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Energy-efficient and Environmentally-friendly Smart Seawater Desalination System

Prof. Chuyang TANG’s Research Group

Department of Civil Engineering

Smart Hybrid Desalination

Challenges of Traditional Desalination Technologies
- Energy Loss
- Resources waste
- Environment & Eco-system issues

\[
\begin{align*}
\Delta G_{\text{osm}} &= (C_1 + C_2) - (C_1 \cdot C_2) \\
\Delta G_{\text{red}} &= -RT \left[ \frac{1}{f} \sum C_i (ln(C_i) - 1) \right] - \frac{1}{RT} \sum (C_i - C_i^*)
\end{align*}
\]

Research Area

A. Co-location system for simultaneous low energy desalination and brine management
- Reverse electrodialysis (RED) → reverse osmosis (RO) for lower osmotic pressure of feed to RO
- RO and power plant → RED for energy recovery from salinity gradient from the RO brine

B. Simulation on RED-Desalination hybrid system

C. RED chemical cell for energy harvesting from controlled acid-base neutralization

D. Rechargeable Salt Battery

E. Efficient Power Extraction Strategies

The project is supported by the Collaborative Research Fund (C7051-17G) from the Research Grants Council of the Hong Kong Special Administration Region, China.

Research Team:
- Ion exchange membranes: P Toy (HKU Chemistry), Y-C Lu (CUHK), F Ciucci (HKUST)
- Power extraction: SC Tan, CK Lee, Ron SY Hui (HKU EEE)
- Process development and integration: CY Tang (HKU Civil)
**High performance RO and NF membranes**

Prof. Chuyang Tang’s Team

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### Nanofoaming of polyamide membranes


Song et al., *J. Membr. Sci.*, 582, 342-349 (2019)

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### Electrospray-assisted interfacial polymerization


Ma et al., *J. Membr. Sci.*, 570-571, 139-145 (2018)

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### Nanostructured membranes


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### Membranes for trace organic contaminants removal


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### Acknowledgement

General Research Fund (Project 17207514) of the Research Grants Council of Hong Kong

Innovation and Technology Commission of Hong Kong Government (Project number ITS/428/16, ITS/208/14, ITS/079/14)

NSFC/RGC Joint Research Scheme sponsored by the Research Grants Council of Hong Kong and the National Natural Science Foundation of China (N_HKU706/16)
**Water filter for rapid contaminants removal**
Prof. Chuyang Tang’s Team

Department of Civil Engineering

### Background - Safe drinking water

An ideal water treatment technology for disaster relief should demand:
- High reliability
- High productivity
- No chemical dosage

### High Performance Multifunctional Nanofibrous Membranes

#### A. Nanofibrous membrane preparation procedures

1. Fabrication of nanofibrous membrane
2. Post-treatment of nanofibrous membrane
3. Disinfection of microorganisms
4. Heavy metal adsorption

#### B. Technical Features

- High porosity
- High internal surface area
- Large water permeability > 50000 L/m²·h·bar
- High disinfection efficiency > 6 log removal
- Contaminants removal > 99%

### High-throughput filter products

#### C. Filter prototype

**Colorful & composable filtration bottle**

**Bacterial removal**

---

#### D. Awards and Commercialization

The water filter products won a Gold Medal at the 47th International Exhibition of Inventions Geneva.

Dr. Hao Guo (left side), a key member of water filter project, was recognized as one of the MIT Technology Review’s Innovators Under 35 for Asia Pacific Region.

The team is actively exploring patent licensing and commercialization opportunities.

### Outcomes

- Preparation of hand-carry gravity-driven water filter with high throughput and water disinfection performance (PCT/CN2016/093965, US 16/323,022)
- Nanostructured Membrane Filter for Rapid Water Purification (US 62/831,382)

### Acknowledge

Innovation and Technology Commission of Hong Kong Government (Project number ITS/079/14, ITS/428/16)
In-situ Young’s modulus of rust in concrete

Dr. SU Kai Leung Ray and LIU Qi-fang

Department of Civil Engineering, The University of Hong Kong

Motivation

Quantification of the in-situ Young’s modulus of rust is a challenging task. Such property is essential for predicting the service life of civil structures and evaluation of the repair and maintenance schedules.

