# When AI Meets the Internet of Things

A BRIEF INTRODUCTION TO CISCO-LA TROBE CENTRE FOR AI AND IOT

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***Abstract*—The Cisco-La Trobe Centre for AI and Internet of Things (IoT) based at La Trobe University is Australia's only industry-sponsored research centre which specializes in combining the superpowers of AI and IoT technologies. The Cisco AIoT Centre was founded by Professor Wei Xiang, Cisco Research Chair of AI and IoT based at La Trobe University, and is technically sponsored by Cisco. The Centre currently has 15 affiliated academic staff and ~20 research students. Since its establishment in October 2020, the Centre has played instrumental roles in securing $12M external research funding from various government and industry sources. Through working closely with Cisco and its clients and ecosystem partners, the Centre has established both academic credentials and extensive industry linkages in priority areas of critical supply chain, sustainability, digital agriculture and digital health.**

***Index Terms*—Artificial Intelligence, Internet of Things**

## I. INTRODUCTION

The Cisco-La Trobe Centre for AI and Internet of Things (IoT) was founded by Professor Wei Xiang in October 2020, who is Cisco Research Chair of AI and IoT at La Trobe University. The Cisco AIoT Centre is unique in the sense that it is Australia's only industry-sponsored research centre that specializes in exploiting the synergy of AI and IoT technologies. The Centre currently has 15 affiliated academic staff and ~20 research students. Since its establishment in late 2020, the Centre has played instrumental roles in securing $12M external research funding from various government and industry sources including the Australian Research Council (ARC). Through working closely with Cisco and its clients and ecosystem partners, the Centre has established both academic credentials and extensive industry linkages in priority areas of critical supply chain, sustainability, digital agriculture and digital health.

The Cisco AIoT Centre prides itself on the so-called "two-pillar" research strategy. That is, on one hand, the Centre members conduct cutting-edge and world-leading academic research. This includes publishing in some of the world's best research publications in its chosen fields, e.g., IEEE TPAMI, TNNLS, TIP, TMC, TSP, and JSAC, as well as winning national competitive research grants such as ARC and CRC grants. On the other hand, the Centre works closely with its industry partners such as Cisco and Optus to conduct impactful research projects aiming at industry-driven real-world problems.

The above provides only a glance at the Cisco AIoT Centre, and more details are given in the rest of this article.

## II. RESEARCH AREAS

The Cisco-La Trobe Centre for AI and IoT focuses on combining AI and IoT technologies, as well as exploiting the synergy between the two powerful technologies. The Center also develops advanced AI and IoT solutions to a few selected vertical application domains including critical supply chains, digital health, digital agriculture, and environmental sustainability.

The key research areas of the Cisco AIoT Centre are detailed as follows.

### A. *Machine-to-machine and IoT Communications*

Ubiquitous connectivity is crucial for IoT sensors. In a world with insatiable thirst for digital connectivity and the explosion of machine-to-machine communications, the need for reliable, high-speed and secure communications is crucial to building a connected society. Ubiquitous and energy-efficient M2M and IoT communications face great challenges in the sense that sensors are often deployed in the field and battery replacement is often not an option or incurs significant labor costs. As a result, power-efficient IoT communications are imperative.

Our strengths in this research area include:

1. Low-power wide-area IoT communications
2. LoRaWAN and NB-IoT sensor communications
3. 5G IoT communications
4. Wireless sensor networking
5. Massive IoT networks

See [10, 13, 15, 20] for examples of our research in this area.

### B. *Advanced 5G, 6G and Satellite Communications*

5G communications networks are being rapidly deployed commercially all over the over, which are becoming critical enabling digital infrastructure for a plethora of applications such as Industry 4.0, smart cities, vehicular networking, etc. Meanwhile, the planning and early development of 6G mobile communications systems have already begun. 5G's ultra-broadband, ultra-reliable, and ultra low-latency communications cannot fully satisfy some emerging applications such as holographic video communications, haptic-based telemedicine, Industry 5.0, etc. Compared with 5G, 6G mobile communications not only excel in power consumption, latency, reliability, privacy and security, but also support non-terrestrial networks through integrated satellite-terrestrial communications with the objective of enabling ubiquitous and high-capacity global connectivity.

Our strengths in this research area include:

1. IoT over satellite communications
2. Integrating space and terrestrial networks for 6G
3. NOMA for 5G and 6G communications
4. Integrated sensing and communications for 5G/6G
5. Advanced error control coding for 5G/6G systems

See [14, 17, 19] for examples of our research in this area.

