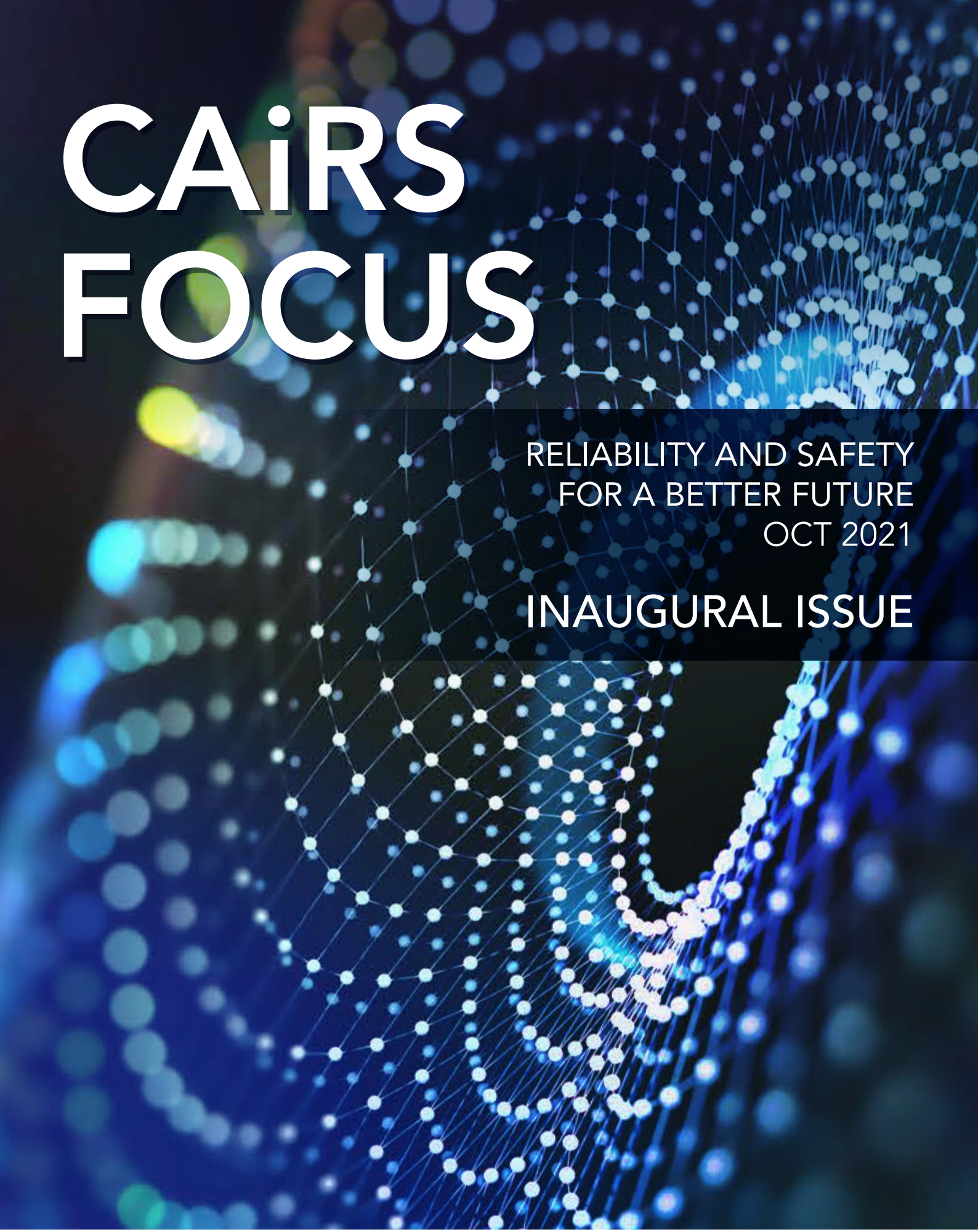

CAiRS FOCUS

RELIABILITY AND SAFETY
FOR A BETTER FUTURE
OCT 2021

INAUGURAL ISSUE

CAiRS
產品可靠性暨系統安全研發中心
CENTRE FOR ADVANCES IN RELIABILITY AND SAFETY

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

UNIVERSITY OF MARYLAND
A. JAMES CLARK SCHOOL OF ENGINEERING

Acknowledgement: This magazine is supported by *Centre for Advances in Reliability and Safety (CAiRS), an InnoHK Research Cluster of HKSAR Government*

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INDUSTRY SHARING

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Message from the PolyU Deputy President and Provost, Chairman, CAiRS Board of Director

Professor Wing-tak Wong

The Hong Kong Polytechnic University (PolyU)

Welcome to the inaugural issue of **CAiRS Focus**, a yearly publication produced by the Centre for Advances in Reliability and Safety (CAiRS), that aims at providing cutting-edge insights and knowledge to professionals, practitioners, and the general public on product reliability and system safety.

As a newly established research centre based in Hong Kong and funded by the InnoHK Research Clusters of the HKSAR Government, CAiRS is committed to becoming the world-leading hub for research in reliability and safety innovation. The Hong Kong Polytechnic University (PolyU) and the Center for Advanced Life Cycle Engineering (CALCE) of the University of Maryland, College Park, USA (UMD) joined forces to launch CAiRS in early 2021, which marked a significant step in furthering impactful research and innovation in Hong Kong and in the region.

CAiRS will harness the emerging technologies that underpin the Fourth Industrial Revolution, such as Artificial Intelligence and Data Science, to advance the safety and reliability of critical systems including Public Utilities, Transportation, Electronics & Micro-electronics, Advanced Manufacturing, and Smart sensor & IoT, to help elevate safety standards across various applications and industries. By leveraging PolyU's robust research capabilities across a broad range of disciplines including engineering, science, technology and other high-impact areas, as well as CALCE's leading expertise in reliability science, I am confident that CAiRS will succeed in promoting innovative safety and reliability solutions that are greatly beneficial to the industries as well as the public in Hong Kong and beyond.

CAiRS already has many research programmes related to AI-based reliability and safety underway, in collaboration with more than 20 local companies. I very much look forward to the scientific breakthroughs that will emerge and the success stories that will be shared in the future as a result of these programmes.

Lastly, I would like to thank members of the CAiRS editorial team, in particular, Ir Professor Winco K.C. Yung of PolyU, Professor Michael G. Pecht and his team from UMD, as well as Professors working with CAiRS from the Industrial and Systems Engineering, Electrical Engineering, and Electronic and Information Engineering departments of PolyU, for their contribution to the launch of this magazine.

I wish you an enjoyable read.

"CAiRS already has many research programmes related to AI-based reliability and safety underway, in collaboration with more than 20 local companies. I very much look forward to the scientific breakthroughs that will emerge and the success stories that will be shared in the future as a result of these programmes."

Message from the Director

Center for Advanced Life Cycle Engineering (CALCE)

Professor Michael G. Pecht
University of Maryland

As the Director of Center for Advanced Life Cycle Engineering (CALCE) at University of Maryland, College Park, Maryland, USA, I would like to welcome everyone to this first issue of the CAiRS magazine.