Progress: a wide range of values from 10MPa to 350 GPa are stated in the literature; no consensus is available.

Difficulty: rust is a granular material; nonlinear elastic; hard to reproduce the elastic behavior of rust.

Methodology

To determine the in-situ Young’s modulus of rust based on a displacement-based inverse analysis method.

Objectives

To address the difficulty involved in modeling the elastic behavior of granular material such as rust with minimal disturbance to the original structural configurations.

Research accomplishments

Non-destructive method by the inverse analysis of displacement.

The in-situ Young’s modulus of rust is evaluated.

Conclusions

The in-situ Young’s modulus of rust can greatly affect the accuracy of service life prediction of corroded concrete structures.

Rust of reinforcement in concrete behaves like a nonlinear material. The Young’s modulus of rust increases with an increase of confinement pressure.

Measured displacements in x direction and y direction by digital image correlation (DIC).
**Introduction**

In the context of climate change, our living environment is vulnerable to various types of water-related natural hazards, such as urban flooding, debris flows, deterioration of stormwater quality due to anthropogenic activities, and so forth. Therefore, our research has been directed towards finding out ways to promote resilience to water-related natural hazards by developing improved understanding of the cascade of hazard chain from its source to receptor. Our approaches involve conducting laboratory experiment, performing field monitoring and developing cutting-edge modelling techniques. Main research areas focus on, but not be limited to several key topics list below.

**Numerical models for hydro-ecosystem**

- Catchment hydrology
- River hydraulics
- Sediment dynamics
- Urban stormwater quantity and quality
- Blue-green Infrastructures

To develop robust numerical models for physical processes of hydro-ecosystem with key features:
- Full dynamic models based on shallow water theory
- Urban and river flood prediction caused by cloudbursts, storm surge
- Stormwater runoff quantity and quality with and without BGIs
- River hydraulic and sediment transport modelling

**Computational hydraulics and sediment dynamics**

- To exploit advanced numerical algorithms to develop robust computational fluid models, and
- To deliver understanding of river hydraulics and sediment dynamics by implementing numerical modelling in combination with available data.

**Blue-Green Infrastructures for Urban Stormwater/flooding**

Key research objectives:
- to better understand urban hydrological processes and associated dynamic processes of urban stormwater runoff over key urban features,
- to develop improved understanding of how blue-green infrastructures (BGIs) affect urban stormwater runoff quality and quantity at multiple tempo-spatial scales,
- to develop approach to evaluate and maximize the benefits of BGIs on urban stormwater management from viewpoint of multi-scales.

Key methodology used:
- Simplified urban hydrological model (SWMM), and sophisticated in-house hydro-morphodynamic model with support of good-quality field datasets.

Figs: Case study in an urbanized catchment of Finland, from left to right: aerial image, land use, configured urban hydrological model (SWMM), and catchment-scale hydrological effects of BGIs (Guan et al, 2015, 2016)

**Urban resilience to weather extremes**

**Aim**: to develop cutting-edge technology and approaches to monitor, predict, prepare for and respond to natural hazards due to extreme weather, particularly focusing on flooding caused by storm surge and rainfall.

**Key research objectives**:
- to develop intelligent high-performance modelling and visualization techniques for flooding in urbanised areas,
- to improve understanding of flood dynamics in urbanized areas with supports of modelling and urban big data,
- to quantify the vulnerability of critical infrastructures to extreme weather,
- to predict the impact of climate change on hazard risk currently and in future.

**Key methodology used**:
- Shallow water model, SPH-DEM coupled model
- Wireless sensors
- Remote sensing
- Big data
- Machine learning
- Data fusion

**Landslide dam failure and debris flow**

**Key research objectives**:
- to develop novel dynamic approaches to model landslide dam failure and debris flow,
- to improve understanding of landslide dam failure mechanisms, debris flow formation and associated hydro-morphodynamics in downstream valley.

