# Mr. Hanlin CAI

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## OVERVIEW

As a highly motivated and collaborative student majoring in engineering, I have a strong interest in the industrial IoT system and network security. During undergraduate studies, I gain valuable experience in hardware design, attack detection, and machine learning. This entails completing a six-month industrial internship, publishing two peer-reviewed papers, and securing five awards at the national level in competitions.

## EDUCATION

**Fuzhou University (FZU) (China-Ireland Cooperative Program)** ***Sep. 2020 – Jun. 2024***

*Bachelor of Engineering in Automation (Taught in English)*

- Current GPA: 3.81/4.00 (Top 8%), Arithmetic Average Score: 88.38

**National University of Ireland, Maynooth (MU)** ***Sep. 2020 – Jun. 2024***

*Bachelor of Science in Robotics and Intelligent Devices (Combined Degrees)*

- Expect to achieve First Class Honours (Third-year score: 88.7)

**Main Courses:** Control System Design, Software Engineering, Operating System, Digital System, Real-time and Embedded System, Robotics and Automation, Algorithms and Data Structures, Machine Learning

- **Course Projects:** Industrial Internship Experience (97/100), Signals & Systems Integration Project (92/100)
- **Scholarships:** FEPG Scholarship **(Highest Award at FZU, Top 0.5%)**, XiamenAir Scholarship **(Top 1%)**, Best Academic Performance Award at MU (Top 2%), First Prize Scholarship at FZU (Top 2%, **Three Times**)

## RESEARCH EXPERIENCE

**Embedded Development Intern, Huading Intelligent Manufacturing Technology Co. LTD., Fujian, China**

***Mentors: SN.ENGR Yuxiong Xia and Dr. Dan Chen*** ***Jan. 2023 – June 2023***

**Outline:**

- Successfully tackled the complexities of instrument inspection with intricate industrial environments by devising an intelligent inspection system leveraging IoT devices, quadruped robots and cloud computing.

**Key Responsibilities:**

- Implemented real-time data collection of sensor modules using ESP32; Integrated machine control with visual algorithms to empower quadruped robots to extract and analyze images of industrial instruments.

**Achievement:**

- Won the Best Technology Award in China national youth science innovation project competition (Top 1%).

**Research Assistant, Laboratory of Industrial Automation Control Technology and Information Processing**

***Supervisors: Prof. Zhezhuang Xu and Dr. Yuan Meng*** ***Oct. 2022 – Present***

**Outline:**

- Addressed the security vulnerabilities and susceptibility to attacks in Bluetooth Low Energy Networks utilizing a hybrid attack detection mechanism based on physical features and machine learning.

**Key Responsibilities:**

- Established a BLE experimental platform, collected datasets using BLE Sniffer & nRF Connect.
- Developed an attack detection algorithm based on temporal convolutional network, text-CNN and SVM.

**Achievement:**

- Secured a research grant of $3000; Authored a research paper and submitted to **AAAI 2024** conference.

**Visiting Student, Cambridge Centre for the Integration of Science, Technology and Culture (CCISTC)**

***Supervisor: Prof. Pietro Liò*** ***June 2022 – Dec. 2022***

**Outline:**

- Resolved the challenge of detecting Multiple-mix-attacks within IoT network systems by developing a detection framework that integrates reconstruction and classification learning approaches.

**Key Responsibilities:**

- Developed a multiple-mix-attacks detection algorithm based on LSTM and random forest models.

**Achievement:**

- Research report achieved a ranking within top 5%; Won an outstanding oversea visiting scholarship ($2400).

## PUBLICATIONS

**[1]** Hanlin Cai, Zheng Li, Jiaqi Hu, Wei Hong Lim, Sew Sun Tiang, Mastaneh Mokayef, Chin Hong Wong*. **"Optimizing Traffic Sign Detection System Using Deep Residual Neural Networks Combined with Analytic Hierarchy Process Model".** *The 28th International Conference on Artificial Life and Robotics, 2023. Recommended for expanding publication in the Journal of Advances in Artificial Life Robotics.*

**[2]** Hanlin Cai, Jiaqi Hu, Zheng Li, Wei Hong Lim, Mastaneh Mokayef, Chin Hong Wong*. **"An IoT Garbage Monitoring System for Effective Garbage Management".** *The 4th International Conference on Computer Engineering, Network, and Intelligent Multimedia (IEEE CENIM), 2022.*