CAiRS is a collaboration between the Hong Kong Polytechnic University (PolyU) and the Center for Life Cycle Engineering, funded by Hong Kong SAR Government. The goals of CAiRS is to conduct research and development to enable advanced design, manufacture and test of next generation reliable and safe electronics for transportation, consumer products, telecommunication systems, public utilities, aviation, and infrastructure in Hong Kong. CALCE is contributing it's expertise in fundamental research in artificial intelligence-based reliability and safety innovation, including anomaly detection and syndromic surveillances, innovative diagnostics for system health management, prognostics for remaining useful life assessment, and functional safety assurance. PolyU brings strong experience in electronics, electrical, computer, mechanical, healthcare, transportation and industrial engineering, with extensive local industrial support bases in Hong Kong (e.g. HKEIA and HKEIC of FHKI). Together, our goal is to create a new paradigm for reliability science and promote customized product health management for different industry sectors, using real-time, in-situ, artificial-intelligence based reliability and safety analytics.

Our ultimate goal is to make Hong Kong known and respected for high quality, reliable and safe components, products, systems and infrastructure. To do this, we will address the scientific and technological electronics reliability and safety challenges of national interest by advancing the symbioses between mathematics, engineering, computing, and data science; launch new interdisciplinary communities; and develop the future national workforce.

> **"Our ultimate goal is to make Hong Kong known and respected for high quality, reliable and safe components, products, systems and infrastructure."**

Prof Michael Pecht (30,000+ citations, 80+ H-Index) has a BS in Physics, an MS in Electrical Engineering and an MS and PhD in Engineering Mechanics from the University of Wisconsin. He is a Professional Engineer, an IEEE Fellow, an ASME Fellow, an ASM Fellow, and an SAE Fellow. He served as editor-in-chief of IEEE Access for six years, as editor-in-chief of IEEE Transactions on Reliability for nine years, editor-in-chief of Microelectronics Reliability for sixteen years, and editor of Circuit World. He has also served on three U.S. National Academy of Science studies, two US Congressional investigations in automotive safety, and as an expert to the U.S. FDA. He is the Director of CALCE (Center for Advanced Life Cycle Engineering) at the University of Maryland (UMd), which is funded by over 150 of the world's leading companies. He is also a Professor in Applied Mathematics at UMd. He has written more than thirty books on product reliability, development, use and supply chain management. He has also written a series of books of the electronics industry in China, Korea, Japan and India. He has written over 700 technical articles and has 11 patents. In 2015 he was awarded the IEEE Components, Packaging, and Manufacturing Award for visionary leadership in the development of physics-of-failure-based and prognostics-based approaches to electronics reliability. He was also awarded the Chinese Academy of Sciences President's International Fellowship. In 2010, he received the IEEE Exceptional Technical Achievement Award for his innovations in the area of prognostics and systems health management. In 2008, he was awarded the highest reliability honor, the IEEE Reliability Society's Lifetime Achievement Award.

Prof. Michael Pecht is inducted as Distinguished University Professor which is the highest honor the University of Maryland bestows on its faculty. This title is conferred in recognition of extraordinary achievement as a teacher, scholar, and public servant.

Message from the Centre Director & Executive Director

Ir Professor Winco K.C. Yung

Centre for Advances in Reliability and Safety (CAiRS)

CAiRS is initiated by PolyU and the key research collaborator is University of Maryland, College Park (UMD). CAiRS is one of the research laboratories (Centres) under **the InnoHK Research Clusters** of the Hong Kong SAR Government. CAiRS' mission is to develop new approaches using AI methodologies for customised management, to ensure the reliability and safety of products and systems used in robotics, medical devices, vehicles, telecommunication, consumer products, public utilities, transportation, microelectronics, power devices, sensors and IoT products as well as a broad range of Advanced Manufacturing applications.

Research programs at CAiRS will adopt and develop novel approaches, such as Physics-of-Failure and reliability modelling, Data-driven Methodologies with industry big data, machine learning algorithms for diagnostics and prognostics. These novel approaches would allow self-reconfiguration and system resilience, as well as real-time prediction of useful life span of products and systems. The ultimate goal is to improve their reliability and safety, availability and affordability. The Centre will continue to leverage on the networks with worldwide top- notch researchers and local industry companies and associations, such as the Hong Kong Electronic Industries Association (HKEIA) and HKEIC of the Federation of Hong Kong Industries, to build a new consortium to deliver impactful researchers and achieve CAiRS mission and objectives.

Also, I am thankful for the unfailing support from Prof. H.C. Man (Chair Professor and Dean of Faculty of Engineering, PolyU) who has facilitated active scholarly involvement of many academic colleagues in CAiRS research programs.

Friends and colleagues, I am sure CAiRS, with her dedicated research teams and many industry partners, would contribute greatly towards the Brand-building of products and systems that are designed, made, and commissioned in Hong Kong, as well as to the development of Smart City in Hong Kong.

> **"CAiRS' mission is to develop new approaches using AI methodologies for customised management, to ensure the reliability and safety of products and systems..."**

ABOUT CAiRS

AN OVERVIEW OF THE CENTRE

CAiRS (Centre for Advances in Reliability and Safety) is a collaboration between the Hong Kong Polytechnic University (PolyU) and Center for Advanced Life Cycle Engineering at University of Maryland (UMD), College Park, Maryland, USA and is *an InnoHK Research Cluster of HKSAR Government.*

CAiRS is to become the world leading and regional hub for Research in Reliability and Safety Innovation with high level of world renowned expertise in Artificial Intelligence methodologies, industry based cluster data, and reliability & safety modelling and algorithms, which are readily available and applicable to different industries (e.g. electronics industry, transportation, consumer products, telecommunication systems, public utilities, health care products, aviation, and infrastructure etc.) in Hong Kong with high potential Technology and Commercials impacts that contribute greatly towards the building of Smart City in Hong Kong.

The mission of CAiRS is to make Hong Kong known and respected for high quality, reliable and safe products, systems and infrastructure. To do this, we will address the scientific and technological electronics reliability and safety challenges of national interest by advancing the symbioses between mathematics, engineering, computing, and data science; launch new interdisciplinary communities; and develop the future national workforce. In the first five years, the Centre will advance the state of art and the state of practice in the reliability and safety of critical systems such as robotics, advanced manufacturing, smart city, and electric vehicles.

So why do these failures keep occurring, when the design and manufacturing companies involved are world leaders that are highly regulated and evaluated? Failures in hardware/ software systems most often arise because current safety and reliability assurance methods are inadequate for the insertion of new (and often immature) technologies into complex critical systems or when attempting to retrofit legacy systems. The continuation of critical system failures is exacerbated by the speed of advancements in e-systems, the increasing complexity of systems, a growing lack of transparency in e-system hardware and software content due to outsourcing of critical subsystems and supply chains, the life extensions expected from critical legacy e-systems, and the lack of resources to replace old e-systems.