### *C. AI-driven Wireless Communications*

Conventional wireless communications system designs have been guided by classic Shannon information theory. However, this design paradigm is nearly reaching its limits and can no longer satisfy the diverse service requirements of future wireless communications systems in bandwidth, throughput, latency, reliability, quality of experience (QoE), etc. Past and present wireless communications systems have been governed by mathematical models and mostly derived from classical communication theories. However, these traditional design techniques are unlikely to meet the QoS and QoE requirements imposed by next-generation wireless communications systems. On the other hand, the advent of AI and machine learning technique is heralding a paradigm shift from traditional communication theory oriented designs to AI-driven designs. It has been proven that AI techniques can achieve superior performances for wireless communications applications attributed to their exceptional learning and optimization capabilities for complex and dynamic communications scenarios.

Our strengths in this research area include:

1. Distributed and federated learning for communications and networking
2. Deep reinforcement learning for computation offloading and resource allocation
3. AI/ML approaches for SCMA and NOMA communications systems
4. AI/ML approaches for spatial modulation

See [3, 4, 7] for examples of our research in this area.

### *D. AI for IoT & Sensor Data Analytics*

With the rise of the Internet of Things (IoT), industries are awash in massive amounts of big data from an increasing array of wired and wireless sensors. These sensors often form networks and continuously monitor and report on essential information like heart rates of a patient, fuel load of forest, etc. It should be taken note that original sensor data are ‘useless’, unless we turn them into information, insights, and knowledge using advanced data analytics techniques such as machine learning. Besides, raw sensor data straight out IoT sensors contain large-scale ‘unclean’ data, which need to undergo data cleaning processes before data analysis can be performed to useful information from cleaned IoT sensor data. Another important branch of data analytics is predictive analytics, which aims at making predictions about future outcomes based on historical data and analytics techniques such as statistical modeling and machine learning. With the aid of sophisticated predictive analytics tools, individuals and organizations alike can use past and present data to reliably forecast trends and behaviors in the future.

Our strengths in this research area include:

1. IoT sensor data imputation
2. Time series data analytics
3. Marine big data analytics
4. Predictive analysis for asset maintenance
5. Physical-informed neural networks

See [5, 8, 9, 12, 18] for examples of our research in this area.

### *E. Light Field Photography Based Computer Vision*

Light field imaging and photography has emerged as a promising technology for capturing richer visual information from our world. As opposed to traditional photography, which captures a 2D projection of the light in the scene integrating the angular domain, a light field collects radiance from rays in all directions, demultiplexing the angular information lost in conventional photography. This higher-dimensional representation of visual data offers powerful capabilities for scene understanding, and substantially improves the performance of traditional computer vision problems such as depth sensing, post-capture refocusing, segmentation, etc. However, the high-dimensionality of light fields also brings up new challenges in light field data capturing, processing, compression, and display. Consequently, light field image and video processing has become increasingly popular in the field of computer vision and computer graphics.

Our strengths in this research area include:

1. Light field multi-view image depth estimation
2. Light field video streaming
3. Light field multi-view video coding
4. Light field based 3D telemedicine

See [1, 2] for examples of our research in this area.

### *F. IoT Security and Privacy*

IoT devices and the data they collect can provide convenience, efficiency and insights into essentially every aspect of our world. Although the IoT brought huge benefits, privacy and security are among the significant challenges of the Internet of Things. Users need to trust IoT devices and related services are secure. Moreover, IoT safety must be considered to prevent the IoT system and its components from causing an unacceptable risk of injury or physical damage and at the same time considering social behaviour and ethical use of IoT technologies to enable effective security and safety. Unlike security and privacy issues in the conventional cyber space, the low capabilities of IoT devices in terms of their energy and computing capabilities, the unreliable nature of the wireless channel, and physical vulnerability are among the contributing factors to some unique security vulnerabilities in IoT. These factors make security and privacy for IoT more challenging than their conventional cyber space counterpart.

Our strengths in this research area include:

1. Physical-layer security for wireless IoT
2. Light weight IoT security algorithms
3. Secure machine-to-machine communications
4. AI and machine learning for IoT security

See [6] for examples of our research in this area.

### G. Digital Twins for Industry 4.0

A digital twin is a digital representation of a physical object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making. This amounts to creating a highly complex virtual model that is the exact counterpart (or twin) of a physical thing. Digital twins offer a real-time look at what's happening with physical assets, which can radically reduce development costs and alleviate maintenance burdens. Digital twins can be used to predict different outcomes based on variable data. With additional software and data analytics, digital twins can often optimize an IoT deployment for maximum efficiency, as well as help designers figure out where things should go or how they operate before they are physically deployed. Digital twins fuse many emerging technologies such as IoT, wireless communications, artificial intelligence, big data analytics and data visualization in the form of virtual and augmented reality. It is recognized as one of the pillars of Industry 4.0, and has found widespread applications in areas such as smart manufacturing, intelligent transport, and digital healthcare.