**[3]** Hanlin Cai, Yuchen Fang, Meng Yuan, Zhezhuang Xu*. **"BLEGuard: Hybrid Detection Mechanism for Spoofing Attacks in Bluetooth Low Energy Networks".** *The 38th AAAI Conference on Artificial Intelligence (One of most important conferences for AI Research). Under review, 2024.*

**[4]** Hanlin Cai, Jiacheng Huang, Yuchen Fang, Shuying Liu, Wenzhuo Fan, Chen Dan, Zhezhuang Xu*. **"Detecting Multiple-mix-attack in IoT Networks through Reconstruction and Classification Machine Learning Techniques".** *IEEE Sensors Journal. Under review, 2024.*

## AWARDS & HONOURS

Finalist of China International Internet+ Innovation and Entrepreneurship Competition (**Top 3%**) *Oct. 2023*
Best Technology Award in China Youth Science Innovation Project Competition (**Top 1%**) *Aug. 2023*
Second Prize in National Collegiate Internet of Things Technology and Application Competition *Aug. 2023*
Finalist Award in International Mathematical Contest in Modeling (**Top 1%** of all 20508 paper) *May 2023*
First Prize in China Contemporary Undergraduate Mathematical Contest in Modeling (Top 5%) *Dec. 2022*
Third Prize in Chinese National College Student Computer Design Competition *Aug. 2022*
Outstanding volunteer in the 44th Session of the World Heritage Committee *July 2021*

## SKILLS & SPECIALTY

**Language Skills:** English (Fluent), Mandarin (Native), Hokkien (Native), Cantonese (Native)
**Programming**: Python, MATLAB, Java, C++, HTML, CSS, JavaScript, Bash, Markdown, LaTeX
**Specialty: Swimming** (Reached Chinese national second-level swimming athlete standard; Championship of 100-meter freestyle swimming competition of Fuzhou University in *June 2022*)

## VOLUNTEER WORKS

**Department of Volunteer Work, Youth League Committee of Fuzhou University**
***Deputy President (Mentor: Dr. Yixuan Hu)*** ***Sep. 2021 – Sep. 2022***

- **Outline:** Managed the planning, operation, and publicity of volunteer service work, and helped mentors to promote the improvement, digitization and intelligence of volunteer service management.
- **Key Responsibilities:** Organized 39 activities (19 volunteer activities for epidemic prevention and control, 12 for community service, and 8 for environmental protection) with over 890 participants in related activities.
- **Achievement:** Responsible for the publicity work of 17 volunteer activities, with a total of more than 240,000 page views, covering more than 40,000 people. Personal volunteer service time exceeded 240 hours.

**Pietro Lio'**
*Professor in Computational Biology*
*PhD in Non Linear Dynamics and Complex Systems*
*PhD in Genetics Sciences*

UNIVERSITY OF CAMBRIDGE

# Letter of Recommendation

13/11/2022

To Whom It May Concern,

I am pleased to recommend our student Hanlin Cai, whom I met with and supervised during the Online Research Training Programme in Artificial Intelligence organised by Cambridge Centre for the Integration of Science, Technology and Culture, University of Cambridge from 25/07/2022 to 04/11/2022.

Cai stood out as a great student in our programme. He proved that, not only can he understand the great potential uses of Artificial Intelligence, but that he understands the mathematical descriptions of what makes AI algorithms a powerful tool in the hands of a data scientist. His project named 'RIGMS Testbed for IoT Cybersecurity Research Using Machine Learning Based Approach' combined hardware IoT system with advance deep learning algrothims, which I deem respectable and highly commendable. I could see a great potential for his work to be published and I enjoyed working and supervising Cai, as he was a very hardworking and organised student and was able to sustain his ideas and opinions with thought-out arguments and in a mannered way, thus generating interesting academic discussion.

The student has worked tirelessly with enthusiasm throughout the programme engaging in discussions and debates, resulting in improving his academic, but also his language and communication skills. The academic input has further expanded the student's knowledge in the field as well. He took part in a research project which was presented to peers in the field and the excellent research and work carried out by him have demonstrated the student's strong capability in critical thinking and research skills.

Cai is wishing to continue further education by studying an advanced degree programme. Based on the student's skills and capabilities that I have witnessed during this programme and the academic development that this programme has resulted in, I can confidently recommend Cai for an advanced degree programme and rest assured that he will excel in this degree.

