PhD studentship (Full-time)

Institution	Xi'an Jiaotong-Liverpool University, China
School	School of Advanced Technology
Supervisors	Principal supervisor: Professor Ka Lok Man (XJTLU) Co-supervisor: Dr Chun Zhao (XJTLU) Co-supervisor: Dr Miao Cui (XJTLU) Co-supervisor: Professor Xin Tu (UoL)
Application Deadline	Open until the position is filled
Funding Availability	Funded PhD project (world-wide students)
Project Title	Self-powered sensory-neuromorphic system for deep-learning recognition enabled by synaptic transistors
Contact	Please email ka.man@xjtlu.edu.cn (XJTLU principal supervisor's email address) with a subject line of the PhD project title. The principal supervisor's profile is linked here: https://www.xjtlu.edu.cn/en/staff?department=computer-science-and-software-engineering&alias=ka-man

Requirements:

The candidate should have a first class or upper second class honours degree, or a master's degree (or equivalent qualification), in Electrical and Electronic Engineering, Electronic Science and Technologies, and Computer Science, or related majors.

Evidence of good spoken and written English is essential. The candidate should have an IELTS score of 6.5 or above, if the first language is not English. This position is open to all qualified candidates irrespective of nationality.

Degree:

The student will be awarded a PhD degree from the University of Liverpool (UK) upon successful completion of the program.

Funding:

The PhD studentship is available for three years subject to satisfactory progress by the student. The award covers tuition fees for three years (currently equivalent to RMB 80,000 per annum). It also provides up to RMB 16,500 to allow participation at international conferences during the period of the award. The scholarship holder is expected to carry out the major part of his or her research at XJTLU in Suzhou, China. However, he or she is eligible for a research study visit to the University of Liverpool up to six months, if this is required by the project.

Project Description:

With the rapid development of Internet of Things (IoT) technologies, adaptive and highly distributed sensors, controllers, and actuators are commonly required to work synergistically to complete the functions of linkage, communication, and interaction with human beings. More advanced and intelligent sensory networks call for neuromorphic sensory devices and bio-inspired interactive systems similar to human brains, targeting the implementation of disordered, event-driven, parallel, and distributed computations. Since synapses are the functional connections of neurons and serve as the basic units of computing and learning, designing physical synaptic devices that exhibit synaptic behaviors is the key step to build brain-like computers. Artificial synapses are increasingly prominent due to their good stability, relatively controllable test parameters, and clear operating mechanisms. In addition, three-terminal synaptic transistors have the merits of multiple inputs, enabling the device to perform concurrent learning, parallel data processing, and spatiotemporal dynamic logic function. Combined with advanced deep learning algorithms, synaptic devices have potential application prospect in the field of intelligent robots, wearable and implementable smart chips, health monitoring, etc.

Research Background

With the rapid development of intelligent human-machine interfaces, more advanced and intelligent sensory networks call for neuromorphic sensory devices and bioinspired interactive systems similar to human brains, targeting the implementation of disordered, event-driven, parallel, and distributed computations.[1-2]

The emerging field of synaptic electronics has been proposed as a surprising new way to conduct neuromorphic computing.[3] The synaptic electronics is a class of artificial devices that exhibit synaptic behavior similar to synapses in the nervous system. Among various synaptic electronics, three-terminal transistors with more analogous neuromorphic configurations and comparable artificial synaptic plasticity have been intensively investigated to simulate synaptic functions and construct sensory neurons.[4]

For intelligent sensor networks, the highly distributed synaptic sensory neurons are more readily driven by portable, distributed, and ubiquitous power sources.[5-6] The synapses are the connection points of two adjacent neurons, which plays crucial roles in the neural information transmissions, such as mechanical and optical signals. From the aspect of the distributed energy supply for a sensory network, a triboelectric nanogenerator (TENG) is versatile and thus able to effectively convert different types of mechanical energy into electricity from the ambient environment.[7] Meanwhile, the artificial neural networks (ANNs) for neuromorphic computing technology, and the t-distributed stochastic neighbor embedding (t-SNE) algorithm, which is a nonlinear dimensionality reduction technique for embedding high-dimensional data to allow visualization in low-dimensional spaces. This artificial sensory and nervous system will be a promising technology for various applications in bio-inspired electronics, such as robotics, cyborg systems, and autonomous artificial intelligence.[8-9]

References to Research Background

[1] C. Wan, P. Cai, X. Guo, M. Wang, N. Matsuhisa, L. Yang, Z. Lv, Y. Luo, X. J. Loh, X. Chen. An artificial sensory neuron with visual-haptic fusion. *Nat Commun* **2020**, 11, 4602.