Our strengths in this research area include:

1. IoT for digital twins
2. Machine learning for digital twins
3. Digital twins for smart manufacturing

See [11, 16] for examples of our research in this area.

### H. Explainable Artificial Intelligence (XAI)

Dramatic success in machine learning has led to a torrent of AI applications. Continued advances in AI techniques promise to produce autonomous systems that will perceive, learn, decide, and act on their own. However, the effectiveness of these systems is limited by the machine's current inability to explain their decisions and actions to human users. Conventional AI autonomous systems act like an opaque "black box", which produces outputs without yielding any decision rationale information. On the contrary, Explainable AI or XAI technology can makes a machine learning system behave like a "white box". This means that an XAI system not only produce more explainable models, while maintaining a high level of learning performance, but also enable human users to understand, appropriately trust, and effectively manage the XAI system. In essence, XAI is a set of processes and methods that allows human users to comprehend and trust the results and output created by machine learning algorithms. EAI helps characterize model accuracy, fairness, transparency and outcomes in AI-powered decision making. AI explainability also helps organizations adopt a responsible approach to AI development.

Our strengths in this research area include:

1. Explainable AI for medical image analysis
2. Explainable AI for time series data analytics
3. Model-dependent and model-agnostic explainability
4. Explainable Transformer networks

## III. Research Collaborations with Industry and Real-World Impact

AI and IoT technologies have been seen dramatic success and uptake by nearly every vertical industry ranging from manufacturing to healthcare. One of the two pillars of the Cisco-La Trobe Centre for AI and IoT is to work with industry partners to deliver real-world impactful research.

In the following, we use two example use cases to showcase how the Cisco AIoT Centre works with its industry partners to tackle real-world problems and to deliver impactful research solutions. It is advised that some project details are deliberately concealed due to confidentiality commitments to our industry partners.

### A. Digital Twin for Modelling the Molten Oxygen Electrolysis Reactor

This project funded by Janco Enterprise Ptd. Ltd. aims to build a digital twin for modelling the molten oxygen electrolysis reactor. The project objective is to maintain optimum Molten Oxide Electrolysis (MOE) reaction conditions in a stainless steel tube furnace. MOE is a method of extracting metal from their ore bodies using electricity and zero carbon in the reaction.

In the established digital twin, Physics-Informed Neural Networks (PINNs) are employed to approximate the solution of partial differential equations (PDEs) to produce a grid-based solution of Finite Element Analysis (FEA) in a fraction of time it would take matrix math approaches to arrive at a solution. This allows for approximation of systems in real-time with minimal feedback from sensors. Edge AI is used in conjunction with MOE to maintain optimum reaction conditions and to allow for optimum efficiency of the process.

### B. Automated Water Channel Inspection Using AI

This project is in collaboration with Southern Rural Water (SRW) to investigate the possibility of utilising an AI system combined with Remotely Piloted Aerial Systems (RPAS) to complete inspections on its channel and drainage network in the Macalister Irrigation District. The Macalister Irrigation District is located approximately 200km south east of Melbourne, in the Gippsland region. In this area, SRW manages some 450+km of open Irrigation Channels, 500+km of open Drains and 50km of pipeline assets. These assets range in size from 2m in width to 10m wide. SRW has an obligation to inspect all its physical assets every 5 years on a rolling basis. Current methods for doing this involve maintenance teams and operators driving the channels and drains from top to bottom, often needing to hop between properties, to assess the condition of each segment and give it a rating. It is also very time consuming and at times dangerous, as operators may need to traverse rough terrain and private land to gain access to the assets.

SRW has engaged the Cisco-LTU AIoT Centre to create an application which analyses RPAS captured video footage, after being trained with SRW data, and detects problems in the channel system dynamically as new videos are fed into it. Future iterations of the application will potentially learn to predict likelihood of occurrences where conditions are met. The application will also produce a report, which captures the

GPS location detailed in the metadata on the video file, the extent and detail of the issue identified (and probability of accuracy) and captures a frame from the video that can be passed on to the maintenance team for human analysis and job planning.

## IV. Research Facilities

The Cisco-La Trobe Centre for AI and IoT is located within the Digital Innovation Hub (DIH) at La Trobe University's Melbourne campus. The DIH is a $9M state-of-the-art innovation facility that is funded by the Victoria State Government. Cisco and Optus are two anchor tenants in the DIH, which will house the Cisco Innovation Central @ Melbourne (ICM) and an Optus 5G Lab.

The DIH features state-of-the-art IoT, networking and computer vision equipment donated by Cisco, alongside cutting-edge high performance computing and data storage infrastructure.

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