Yours sincerely,

Pietro Lio'
Computer Laboratory, William Gates Building
JJ Thomson Avenue Cambridge CB3 OFD
Telephone: 01223 763604; Fax: 01223334678; E-mail: pl219@cl.cam.ac.uk

Intern No. DIC202200102338

7th November 2022

UNIVERSITY OF CAMBRIDGE

Cambridge Centre for the Integration of Science, Technology and Culture

# Programme Transcript

Student: Hanlin Cai

Subject: AI

Programme Leader: Prof. Pietro Lio'

Programme Period: 25/07/2022 – 04/11/2022

Research Project Title: RIGMS Testbed for IoT Cybersecurity Research Using Machine Learning Based Approach

| Programme Assessment | Grade |
|---|---|
| Participation | A |
| Research Proposal | A |
| Research Report | A |

Description of Grading System

A - Excellent B - Very Good C - Good

D - Satisfactory E - Sufficient F - Failed

This is to certify that the above-named student attended the Online Research Programme organised by the Cambridge Centre for the Integration of Science, Technology and Culture, University of Cambridge, and obtained the results indicated above.

Professor Nicola Clayton, FRS

Director of Cambridge Centre for the Integration of Science, Technology and Culture,

University of Cambridge

Intern No. DIC202200102338

7th November 2022

UNIVERSITY OF CAMBRIDGE

Cambridge Centre for the Integration of Science, Technology and Culture

# Certificate of Completion

This certificate is presented to

## Hanlin Cai

in recognition of the accomplishments and contributions in completing the **Cambridge Online Research Programme** in **Artificial Intelligence** from 25th July to 4th November, 2022 by the Cambridge Centre for the Integration of Science, Technology and Culture of the University of Cambridge.

Professor Nicola Clayton, FRS
Director
Cambridge Centre for the Integration of Science, Technology and Culture
University of Cambridge

Professor Pietro Lio'
Professor
Department of Computer Science and Technology
University of Cambridge

# Securing Billion Bluetooth Devices leveraging Learning-based Techniques

*Keywords: Bluetooth Low Energy, Security and Privacy, Deep Learning*

**Introduction:** Named after the Viking King Harald Bluetooth, Bluetooth is one of the most popular protocols for short-range wireless communications. The advent of the Bluetooth Low Energy (BLE) standard has further solidified its dominance in the era of IoT and 5G. It is expected that BLE will be empowering up to 7.5 billion devices by 2027 [1]. This exponential adoption, however, is overshadowed by BLE's inherent security limitations and firmware vulnerabilities, which render devices susceptible to spoofing attacks, compromising not only the integrity of myriad BLE-enabled systems but also the confidentiality of sensitive data in transit [2].

**Background:** In response to the security challenges, an out-of-the-box detection method has been proposed, leveraging BLE's cyber-physical features to defend against spoofing attackers without requiring any interference or updates [3]. Additionally, several works rely on learning-based techniques to identify the malicious packets within BLE network traffic. A learning framework that integrates reconstruction and classification models was suggested to classify packets as benign or malicious inside each suspicious batch with high precision near 99.0% [4]. However, most existing methods struggle with the challenge of reconciling high detection accuracy with low computational cost, which limits their applicability across a more expansive range of real-world situations [5, 6].

***Prior Work by the Applicant:*** During my internship at State Key Laboratory of Industrial Automation Control Technology and Information Processing in my college, I spearheaded a research initiative focused on detecting spoofing attacks in BLE networks through cyber-physical feature judgment. To evaluate the judgment algorithm, I established a physical BLE testbed by deploying 16 mainstream consumer BLE devices like smart thermometers and door locks, as well as four simulated attacker platforms. By collecting approximately 902,980 benign advertising packets and 107,546 spoofed advertising packets, the dataset used for detection algorithm validation was formed. Experimental results show that our proposed algorithm achieved an average accuracy of over 98.7% and can be deployed on low-cost off-the-shelf platforms. This prior work can contribute substantial data and code [7] and valuable experience to support my forthcoming research.

**Proposal:** I propose to further explore the challenge of advanced spoofing attacks detection through combining the reconstruction model and classification model for efficient large-scale online detection. Previous works [4, 8] have verified the effectiveness of extracting characteristic features of BLE networks for learning, these statistical features include used channel numbers (*UCN*), advertising interval (*INT*), received signal strength (*RSS*), and carrier frequency offset (*CFO*). However, two essential enhancements must be made to existing learning strategy for a better balance between high accuracy and low detection cost. These focus on pre-detection and key feature extraction.