Currently, we have 5 programs with 15 research projects related to AI-based Reliability and Safety Advances which are collaborated with 27 local companies. There is the brief information of the 5 programs:

PROGRAM 1: Anomaly Detection and Syndromic Surveillances

Project 1.1	Informative Feature Discovery and Selection
Project 1.2	Early Detection of Degradation in Electronic Interconnects
Project 1.3	Anomaly Detection for Systems under Indeterminate Operation Conditions

PROGRAM 2: Innovation Diagnostics for Health Management

Project 2.1	Transfer Learning for Adaptive Diagnostics and Simulation-Based Analysis
Project 2.2	Ensemble Methods for Individualized Fault Diagnosis

PROGRAM 3: Prognostics for Remaining Useful Life Assessment

Project 3.1	Development of Canaries for Catastrophic Failure Prevention
Project 3.2	AI-Based Safety Assurance
Project 3.3	Forecasting Maintenance
Project 3.4	Use of Failure Models and Bayesian Methods for Real-Time Failure Prediction and Uncertainly Management

PROGRAM 4: Safety Assurance: Improve Functional Safety

Project 4.1	Functional Safety Improvement through Expanded Diagnostic Coverage and Reduction in Testing Effort
Project 4.2	Hybrid Strategies for AI-Based Safety Assurance
Project 4.3	Functional Safety Verification of Systems that Implement AI

PROGRAM 5: Data Analytics Platform for Reliabiltiy

Project 5.1	Sharable Knowledge Database
Project 5.2	Integrity of Sensor Data
Project 5.3	Data Visualization and Modelling for Processes, Products and Systems

Highly experienced teams of professionals in doing reliability & safety research of the two collaborating parties is the core of CAiRS. CALCE is involved in fundamental research in artificial intelligence-based reliability and safety innovation, including anomaly detection and syndromic surveillances, innovative diagnostics for system health management, prognostics for remaining useful life assessment, functional safety assurance and data analytics platform for reliability. PolyU brings strong experience in electronics, electrical, computer, mechanical, healthcare, transportation and industrial engineering, with extensive local industrial support bases in Hong Kong (e.g. HKEIA and HKEIC of FHKI), their applied research approach will create a new paradigm of customized health management for different industry sectors, using real-time, in-situ, artificial-intelligence based reliability and safety models with industry data analytics, machine learning, adaptive life-cycle valuation, and algorithms practical and applicable to various industry sectors.

CAiRS 產品可靠性暨系統安全研發中心 CENTRE FOR ADVANCES IN RELIABILITY AND SAFETY

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

UNIVERSITY OF MARYLAND A. JAMES CLARK SCHOOL OF ENGINEERING

OUR COLLABORATORS

Supporting Organizations

HKEIA® 香港電子業商會

Hong Kong Electronics Industry 香港電子業總會 Council
香港工業總會轄下 A FHKI Council

Supporting Companies

ASM

COMPASS TECHNOLOGY "We Bring FLEX-ibility To Life."

HKF 香港小輪（集團）有限公司 HONG KONG FERRY (HOLDINGS) CO. LTD.

Technological Collaborator

NVIDIA

Industrial Collaborators

Public Utilities

港燈 HK Electric

HKT

煤氣 Towngas

Transportation

BRAVO TRANSPORT

HAECO

HKF 香港小輪（集團）有限公司 HONG KONG FERRY (HOLDINGS) CO. LTD.

KOAS LIMITED 佐臻科技有限公司

KMB

MTR

Electronics & Micro-electronics

Amc SINCE 1966 Power for Excellence

COMPASS TECHNOLOGY

Defond

GERMAN POOL 德國寶

Kin Yat Holdings limited

ProVista GROUP 保力集團 PROVISTA • PRECISION • PROTRONIC

Advanced Manufacturing

ASM

EPRO AT

GPB GP Batteries International Limited 金山電池國際有限公司

KENTA

LEO PAPER GROUP

SAE MAGNETICS (HK) LTD

Smart Sensor & IoT

iRobot

LAMBDA SENSE

MERIDIAN Innovation

RASPECT AI-powered Predictive Inspection for Architecture.

KUJU by Tronica

*Names are listed in alphabetical order

OUR EVENTS

Aims to promoting product reliability and system safety, CAiRS has organized a series of activities such as visits, webinars and technical seminar etc. with ultimate goals to build up the world brand "Made in Hong Kong" in high quality, reliable and safe products, systems and infrastructure for Hong Kong Industry.

Snapshots of Industry Partner & Organization Visits


ASM


COMPASS


GERMAN POOL


GP BATTERIES


HAECO


HK ELECTRIC


MTR


HK FERRY


KIN YAT

MERIDIAN


BRAVO TRANSPORT


PROVISTA

26 Nov 2020

Webinar on
"How Products Reliability and Systems Safety help Local Industry to address market needs and promote business opportunities"

15 Jan 2021

Webinar on
"System Reliability and Maintenance – Key Success Factors for your Business"

25 Mar 2021

Webinar on
"Reliability Enhancement of Electronic Parts, Products and Systems"

18 May 2021

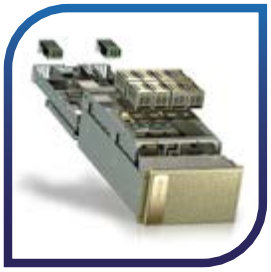
Technical Seminar
"Artificial Intelligence – Transforming Products and Impacting Safety & Reliability"

WEBINARS & SEMINAR

OUR LABORATORIES

We have our own laboratories and supercomputer that facilitate the data collection from wide variety of components, products or systems for our research projects. Below are some of the equipment and please visit our webpage for details.

HIGH PERFORMANCE COMPUTING



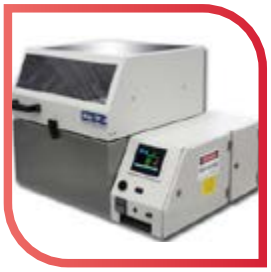
NVIDIA DGX A100

LIFE CYCLE ASSESSMENT

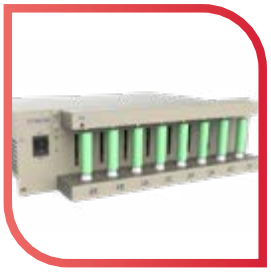
Powertester

Power Device Analyzer

Interrogator



Benchtop Vibration Table



Battery Charge/ Discharge Testing System

Shock Machine

TEMPERATURE & ENVIRONMENT TESTING

High Temperature Oven

Temperature and Humidity Chamber

Highly Accelerated Stress Test (HAST) Chamber

Thermal Shock Chamber

FAILURE ANALYSIS

X-Ray Microscopy

X-Ray Fluorescence Spectrometer

Electrodynamic Tester

Nanoindenter

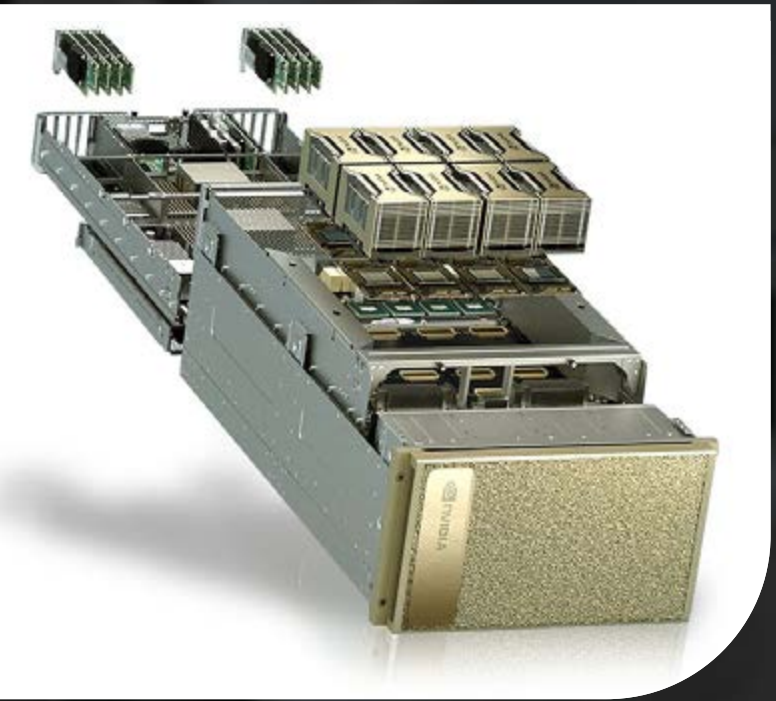
The Powertester PwT 1500 at CAiRS is the first system installed in Hong Kong and the only machine that does automatic power cycling, by powering the modules tens of thousands, potentially millions, of cycles while simultaneously producing analytical data for real time failure in progress diagnosis. Therefore, it can reduce total testing time up to 10x.