**Key methodology used**:
- Shallow water model, SPH-DEM coupled model

**Figs**: Case study: cloudburst-induced urban flooding in Leicester, UK on 28 June, 2012, city-scale modelling and visualization based on Google Map.
Intelligent Computational Infrastructure to Support Energy Efficient Buildings and Emergency Response

Dr. Sanghoon Lee, Huaquan Ying, Hui Zhou, Mun On Wong
Construction Informatics Lab

Goal: To effectively and efficiently support collaborative design and operations and maintenance of energy efficient buildings and emergency response

Objectives:
- To develop AI-driven algorithms to create BIM models from different sources including images, drawings, point-clouds, and text
- To develop IDM/MVD (Information Delivery Manual/Model-View-Definition) and information network for seamless information exchange between objects and stakeholders in real-time
- To develop intuitive interfaces for effective visualization of information on difference devices (e.g., AR glasses, VR immersive system, smart phone, tablet, smart watch)

Application Areas:
- Energy efficient building design and simulation
- Daily operations and Maintenance (O&M) of buildings
- Emergency response
- Education and training

Key Research Areas

Information Modeling
- Recognition of objects from images
- Detection of shapes, dimensions and properties of the objects
- Generation of BIM models in different LODs

Information Exchange
- Extraction of information requirements (IDM/MVD) based on the players’ roles and purposes
- Development of information network
- Collaborative communication protocol between objects and stakeholders

Information Visualization
- Optimized information visualization in different field devices/systems such as wearable devices, mobile devices to support field work and full-scale immersive systems such as CAVE for design review and training

Automated Code Compliance Checking

Information Visualization and Interaction in VR

AI-driven BIM Modeling from Images

Mask R-CNN Approach to create BIM objects

Training and Recognition
- Case Study: Generating IFC BIM objects from images

Information Exchange and Visualization for Energy Efficient Building Design

Information Exchange and Visualization for Collaborative Emergency Response

Participants’ Interactions in the multi-user system

Fire emergency-related data set

An example of the multi-user system
Removal of the pollutants in wastewater treatment is not only difficult and costly (US$0.4/m³) but also produces a large amount of sludge (~1 ton dewatered sludge/1000 m³).

Disposal of the sludge, and the food waste as well, is one of the most challenging and expensive environmental problems for large cities.

On the other hand, major pollutants (organics and nutrients) in wastewater are valuable resources that should be recovered instead of being degraded or wasted with the sludge.

In this project, novel technologies, namely Enhanced Separation and Sludge Refinery (ESSR), will be developed for advanced wastewater treatment and food waste processing.

Chemically-enhanced Membrane Filtration (CeMF), together with the side-stream Acidogenic sludge and food waste Co-Fermentation (sACF), for phosphate recovery and organic hydrolysis for use in biosynthesis of polyhydroxyalkanoates (PHAs) and caporate and denitrification;

Thermal Sludge Hydrolysis followed by fungal Fermentation and Refinery (SHFR) for sludge minimization and production of ethanol and hyphae fibers, with the subsequent recovery of ethanol and ammonia from the solution;

Integration and pilot demonstration of the novel CeMF-sACF and SHFR modules for advanced wastewater treatment with improved nutrient removal, energy saving, resource recovery and sludge reduction, together with the assessment of the effluent quality and its impact on the receiving aquatic ecosystem.

To develop a new wastewater treatment process aiming for effective and energy-saving treatment, sufficient nutrient removal and high-quality effluent;

To create the capabilities of recovering resources and energy from municipal wastewater, achieving sludge minimization together with the production of value-added products; and

To present an advanced urban water pollution control system with a sound integration of wastewater treatment, resource recovery and minimization of sludge and food wastes.

