2021 Issue 03

SUTD Honours And Research Programme (SHARP) Newsletter

Innovating Research with Design

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SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

INTERVIEW WITH SHARP INSTRUCTORS ON RECEIVING THE 2020 SMP OUTSTANDING MENTOR AWARD

Science Mentorship Programme (SMP) is jointly organised by the Gifted Education Branch of the Ministry of Education (MOE) with the local tertiary institutions which includes Universities, Polytechnics and Research Institutes. The programme is targeted at Secondary 3 to Secondary 4 students from School-Based Gifted Education (SBGE) and Integrated Programme (IP) schools with an interest in and aptitude for scientific research.

Faculty mentors are invited to offer research projects for the students in November. Students who are keen to participate in the programme could apply for projects that interest them in January of the following year. Successful applicants will work on their projects, and at the end of the programme, they are required to present their research findings during the Youth Science Conference (YSC). More information of SMP can be found at https://www.moe.gov.sg/programmes/gifted-education/special-programmes

Dr. Keegan Kang
Instructor for SHARP Honours Session
Lecturer, Engineering Systems and Design (ESD)

Dr. Tan Da Yang
Instructor for SHARP Honours Session
Lecturer, Science, Mathematics and Technology (SMT)

How do you work in the SMP?

Da Yang: A group of students from River Valley High School contacted Keegan and they expressed interest in working on a project involving quantum cryptography. In turn Keegan roped both Wei Pin, Lecturer from SMT, and myself into this project.

The work involved regular meetings with the students to first teach them the basics of quantum mechanics and quantum key distribution and associated mathematical formalism. Once they were familiar with the fundamentals, the remaining work would be to provide guidance for them to refine and answer the proposed research questions. At the end of the programme, the students took part in the YSC and we guided them in their writing of the conference paper.

The pandemic posed many challenges: the vast majority of the meetings were done online, which means that we had to think of new strategies to communicate. For instance, when discussing the theories, it would usually be easier to communicate in person and we could make use of the whiteboards to write and discuss. This way, the discussions would be much interactive. However, the interactivity of such discussion is significantly diminished when done over online conferencing.

On the other hand, because of the pandemic, the entire duration of the project was lengthened to almost a year, so students had the opportunity to explore the topic further.

Keegan: The students did the project from March – July. Usually for SMP, students would travel each week to the institution sponsoring the project. However, due to the pandemic, the meetings were conducted virtually. There would also be a 1-month attachment at the workplace of the project sponsor. Afterwards, the project would be judged by a committee of scientists.

For me, I have been offering SMP projects since 2019, and this is the third year I have offered such projects. Generally, I offer some maths and computing related projects, where students get a peek at what I am doing for research, as well as learn some programming and LaTeX skills.

What research project did you propose, and what was the project about?

Da Yang and Keegan: We designed a small project for the students to explore the basics of quantum key distribution using the well established BB84 protocol. Given that they are secondary school students, we have to ensure that the project should not be mathematically demanding on the students, and quantum key distribution neatly fit into this requirement since it does not take much beyond their school knowledge, e.g. matrices and vectors, to understand the basics. With that, the students investigated if there are any form of scaling behaviours in terms of the length of the key rate with respect to the error rate.

How do you feel after being awarded the 2020 SMP Outstanding Mentor Award?

Da Yang: It is certainly an honour to receive the award, but more importantly, I hope that the students have learnt skill sets and knowledge about both conducting research and quantum physics along the way. I will continue my (ever) ongoing work of engaging young students into the wondrous world of Science, Technology, Engineering and Mathematics (STEM) subjects, particularly Physics.

Keegan: I actually feel quite thankful and humbled this year, considering it is the COVID-19 period, and the project mentoring was done online.

How is SMP similar to or different from SHARP?

Da Yang: While undergraduates are generally more matured in terms of content knowledge and learning capacity compared to the SMP students, research is something new for them in both cases. The experience of being a mentor is helpful in knowing what sort of problems the students face when it comes to research, and how do I, as a mentor, help students to overcome the problems and to bring them to greater heights.

Keegan: Generally, the task is the same – explaining what I do at a very high level to students – such that regardless of the educational background (Secondary School / Polytechnic / Junior College), they are able to understand the main gist of what I am doing, and try to offer some improvements.

Sometimes, I will actually tell the SHARP students that if a secondary school student can do it, so can they!