***Pre-detection:*** The extensive computational overhead of current reconstruction models hinder their suitability for real-time online detection. To improve this, I propose a novel pre-detection algorithm derived from my prior work, which promises to substantially decrease the computational load, making continuous online detection feasible without incurring exorbitant processing costs.

***Feature Extraction:*** While the all-feature end-to-end models like Transformer have demonstrated outstanding performance in network text-classification tasks [9], their substantial resource requirements render it impractical for deployment within BLE networks. Thus, I propose to circumvent this by embedding key feature extraction into cost-efficient classification models, striking an optimal balance between computational resource demands and network packet analysis efficacy.

**Method:** In this study, I plan to develop a novel hybrid detection mechanism for BLE spoofing attack detection in three stages: (i) pre-detection, (ii) reconstruction, and (iii) classification.

***Pre-detection Algorithm:*** The specificity features of advertising packets can be used to determine malicious activities within BLE networks. The abrupt changes in *UCN* and *INT* can be attributed to the occurrence of potential attacks. Additionally, to detect advanced spoofing attacks, *RSS* and *CFO* are utilized to implement a continuous pre-detection mechanism. In my work, three network sniffers will be deployed to collect the value of *RSS* and *CFO* in the lookback window to infer valid ranges, and then inspect relevant values of advertising packets in the observation window. Once the system detects an abnormality in either of these network features, an alarm will be raised. This pre-detection algorithm can be deployed in BLE devices without any interference.

***Reconstruction Model:*** Following the pre-detection stage, where the system potentially identifies malicious activities and triggers an alarm, the focus shifts to the reconstruction analysis. In the offline training phase, I aim to minimize the error between learned data $D_L$ and original dataset $D_T$. In the online testing phase, if the input data batches contain any malicious packet, the reconstruction error will obviously increase. In this research, network reconstructions are conducted using a lightweight temporal convolutional network (TCN) [10]. The residual is defined as $R(D_T, D_L) = |D_T - D_L|$ with $D_L = f(D_T)$ and $f$ represents the transformation of TCN auto-encoder. Subsequently, I will evaluate the residual to determine the anomaly score $\alpha$ for each data batch, as illustrated in Equation (1), where $R_\alpha$ represents the corresponding residual, $\mu$ is the mean value of the residual, and $\sigma$ is its standard deviation. In a word, the reconstruction model is employed to detect suspicious data batches within network traffic. In the next step, classification models will be utilized to identify the malicious packets involved in each suspicious batch.

$$\alpha = \begin{cases} 0, \ when \ |R_\alpha - \mu R_\alpha| \leq 3 * \sigma R_\alpha \ \longrightarrow \ Normal \ Batch \\ 1, \ when \ |R_\alpha - \mu R_\alpha| > 3 * \sigma R_\alpha \ \longrightarrow \ Suspicious \ Batch \end{cases} \tag{1}$$

***Classification Models:*** Upon the identification of suspicious batches, the next stage is to categorize these packets into different classes: benign or malicious. In this study, the text-convolutional neural network (text-CNN) [11] is employed for traffic feature extraction while the packet classification will be conducted using four cost-efficient classifiers (SVM, KNN, Random Forest and Naïve Bayes) to prevent bias in text analysis [12]. The network payload-based features are generated by converting the payload bytes into low dimensional vectors utilizing the *Word2Vec* techniques. These vectors served as the input for the text-CNN model, and the extracted key features were concatenated with statistical features and provided for the final classification models.

**Evaluation:** I will conduct experiments based on the dataset collected from real-world BLE networks. In prior work, I have built a physical BLE testbed with 16 user BLE devices, 4 attacker platforms, and 3 network sniffers. This testbed will be further expanded and be used to generate large-scale data for model training and online testing. Also, I will perform experiments based on known real-world attacks like InjectaBLE [13] and Btlejack [14]. The results of my method will be compared to baseline models, including BLE-guardian [15], BlueShield [3], and BLEDiff [16].

**Broader Impact:** This proposal addresses a crucial challenge in Bluetooth security and provides a substantial dataset for wireless security research. Beyond security improvements, the approach encourages interdisciplinary collaborations and sets a precedent for deploying deep learning models in resource-constrained environments. Successful outcomes can significantly reduce the global economic and social repercussions of attacks on billions of Bluetooth devices, influencing not only the field of cybersecurity but also the daily lives of countless users dependent on these technologies.

## References


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