It provides thermal transient measurement for junction temperature characterization and Rth identification following the JEDEC JESD 51-1 static test method and support the JEDEC JESD51-14 transient dual interface measurements.

Typical Applications:
- Power electronics thermal simulation and test
- Comprehensive diagnostics for thermal reliability

EQUIPMENT HIGHLIGHTS

These two machines are unique in our research centre especially in Hong Kong. The Powertester enables Non-Destructive Test (NDT) capability on power electronics while supercomputer enhances our research projects on data analytics to achieve incredible scientific and engineering breakthroughs.



The NVIDIA DGX™ A100 supercomputer is a universal system for all AI workloads—from analytics to training to inference. It is the first off-the-shelf hardware/software stack specifically designed for Deep Neural Networks (DNN) workloads for artificial intelligence (AI) applications.

The DGX™ A100 is the first compute platform which delivers a 5 PetaFLOPS AI Performance in a single node.

Typical Applications:
- Reliability engineering, safety analysis and simulation
- Safety-critical autonomous systems on ground and air

Professor Kenneth Lam
The Hong Kong Polytechnic University

Nowadays, there are different kinds of machine and system for a variety of purposes. Machines do not know the world by themselves unless connected with sensors. Sensors play an important role in the construction of a reliable system. One of the commonly used sensors is a camera. Through a camera, we can detect the size of an object and what it is about; this ability is known as computer vision. By using image processing and pattern recognition, we can understand more about the objects we have detected. The other technique we normally use is AI. It is based on data-driven methods, and we can use different machine-learning-based algorithms to classify the patterns, which provide more meaningful and accurate results.

Informative Feature Discovery and Selection

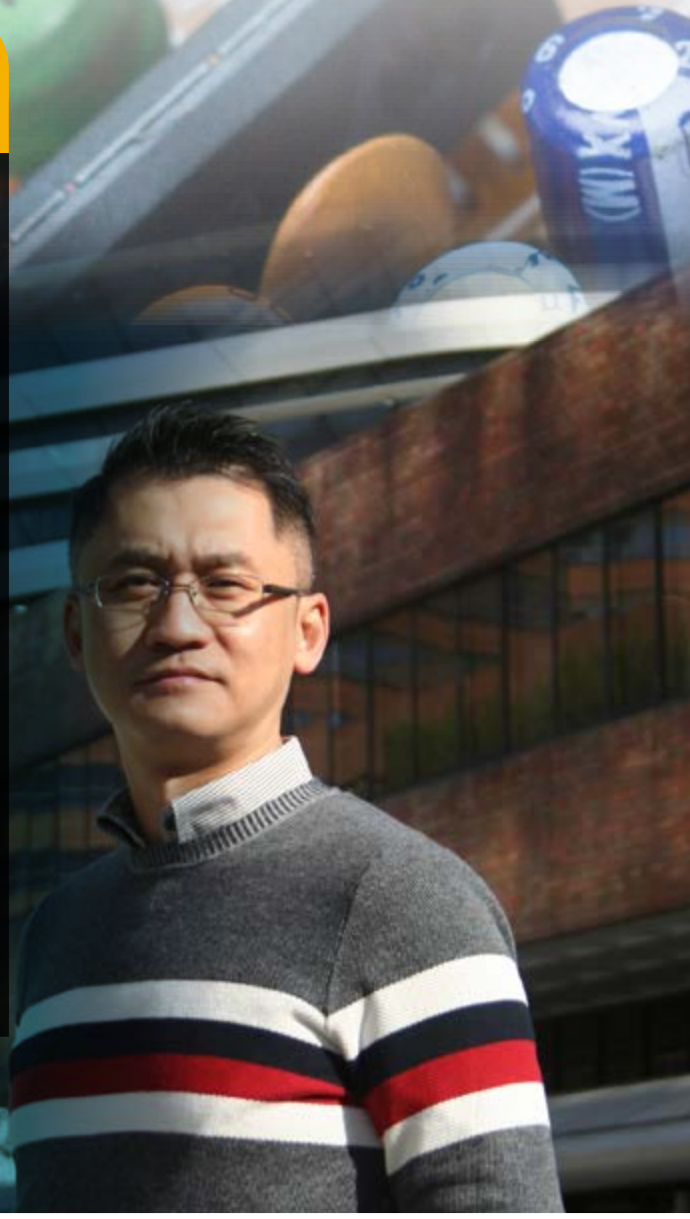
Complex systems have a wide range of performance characteristics, which can vary depending on user demands, operational modes, and usage conditions. Syndromic surveillance involves intelligent sensor selection and placement, and context-aware interpretation of sensor data to detect the many possible fault modes. Features are selected based on similarity measures with respect to known failure modes, combined with genetic programming for identification of new combinations of features for improved fault detection. Advanced time-frequency analysis of vibration data can be applied for condition monitoring of machinery and will serve as the input to feature learning based on convolutional neural networks and deep residual networks. Data fusion methods can also be developed to reduce dimensionality of sensor data, making data analysis and algorithm implementation more efficient and accurate.

Early Detection of Degradation in Electronic Interconnects

This project involves non-destructive monitoring of interconnects in electrical circuits for early detection of degradation that can lead to current leakage, short circuit, or open circuit failures. This will be accomplished through development of canaries for early detection of specific failure mechanisms, and through innovative use of electrical performance characteristics, such as impedance analysis, for non-invasive monitoring of the interconnects. Canaries are dedicated structures that reside on the target system and fail according to a prescribed failure mechanism at an accelerated rate compared to the target system. Canaries can be designed by the acceleration of failure relative to the functional circuit by changing the dimensional characteristics or accelerating the failure mechanism by increasing the stress level applied to the target structure.

Dr Ka Hong Loo
The Hong Kong Polytechnic University

On feature discovery, it is essential to identify the main aging or failure pre-cursors of semiconductor devices by means of accelerated aging tests and device characterization in different aging stages. Knowledge of these pre-cursors and the trends of their variations over the course of aging will provide the basis for developing accurate lifetime model using AI techniques which will enable us to predict the remaining useful lifetime of third-generation semiconductor-based power electronic systems when used in combination with some innovative non-destructive online health monitoring methods. The continuous monitoring of the essential health parameters will also enable us to detect any anomalous conditions accurately and timely and trigger the shutting down of the malfunctioning systems before catastrophic failures occur.



Professor Kenneth Lam
The Hong Kong Polytechnic University

We can use AI and other like computer vision on automatic anomaly detection. They can be applied on PCB boards, wafers, other electronic components or even machines in the different systems. With the use of advanced algorithms, we can monitor the health of the system and locate the anomaly. This can reduce the cost on delayed response of anomaly during system operation status and further improve the efficiency and competitivity of the products or systems.

Anomaly Detection for Systems under Indeterminate Operating Conditions

Operating conditions are usually changing among different states. They are sometimes indeterminate because of a lack of adequate monitoring. For example, at any given time, temperature readings on a microprocessor in a computer could be affected by the operating system, software, and specific software instructions that are running, the ambient temperature, the proximity and speed of a cooling fan, the amount of dust in the chassis, the age of the circuitry, etc. Even when sensors are employed to monitor the condition of such a computer, most of these operating conditions would not be monitored or tracked. Health monitoring data of a healthy system under indeterminate changing operating conditions form clusters. Advanced clustering algorithms will be used to separate healthy data according to operating conditions and allow identification of anomalous behavior.