[2] S. Dai, Y. Zhao, Y. Wang, J. Zhang, L. Fang, S. Jin, Y. Shao, J. Huang. Recent Advances in Transistor-Based Artificial Synapses. *Adv. Funct. Mater.* **2019**, 29, 1903700.

[3] S. Oh, J.-I. Cho, B. H. Lee, S. Seo, J.-H. Lee, H. Choo, K. Heo, S. Y. Lee, J.-H. Park. Flexible artificial Si-In-Zn-O/ion gel synapse and its application to sensory-neuromorphic system for sign language translation. *Sci. Adv.* **2021**, 7, eabg9450.

[4] J. Yu, X. Yang, G. Gao, Y. Xiong, Y. Wang, J. Han, Y. Chen, H. Zhang, Q. Sun, Z. L. Wang. Bioinspired mechano-photonic artificial synapse based on graphene/MoS2 heterostructure. *Sci. Adv.* **2021**, 7, eabd9117.

[5] F. Wen, Z. Zhang, T. He, C. Lee. AI enabled sign language recognition and VR space bidirectional communication using triboelectric smart glove. *Nat Commun* **2021**, 12, 5378.

[6] M. Wang, Z. Yan, T. Wang, P. Cai, S. Gao, Y. Zeng, C. Wan, H. Wang, L. Pan, J. Yu, S. Pan, K. He, J. Lu, X. Chen. Gesture recognition using a bioinspired learning architecture that integrates visual data with somatosensory data from stretchable sensors. *Nat. Electron.* **2020**, 3, 563.

[7] J. Yu, G. Gao, J. Huang, X. Yang, J. Han, H. Zhang, Y. Chen, C. Zhao, Q. Sun, Z. L. Wang. Contact-electrification-activated artificial afferents at femtojoule energy. *Nat Commun* **2021**, 12, 1581.

[8] Y. Luo, X. Xiao, J. Chen, Q. Li, H. Fu. Machine-Learning-Assisted Recognition on Bioinspired Soft Sensor Arrays. *ACS Nano* **2022**, DOI: 10.1021/acsnano.2c01548.

[9] Y. Lu, H. Tian, J. Cheng, F. Zhu, B. Liu, S. Wei, L. Ji, Z. L. Wang. Decoding lip language using triboelectric sensors with deep learning. *Nat Commun* **2022**, 13, 1401.

Objectives and Research Questions

This topic is focused on the fields of sensory-neuromorphic system, deep-learning recognition, synaptic transistor and triboelectric sensor with the objectives shown below:

1. By directly converting mechanical stimuli to electrical signals, TENGs can operate as self-powered sensors for tactile sensing without extra power supply, which is vital for developing maintenance-free systems. Therefore, TENG technology could be utilized to realize artificial nerve sensing with self-powered capability, ultra-wide material applicability, and flexibility/stretchability.

2. Employing two-dimensional materials as the floating gate and light-responsive perovskite materials to prepare synaptic transistors offer approaches to prepare high-performance synaptic devices. Furthermore, characteristic signals of synaptic devices, such as the excitatory post synaptic current (EPSC), synaptic short-term plasticity (STP), long-term plasticity (LTP), paired-pulse facilitation (PPF) and spike-time-dependent-synaptic plasticity (STDP), etc.

3. Conduct training and recognition tasks obtained from triboelectric sensors and evaluate the performance of sensory-neuromorphic systems. Meanwhile, Artificial neural networks (ANNs) and the t-distributed stochastic neighbor embedding (t-SNE) algorithm need to be further built to demonstrate the feasibility of improved image recognition assisted with mechanical plasticization, as demonstrated in Figure 3.