Image by Scott Graham from Unsplash

RESEARCH PROJECT

AY2020 Term 1 Honours Session # ^

Project Title: **Exploring Chaos Computing Using Chua Circuit: All-Electric-Controlled Chaotic Logic Gates**

Group Member: **Chew Lijie Bryan, Feng Zhuoer**

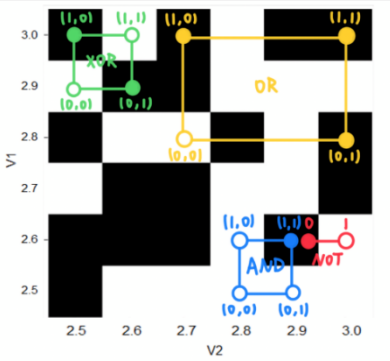
Project Supervisor: **Asst. Prof. Ang Yee Sin**

Motivation: Chaos computing is a computing architecture that harnesses the complexity inherent in non-linear dynamical systems. Chaotic logic gates – an important building block of a computer – can be dynamically and flexibly tuned to perform various logical operations. A "chaos computing chip" can potentially be designed to take on large variety of computational tasks, and is capable of dynamically 'morphing' into different specialized systems, such as CPU, GPU and memory, in real time.

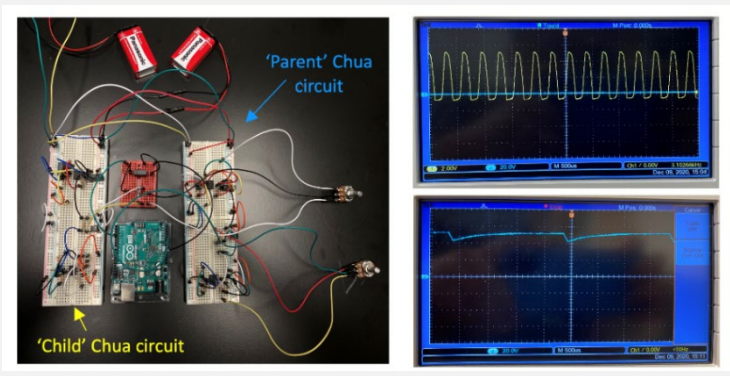
Chua Circuit, invented by Leon Chua in 1983, is an electronic circuit capable of producing electrical chaos. The electrical signal produced by this circuit rarely repeat itself and behaves in a chaotic fashion. Despite being actively studied in the past decades, how Chua circuit can be designed into voltage-tunable logic gates remain an open question thus far. In this project, we experimentally studied a Chua circuit and computationally explored how such circuit can be used to achieve tunable chaos logic gates.

Innovation and Outcome: We employed two voltage-controlled MOSFETs as tuning knobs in designing a dynamically tunable Chua circuit. Aided by a logic design map (see figure below) and *NI Multisim* circuit simulator, we demonstrated that our proposed logic gate can perform four important types of logic gates (AND, OR, NOT, and XOR gates). This logic gate thus meets the operational requirements of modern-day digital computer.

Gate	Input "0"	Input "1"	Input Set	Output
AND	V1 = 2.5V	V1 = 2.6V	(0,0), (1,0) or (0,1)	0
	V2 = 2.8V	V2 = 2.9V	(1,1)	1
OR	V1 = 2.8V	V1 = 3.0V	(0,0)	0
	V2 = 2.7V	V2 = 3.0V	(0,1), (1,0) or (1,1)	1
NOT	When V1 = 2.6V		1	0
	V2 = 2.9V	V2 = 3.0V	0	1
XOR	V1 = 2.9V	V1 = 3.0V	(0,0) or (1,1)	0
	V2 = 2.5V	V2 = 2.6V	(1,0) or (0,1)	1



To understand the behaviours of Chua circuit, we experimentally prototyped three functional and all-electrically tunable Chua circuits. By using an Arduino module, we demonstrated the coupling of two separated Chua circuits. Such demonstration reveals that multiple Chua circuits can be cascaded to form complex circuits, thus offering a proof-of-concept on the feasibility of integrating chaos gate into compact chips. We also converted the voltage output of a Chua circuit into audio signal, thus allowing us to directly 'listen' to the elusive and mysterious chaotic dynamics.



Left: All-electric tuning of 'child' Chua Circuit. **Upper Right:** Output of the Parent Circuit in the presence of Arduino voltage interference. **Lower Right:** Post-processed voltage input into the MOSFET in the 'child' Chua Circuit

Significance and Outlook: Our computational simulation and experimental investigation reveal that Chua circuit is a feasible component for the development of chaos logic gate – a key building block of chaotic computer. Looking forward, the chaos logic gate developed in this work can be expanded into more complex circuits, such as digital full adder. It will also be interesting to explore how 3D printing technology can be used to design advanced chaos circuits. Finally, how chaotic dynamics can be harnessed for quantum computing remains an open question thus far. Future works could be designed to answer these questions.

Honours sessions are advanced classes offered on top of the regular Freshmore courses in Terms 1 to 3. It is specially designed to equip SHARP students with research methodology and to deepen their subject domain knowledge.

^ This research project is related to the topic, **Nonlinear Systems and Chaos**, that was taught in AY2020 Term 1 Honours Session. In this topic, students will learn about the important concepts of nonlinear dynamics and chaos focused on its applications to science and engineering.

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