Transfer Learning for Adaptive Diagnostics and Simulation-based Analysis

Decisions on when to maintain a system, which components or sub-systems must be repaired and what tasks must be executed to recover from a present or anticipated fault can be guided through AI algorithms trained using data obtained from model-based simulation. In addition, transfer learning will be used to provide the flexibility to autonomous systems that will enable successful decision-making and fault management. Traditional machine learning algorithms try to learn each task from scratch, whereas transfer learning transfers knowledge from previous tasks to a target task when the latter has fewer high-quality training data.

Professor Edward Chung
Dr Siqi Bu
The Hong Kong Polytechnic University

System models can be used to simulate the performance of systems in both healthy and faulty states when actual data are scarce, are costly to obtain, or do not completely cover the space describing possible operating states of the system. State of the art statistical methods can enable exploration of multidimensional parameter space to create a data set for use in training diagnostic models with respect to both the nature and severity of possible faults.

Professor Edward Chung
The Hong Kong Polytechnic University

In this project, after identified the pain point, we will determine different sets of classifiers. Training data will be used for multiple classifiers through different machine learning techniques and AI approach. After evaluated performance of the classifiers, the outcome will be finally selected based on weighting. This project can be applied to several areas of transportation and can also benefit the development of reliable transportation system.

Ensemble Methods for Individualized Fault Diagnosis

The key idea of ensemble learning is to create a diverse set of classifiers that can be used for classification problems and combine their outputs to exceed the classification performance of a single classifier. In an ensemble learning process, training data sets are configured for training multiple classifiers in an ensemble, selected for their diversity and effectiveness at handling different types of complexity. To design an efficient ensemble learning method, a dynamically weighted majority voting decision rule shall be considered, which can avoid the use of unnecessary classifiers by activating or deactivating classifiers in the ensemble.

Development of Canaries for Catastrophic Failure Prevention

Designers often establish the usable life of products and warranties based on extrapolating accelerated test results to assumed usage rates and life-cycle conditions. To address the actual life-cycle conditions, products can be equipped with life consumption monitors for in situ assessment of remaining life. One of the vital inputs in making end-of-life decisions is the estimate of degradation and the remaining life of the product. Using the health monitors installed within the product, the reusable life can be assessed without having to disassemble the product. Physics of Failure (PoF) is one approach to the implementation of prognostics that utilizes knowledge of a product's life-cycle loading conditions, geometry, material properties, and failure mechanisms to estimate its Remaining Useful Life (RUL). The use of canary devices is one approach to take the uncertainties in the operating environment of electronics into account.

Dr Steven Boles
The Hong Kong Polytechnic University

Battery is a commonly used energy storage device that we use every day. Demand for lithium-ion batteries is forecast to surge after a virus-linked stumble in 2020. It is a valuable topic to analyze the reliability and safety of batteries. We would research the physics of failure and failure mechanisms on Lithium batteries. For example, gas generation from cathode and electrolyte decomposition are both interesting topics to consider through this project. Our approach is to deploy Fibre Bragg Grating (FBG) sensor, a 'canary device', inside the battery. We can analyze the health of the batteries by investigating the pressure and temperature change on/inside the battery cell. This also brings us to analyze the thermal conductance and electrochemical reaction inside the cells. Ultimately, we hope this research can help to improve the design and reliability of the batteries.

Dr Siqi Bu
The Hong Kong Polytechnic University

Some of the first efforts in diagnostic health monitoring of systems involved the use of sensing, defined as a hardware/software diagnostic means to identify and locate faults. A monitoring system can consist of error discovery, correction, and self-verification sub-systems by using AI techniques. Two types of monitoring concepts can be employed in the systems: interruptive and continuous. The concept behind continuous monitoring system is that equipment is monitored continuously and automatically without affecting normal operation.

Forecasting Maintenance

Most systems and products contain some electronics and electrical machines for functionality and performance. With the increase on the Internet of Things (IoT), the electronic and electrical contents are, in fact, rapidly increasing. If one can assess the extent of deviation or degradation from an expected normal operating condition, this information can be used to meet several powerful goals, including: (i) providing advanced warning of failures;

(ii) minimizing unscheduled maintenance, extending maintenance cycles, and maintaining effectiveness through timely repair actions;

(iii) reducing the life-cycle cost of equipment by decreasing inspection costs, downtime, and inventory; and

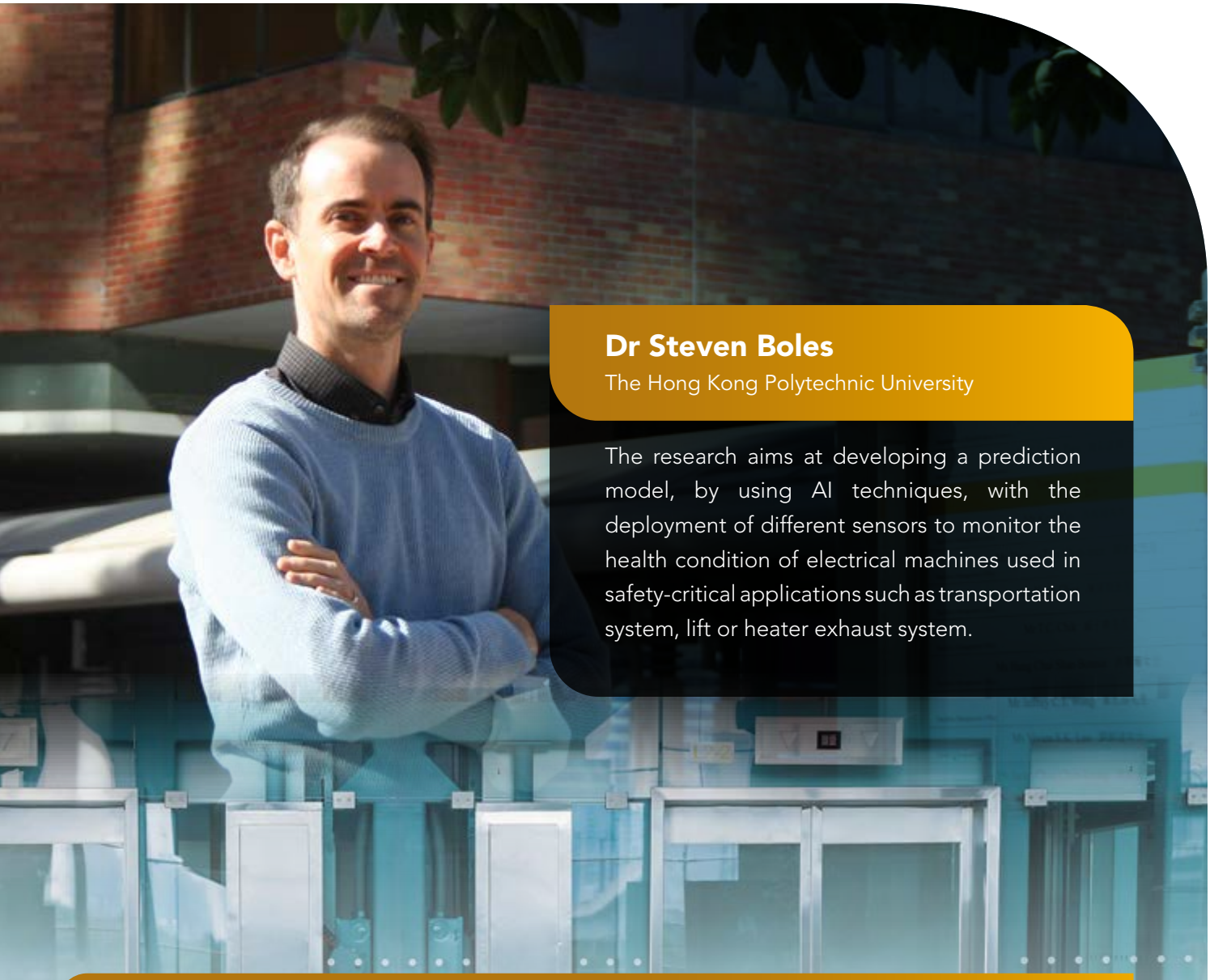
(iv) improving qualification and assisting in the design and logistical support of fielded and future systems.

