analysis via classical robust control techniques, e.g., the formulation as linear, time-invariant problems. This tutorial is written for the control theorist and presents an introduction to quantum systems, issues that arise when applying classical robust control theory to quantum systems, typical methods used by quantum physicists to explore such systems, and a discussion of open problems to be addressed in the field. This tutorial's focus on general, practical applications allows the control researcher to understand and begin applying their knowledge to advance this burgeoning field.**

Index Terms—**Quantum Systems, Quantum Information, Quantum Control, Robust Control**

quantum systems are only marginally stable. Progress in decoherence-based state preparation [10], [11] and bath engineering [12] has not strongly leveraged robust control theory. Therefore, more research is needed into the theoretical underpinnings of robust quantum control as well as practical applications and eventual implementation into real systems. The overarching questions still remain to be answered: Can a quantum system ever be inherently robust, especially in the absence of stability? What are the fundamental device limitations established by quantum robust control protocols? Will we ever be able to move past the current noisy, intermediate-scale quantum (NISQ) era and build useful, scalable, and robust devices that are promised by the second quantum revolution? This remains to be seen, but some hope can be offered by the success of related applications that rely on quantum phenomena and control such as nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) (see, e.g., [13]–[17], among many others). If we can see a coherent signal from the many

What worked & what didn't?

- Scientific discussions inspired *new research* including ***student-led publication***
- Social activities – informal interactions created sense of community facilitating collaboration
- **Survey paper** – *better tools needed* to enable effective collaboration; identify target journal first
- **Administration** – financial and legal issues caused numerous problems
- **Recruitment** – desirable to advertise more broadly
- Planned follow-up workshop (Summer 2020) disrupted by pandemic ...

Summary

- ASI's **great opportunity for community-building**
- **Interaction with peers** and range of academics broadens students' perspective beyond narrow focus on their own PhD project
- **Networking and collaboration** opportunity for students
- Experience different education systems
- **Skill development**, improving resumes and employment prospects
- **Can produce tangible results**
- **… but there are challenges**
- In-person events expensive to run and vulnerable to disruption
- Complex logistics, timing, organization

Opportunties going forward

Pandemic has also created new opportunities

- New tools to improve collaborative work
- New ways of working (online/remotely)

Challenges – a lot of interaction happens at social events

Effective technology to create virtual communities to

- Enable students to network with peers internationally
- Broaden academic horizons by interaction with range of academics
- Focus beyond narrow PhD topics
- Facilitate student-driven collaborative projects