4. The programmable persistent photonic conductivity and mechanical behavior-derived modulation/erasure/ plasticization are required for in-memory neuromorphic computation of various sensory data (optical, photonic, tactile, pressure, displacement, etc.) and dual-modal assisted imitation of memory behavior and associative learning.

The research questions, research hypotheses or other ways relevant to the discipline has been concluded:

1. How to improve the recognition accuracy of collecting data sets by optimizing neural network algorithms?

2. How to obtain a stable and low-noise sensory signal as the gate voltage of the synaptic transistor through circuit module optimization, and achieve controllable synaptic characteristics?

3. How to investigate a suitable approach to reach gate-electrolyte modulated synaptic plasticity and photo-stimulus modulated synaptic plasticity?

Research Methods and Approach

Considering the research questions mentioned previously, this project will adopt follow methods to study the proposed research questions:

1. In order to prepare suitable flexible triboelectric sensors, it is necessary to select suitable electrode materials and triboelectric materials. The sensitivity of the sensor could be improved by surface structure modification, and multi-channel sensing could be established by constructing the sensing array. The electrical output parameters such as open-circuit voltage, short-circuit current, and transferred charge are measured by the Keithley meter. A linear motor is utilized to load pressure on the triboelectric sensor. The equivalent circuit diagram should be built, and the COMSOL

Multiphysics could be used to simulate the pressure-strain model and analyze the working mechanism of the sensor. Combining atomic force microscopy (AFM) and Kelvin Probe force microscopy (KPFM) probes, the surface potential could be detected to analyze the electron transfer process.

2. For synaptic device, electrical-stimulus modulated synaptic emulation will be measured to evaluate the gate-electrolyte modulated synaptic plasticity. The gate will receive a pre-synaptic signal and the drain-source will be applied on a constant voltage to read the synaptic weight. By changing the characteristics of the pre-synaptic signal, the ability of the device to achieve various short-term synaptic plasticity and long-term synaptic plasticity will be studied.

3. The multilayer perception-based ANN simulation includes three layers: input layer, hidden layer, and output layer. The three layers are fully connected via synaptic weights, which are updated during the training process by using the BP (Back Propagation) algorithm. Here, the synaptic weights can be expressed by the conductance difference between two equivalent synaptic devices. Through analyzing the difference between the output value of the output vector and the label value of the input value, the synaptic weight matrix difference is calculated according to the gradient descent method. The categorical cross-entropy function is applied as the loss function, and prediction accuracy is used to evaluate the model.

Provisional of Training

From the academic perspective, the research topic is a cutting-edge research area, which will be a unique chance for a PhD student to investigate. The relation between characteristic and theory will be a novel subject in the next generation sensory-neuromorphic system for deep-learning recognition. With PhD scholarship associated with the project, a young scientist will be trained and educated within the following scopes:

1. Cross technology and discipline knowledge about nano-scale electronic device;

2. Completely new concept and theory for self-powered triboelectric sensors;

3. Solid knowledge of semiconductor and gate dielectric;

4. Core intellectual property on the fabrication process of synaptic devices;

5. Hands-on experience in lab from preparation, deposition to characterization;

6. Independent problem-solving skill from experiment and data analysis;

7. Independent research planning and project management skill;

8. Sustainable career development in both academic and industry.

For more information about doctoral scholarship and PhD programme at Xi'an Jiaotong-Liverpool University (XJTLU), please visit

https://www.xjtlu.edu.cn/en/admissions/doctoral/entry-requirement-phd/
https://www.xjtlu.edu.cn/en/admissions/doctoral/postgraduate-research-scholarships

How to Apply:

Interested applicants are advised to email ka.man@xjtlu.edu.cn the following documents for initial review and assessment (please put the project title in the subject line).

- CV
- Two formal reference letters
- Personal statement outlining your interest in the position
- Certificates of English language qualifications (IELTS or equivalent)
- Full academic transcripts in both Chinese and English (for international students, only the English version is required)
- Verified certificates of education qualifications in both Chinese and English (for international students, only the English version is required)
- PDF copy of Master's Degree dissertation (or an equivalent writing sample) and examiners reports available