Use of Failure Models and Bayesian Methods for Real-time Failure Prediction Uncertainty Management

In general, to implement a precursor reasoning-based Prognostics and Health Management (PHM) system, it is necessary to identify the precursor variables for monitoring and then develop a reasoning algorithm to correlate the change in the precursor variable with the impending failure. The fusion approach is beneficial when the available data is inadequate to implement prognostics. To improve the prediction accuracy and precision, it is often necessary to use Bayesian updating to incorporate new data for prediction. Hence, the probabilistic approach is used in conjunction with online precursor trends to update estimates with new data available from online sensors. While the trend monitoring identifies the deviation from normal equipment operation, the probabilistic model with uncertainty bands provides an estimate of the prognostic distance — a performance metric crucial for fixing the deficiency either through repair or replacement.

Dr Ka Hong Loo
The Hong Kong Polytechnic University

Temperature fluctuations encountered in semiconductor devices, including third-generation semiconductor, during their operation constitute a major reason for their failures. Post-failure analysis often shows that degradation in packaging materials due to temperature fluctuations is the main reason causing these failures. As different packaging technologies and packaging materials are used by different semiconductor manufacturers, it is difficult to generalize the findings obtained from one device to other devices. As a result, a large number of aging tests and post-failure analysis must be conducted. Moreover, in order to apply AI techniques to the condition monitoring and lifetime prediction of semiconductor devices, a large amount of training data must be collected in advance for mapping different failure causes to failure effects.



Dr Steven Boles
The Hong Kong Polytechnic University

The research aims at developing a prediction model, by using AI techniques, with the deployment of different sensors to monitor the health condition of electrical machines used in safety-critical applications such as transportation system, lift or heater exhaust system.

Functional Safety Improvement through Expanded Diagnostic Coverage and Reduction in Testing Effort

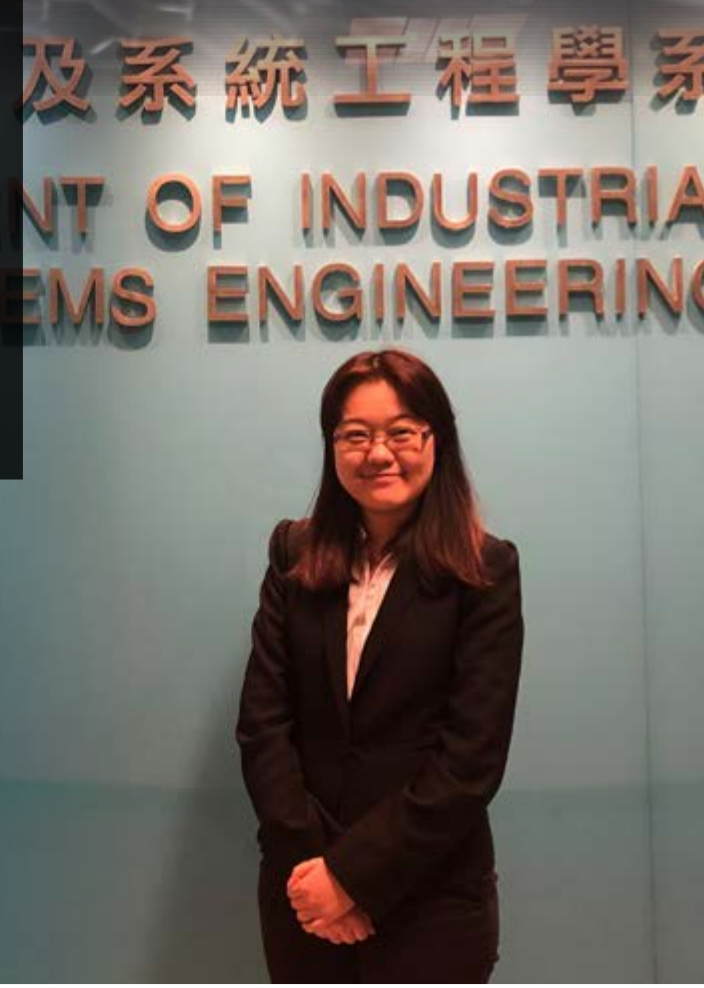
Safety-critical applications have stringent demands for functional safety and reliability. The safety integrity level (SIL) expresses the required risk reduction needed to reduce the risk to an acceptable level. Manufacturers can resort to two approaches – increasing redundancy and improving diagnostic coverage. However, adding redundancy consumes a lot of space and energy, and adds to the cost and opens up the possibility of common cause failures. Hence, we focus efforts on improving the diagnostic coverage through improving the fault diagnosis capabilities of the system using deep learning. This is done by solving an optimization problem, where the fitness function is minimizing the false positives (test case is selected but would pass) with the constraint of false negatives (a test case is not selected but would fail) kept below the maximum tolerable limit. Significant reductions in testing time can be achieved without significant reduction in the quality of the regression test for assessing the system reliability.

AI based Safety Assurance

The life-cycle profile of a product or system consists of manufacturing, storage, handling, and operating and non-operating conditions. The life-cycle loads including thermal, mechanical, chemical, physical and electrical loads both individually or in various combinations, may lead to performance or physical degradation of the product or system and reduce its service life. The extent and rate of system degradation depend upon the magnitude and duration of exposure to such loads, like usage rate, frequency, and severity. If these loads in situ can be measured, the load profiles can be used in conjunction with damage models to assess the degradation due to cumulative load exposures.

Dr Carman Lee
The Hong Kong Polytechnic University

This project is to study the system health assessment to ensure the reliability and safety. It is an approach to place a doctor on the shoulder of components and systems. We study the correlation between the loads and the failures, and we would design the models for the health diagnosis and even prognosis ultimately. The goal of the project is to improve safety assurance of the system by the intelligent methods through the load profiles and damage models.



Professor Felix Chan
The Hong Kong Polytechnic University

The variation and degradation of the specific parts may lead to the malfunction of the critical systems after certain period. It is important to identify the anomaly for these critical parts as it may affect the safety of the final products. However, the results relied only on human detection are not reliable as there may be fatigue and human error for large variety of products and systems. Advanced techniques on artificial intelligence together with approach on data driven and physics of failures can help to improve the results when we are facing the concerns on the quantity and quality of original data in real application.

Hybrid strategies for AI-based Safety Assurance

A safety critical system is one in which non-tolerable consequences have a sufficiently low probability of occurring. AI algorithms need relevant observations to be able to predict the outcome of future scenarios accurately, and thus, data-driven models alone may be insufficient to ensure safety. Hence, we use a hybrid approach by combining data driven approaches with physics of failure approaches.

The first step towards understanding the response of a system is by probing the system through virtual or real experiments. The second step is to be able to estimate the system response at points where the system has not been probed. This is usually done by constructing a surrogate model. The third step is to decide which experiments to run consecutively in order to maximize the information gained. This is done using existing knowledge of the system including associated consequences and risks. The lack of data makes application of AI to safety-critical systems a unique problem and hence we formulate a generic approach for using AI in safety-critical systems.

Functional Safety Verification of Systems that Implement AI

Usages of AI to carry out safety-critical functions are not popular in current editions of functional safety standards because of lack of their transparency and analytical methods. By specifying safety criteria for the functional behavior of AI, we will analyze on the AI implementations to be certifiable to the standards. In this project, an example of a safety criteria is safety argumentation, which improves the repeatability of functional safety verification and makes it more understandable.

Dr Nick Chung
The Hong Kong Polytechnic University

Functional safety is part of the overall system safety or equipment that depends on active control and the correct functioning of the safety system in a predictable manner. Through safety analysis, we target to implement corrective or preventive actions on the system using interpretable Artificial Intelligence methods to reduce the risk of unacceptable accidents. I believe the development of specifying the criteria in the industry on this aspect is valuable for many industries in our coming future.

Dr Haibo Hu
The Hong Kong Polytechnic University

There are needs for manufacturers to use their data from production, testing, root cause failure analysis, and warranty service to contribute to and enhance overall product reliability and safety. This project would set up a sharable knowledge database based on participation from the industrial companies, potentially contributed on an anonymous basis. It would involve setting up an IT infrastructure to support collection, storage, analysis, and dissemination of data on failures and safety with high standard of data confidentially and privacy. I hope this can help the industry to achieve another level on the improvement of reliability together.

Sharable Knowledge Database

Specific algorithms and models are needed for prediction of product reliability and safety. Data from local industry is one of the most important inputs for the development of these models. Industry needs a comprehensive industrial data set to allow the development of algorithms and models to avoid unpredicted failure and ensure reliability and safety in the field. Substantial data sets are needed to enable training of algorithms and models for prediction of remaining useful life of devices to simulate use patterns and scenarios for different types of products and customers. Subject matter experts will apply label the industrial data in order to enable the dataset to be used for training of models and algorithms, as well as providing educational value for teaching engineering students and those entering industry how to recognize various types and causes of failure.

Integrity of Sensor Data

Methods would be developed to ensure the reliability of sensors and the integrity of data produced by sensors. Sensor data integrity spans the spectrum from accuracy of measurements produced by a sensor to the appropriateness of the signal processing and compression local to the sensor, to absence of errors introduced during transmission of data through a network, to the avoidance of data corruption by the remote system upon translation, post-processing, categorization, labeling, and storage of the data. Strategies for sensor evaluation would include assessing sensor health through self-calibration, built-in tests, characterization of sensor response, and context-sensitive modeling. Ensuring data integrity beyond the sensor requires AI-based methods such as single point checks (e.g., identification of missing, non-sense, and physically improbably data), internal consistency checks, anomaly detection, communication channel testing, and cross-correlation with comparable scenarios. This would lead to autonomous, machine learning-based methods for assurance of data integrity. The goal is to ensure that critical decisions regarding system operation and maintenance, as well as the operation of robots and other autonomous systems are based on reliable data.

Dr Daniel Lun
The Hong Kong Polytechnic University

We frequently heard about 'Smart City' in recent years. One of the important components of a smart city application is the sensor. We get different sensor data from the environment and then analyze them to make decision for the application. If the data gathered are not appropriate to interpret the actual situations, the analysis or decision we made will be affected. Therefore, it is important to discover and analyze the data from sensors by intelligent methods and alert the user to have earlier action to ensure the decision made are based on the reliable data. We believe the result of this project will have a strong impact on the development of smart city applications.

Professor Francis Lau
Dr Haibo Hu
The Hong Kong Polytechnic University

Data Visualization is basically the representation of information and data using visual elements such as charts, graphs, and maps. It enables human to comprehend the data much more easily and identify the trends, patterns, outlines, and correlations between large datasets. In this project, innovative methods will be developed for representation of multi-dimensional data to facilitate the interpretation, modelling and expert checking of validity.

Data Visualization and Modeling for Processes, Products and Systems

Innovative methods will be developed for representation of multi-dimensional data and images, to facilitate interpretation, modeling, expert checking of validity, and educational use. Statistical and machine learning-based models of reliability data will be developed and will include the data in the sharable database. The idea is to visualize complicated data objects or model output in a clear and understandable way for industrialist to apply AI methodology in a solid way. These methods could be applicable to manufacturing processes, products or systems of local industries.

INDUSTRY SHARING 7

ASM is an equipment supplier for semiconductor and electronics assembly, including silver sintering, die attachment and wire bonding equipment for power device/module. Power devices are widely used in lots of electronic systems for different purposes, including EV, solar farms, motor drives and power supplies. As an equipment supplier and power electronics developer, reliability assessment of the power modules is one of our interesting topics for the development of the equipment. We are happy to be one of the supporting companies of CAiRS on the continuous development and application of the reliability research in semiconductor and electronics.

ASM

Peter Ng
Vice President, Enabling Technology Group, ASM Technology Hong Kong Limited

Compass was founded in 1997 with an ambition to be the world's best flexible substrate supplier. We are proud of our Hong Kong heritage; and make all our products to our own exacting standards. Through the collaboration with partners, and with the application of new technology to the leading industries in Hong Kong, we expect CAiRS to lead, innovate and help the electronics industry in creating not just safer, more reliable products but also bridge local re-industrialization with the world. We shall continue to create, manufacture and assemble flexible substrates, innovative modules and multi-functional design solutions for fast-to-market, high performance, high reliability market segments including medical imaging, monitoring, optical telecommunication and high-density display interconnects.

Chee Cheung
CEO, Compass Technology Company Limited

COMPASS TECHNOLOGY

Lighting up the homes and businesses of Hong Kong since 1890, HK Electric has a long record of providing a safe and highly reliable electricity supply at a reasonable price to customers on Hong Kong and Lamma islands. Since 1997, its power supply reliability rating has been maintained at over 99.999% – one of the best records in the world. We are happy to work with CAiRS on applying data-driven modelling to predict the potential anomalies of underground high-voltage cables so as to avoid electricity supply interruption caused by cable fault.

港燈 HK Electric

Ir Wilson Kwok
Head of Technical Services, Hong Kong Electric Co., Ltd

HKT delivers end-to-end integrated solutions employing emerging technologies such as 5G, cloud computing, Internet of Things (IoT) and artificial intelligence (AI) to accelerate the digital transformation of enterprises and contribute to Hong Kong's development into a smart city.

More than 130 smart city initiatives were mentioned in the Smart City Blueprint for Hong Kong 2.0 released in 2020. Many of these initiatives are related to smart surveillance. To cope with the trend, we are now working with the research team at CAiRS to detect anomalies in surveillance videos through machine learning. CAiRS has one of the fastest supercomputers in South East Asia so any problems in the video cameras can be identified quickly on-site and sent to the user for further action.

We believe there is a great potential for further collaboration between HKT and CAiRS which can help us strengthen our video surveillance solutions and smart city applications.

LEUNG Wing Keung
Senior Vice President, Integrated Project & Technology Services, HKT

HKT

I appreciate the effort of CAiRS on our project since last year. Our train track condition monitoring system is an integrated solution with advanced sensors and software systems on monitoring the condition of trains and tracks. The goal for this project is to enrich the functionalities of our product by providing diagnostics on anomalies and predictive analysis.

KDAS LIMITED 凌達科技有限公司

Ir Dr Kang Kuen Lee
CEO, KDAS Limited

Every day, MTR connects people and communities. As a recognised world-class operator of sustainable rail transport services, safety, reliability, customer service and efficiency are of paramount importance. MTR has extensive end-to-end railway expertise with more than 40 years of railway projects experience from design to planning and construction through to commissioning, maintenance and operations. Going beyond railway delivery and operation, MTR also helps create and manages dynamic communities around its network through seamless integration of rail, commercial and property development.
We are now joining hands with CAiRS in researching and applying various data analytics techniques and computer vision methods in enhancing our maintenance and operational performance. With the collaboration, we are happy to work with CAiRS research team for advancement in safety and reliability.

MTR

Chan Hing-keung
General Manager, Engineering & Innovation Centre, MTR

Defond is the leading global supplier in electromechanical and electronic switches, modules, battery packs and other innovative HMI (Human Machine Interface) solutions while CAiRS expertise in reliability modeling with data science and AI technology. We are delighted to work with CAiRS's research team to establish reliability analytics into our product life cycle. We are looking forward to a long-term partnership with CAiRS and apply the research findings on our products in the coming future.

Ernest Tam
Head of Marketing, Defond Electrical Industries Limited

Defond

German Pool strongly believes in providing our customers high quality, safe and innovate products at a reasonable price. While determined to deliver an excellent standard of lifestyle to customers, we are pleased to take this opportunity to collaborate with CAiRS to seek continuous improvement on our product's reliability. We understand the programs are led by the professors in The Hong Kong Polytechnic University and the concept of reliability analysis can be applicable to our wide range of home, professional, and commercial appliance & systems with great impact in the industry.

GERMAN POOL 德國寶

Aldous Leung
Senior Engineering Consultant, German Pool (HK) Ltd

Your timely opening of CAiRS to offer and advance reliability and safety analysis science and know how contributes greatly to today's industry that is gearing towards smart production in the era of Industry 4.0. Innovation of AI testing techniques and discovery of data centric process parameters that help to safe guard quality conformity and compliance are essential elements of successful and sustainable smart production. You have the leadership and expertise that will make CAiRS prosperous and increasingly influential. Congratulations and best wishes. May this new endeavour bring huge success and professional fulfilment to all members of the CAiRS team.

Dr Vincent WC Fung
Non-Executive Director, Kin Yat Holdings Limited

We are one of the advanced material suppliers for battery and a contender to powering the Hydrogen Economy. It is a wonderful opportunity to work with Dr. Boles and his team at CAiRS to conduct research on the enhancement of the reliability of our battery materials and hydrogen related systems. The research approach from CAiRS including those advanced reliability modeling and the study of the physics of failure can help us to enhance the reliability of our products and create the value to us.

Albert Lau
Founder and CEO, EPRO Advanced Technology Ltd

GP Batteries as a major global supplier of primary and rechargeable batteries and one of the largest consumer battery manufacturers in China, we supply an extensive range of battery products to OEMs, leading battery companies as well as consumer retail markets under our GP brand. Product Reliability is of utmost importance in our industry and a key expectation from any battery users. It is a definite advantage to have predictive assessments at design and manufacturing phases where the reliability level of new products is evaluated and improved. Therefore, we are working with CAiRS on new approaches to access product reliability using advance sensors and data analysis for the betterment of our processes. We expect the close and continuous collaboration with CAiRS can enable us to achieve even higher standards on product reliability.

Dr Percy Chan
Quality Director, Group Quality Assurance, GP Batteries International Ltd

GP Batteries International Limited
金山電池國際有限公司

Good to know the establishment of CAiRS which not just facilitates the deployment of academic research in industries for reliability and safety enhancement but also pushes research excellence in the area of reliability and safety innovation that leverage the unique strengths of CAiRS. Kenta is a well-established manufacturer which is proficient in product development, tooling fabrication, and precision injection molding. We have a common interest with CAiRS in developing highly reliable and safe products, especially those parts used for automotive. I look forward to the continuous development with CAiRS in the coming years.

Maggie Tsoi
Assistant General Manager, Kenta Enterprise Company Limited

Protronic (Far East) Ltd. is one of the subsidiaries of ProVista Group. ProVista Group is a Hong Kong based electronics conglomerate with strong R&D, Engineering and Manufacturing capacities, and excels in a wide range of electronic products covering power and solar energy, automotive, lifestyle & care, and security. Product reliability and system safety is an important and major issue for electronic products and applications. That's why we support CAiRS on the continuous development and application of the reliability research in power electronics.

Steve Chuang
Founder & CEO, Protronic (Far East) Ltd.

ProVista GROUP 保力集團
PROVISTA • PRECISION • PROTRONIC

RaSpect is a start-up with a vision of making cities safer, greener, and smarter. Its technology aims to empower urban infrastructure for robust city management. Its built infrastructure inspection product uses AI to autodetect defects and help assess conditions to predict remaining life. It evaluates buildings, roads, and tunnels. RaSpect aims to monitor building services using IoT sensors and big data analytics. Such real-time monitoring includes Electrical and Mechanical equipment such as elevators, escalators, chillers, HVAC, power supply system, indoor comfort etc. In recent years, with the growth of urbanization (54% of people live in cities), lifts are becoming ubiquitous, and their maintenance is crucial to ensure safety and reliability. The current practice of corrective or condition-based maintenance is costly and cannot prevent break-down. Predictive maintenance can reduce cost and increase service life while minimizing downtime. RaSpect provides wireless sensors to monitor elevator health conditions and assess its system safety and reliability. Real-time alerts are issued when the sensors exceed pre-set levels. Considering the mission of CAiRS, which aims to support the industry in its effort to bring innovation, such as the application of AI to ensure safety and reliability in different industrial sectors, RaSpect is delighted to be a partner. Along with leading elevator manufacturing companies, RaSpect and CAiRS hope to develop an AI-powered model for Lift safety and reliability.

RASPECT
AI-powered Predictive Inspection for Architecture.

Harris Sun
CEO & Founder, RaSpect Intelligence Inspection Ltd.

Meridian Innovation is an exciting start-up, pushing the boundaries of thermal imaging with a suite of technologies – from a novel microchip infrared sensor to software solutions and thermal data analytics. Our cost-effective thermal imaging camera modules can be manufactured and deployed in mass volume, in conjunction with key emerging technologies related to industry, smart cities and smart buildings. In such a scenario, the ability to dynamically evaluate the reliability and remaining lifetime of the camera module – while the sensors are connected and operating – is of primary concern, in order to predict maintenance, and to accurately assess the cost of the installation and operation of the thermal imagers.

Our collaboration with CAiRS aims to develop innovative solution to this problem by means of deep learning techniques, in order to detect anomalies in the thermal imaging data and to discern the root cause of the problem – whether it relates to a degradation of the sensor pixels, or the lens, or the packaging of the camera module, A further objective is to attempt to compensate for the degradation without disrupting the operation or flag the malfunctioning module. For a young company, which has to focus its resources exclusively to augmenting its manufacturing capacity and R&D efforts on product development, the assistance of CAiRS with reliability-related research is of great value and we are grateful for their support.

Dr Stanislav Markov
Data Scientist, Meridian Innovation Limited

MERIDIAN Innovation

Internet of Things is one of the trends in recent years and Tronico has developed wide range of IoT devices and its ecosystem, including gateway, temperature sensors, lighting control, etc. We are happy to work with CAiRS to analyze the impact of different environmental factors on our devices in order to further enhance the field reliability of our products.

KUJU by Tronico

Alex Chan
General Manager, Tronico Technology Company Limited

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