(1) Research tasks and program members

• 10 members
  (2 collaborators & 2 international advisors)
• 3 institutions

(2) Group meetings and workshops

System integration at Nanshan wastewater treatment plant, Shenzhen

HK$10M donation from WYNG Foundation and Philomathia Foundation
Introduction

- In conventional municipal wastewater treatment process, the primary sedimentation process requires a long HRT (around 2 h), with rather low efficiencies in organic and phosphorus removal rate, leading to large tanks and an expensive treatment cost of the downstream biological treatment.
- Present study utilized flat-sheet ceramic membrane (FCM) ultrafiltration, instead of conventional sedimentation, to filter municipal wastewater directly, which can shorten HRT and the ceramic membranes can be readily placed inside tanks for low-pressure filtration.
- Coagulation was applied prior to filtration to enhance pollutant removals and decrease membrane fouling rate.
- Coagulation: Direct removal of organic and phosphate from raw sewage.
- Concentrate organic and phosphate into the sludge to allow resource recovery, reduce organic loading on post-treatment, and ii) concentrated sludge with high organics and nutrients concentrations to facilitate follow-on resource recovery.
- The coagulation-FSCMF (C-FSCMF) hybrid procedure is expected to produce i) clean filtrate out to reduce organic loading on post-treatment, and

Methodology

- Replaces the primary sedimentation tank with the flat-sheet ceramic membrane filtration tank;
- Coagulation: Direct removal of organic and phosphate from raw sewage.
- Concentrate organic and phosphate into the sludge to allow resource recovery, reduce organic loading on post-treatment, Shorten HRT compared with conventional sedimentation;
- Aeration: Keep the mixture in membrane tank suspended and reduce the membrane fouling rate.

Test water: Stanley Sewage Treatment Works (Stanley STW)
- Coagulants: FeCl3, Polyaluminum chloride (PAC)
- Ceramic membrane:
  - Pore size: 100 nm
  - Size: 25 cm x 25 cm x 5 mm
  - Area: 0.04 m2
  - α-Al2O3
  - Meidensha corporation, Japan
  - Outside-in filtration mode

Research accomplishments

(1) Performance of C-FCMF hybrid procedure on wastewater treatment

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Cleaning strategy</th>
<th>RW</th>
<th>RW-FSCMF</th>
<th>PAC-C-FCMF</th>
<th>FeCl3-C-FCMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>1.5% NaClO</td>
<td>12</td>
<td>0.002</td>
<td>0.101</td>
<td>0.030</td>
</tr>
<tr>
<td>2nd</td>
<td>1.5% H2O2</td>
<td>12</td>
<td>0.004</td>
<td>0.102</td>
<td>0.031</td>
</tr>
<tr>
<td>3rd</td>
<td>0.1 M citric acid</td>
<td>12</td>
<td>0.006</td>
<td>0.101</td>
<td>0.031</td>
</tr>
<tr>
<td>4th</td>
<td>0.1 M NaOH, 0.1 M HCl</td>
<td>12</td>
<td>0.007</td>
<td>0.102</td>
<td>0.032</td>
</tr>
<tr>
<td>5th</td>
<td>0.1 M NaOH, 0.1 M HCl</td>
<td>12</td>
<td>0.010</td>
<td>0.103</td>
<td>0.033</td>
</tr>
<tr>
<td>6th</td>
<td>0.1 M NaClO, 0.1 M citric acid</td>
<td>12</td>
<td>0.013</td>
<td>0.104</td>
<td>0.034</td>
</tr>
<tr>
<td>7th</td>
<td>1.5% NaClO, 0.1 M citric acid</td>
<td>12</td>
<td>0.014</td>
<td>0.105</td>
<td>0.035</td>
</tr>
<tr>
<td>8th</td>
<td>1.5% NaClO, 0.1 M HCl</td>
<td>12</td>
<td>0.018</td>
<td>0.106</td>
<td>0.036</td>
</tr>
</tbody>
</table>

Fig. 3. Long time operation of the system for 8 cycles with different cleaning strategies

(2) Membrane fouling resistance and distribution

LAP: Loosely Attached Pollutant, causing R<sub>w</sub>:
SAP: Strongly Attached Pollutant, causing R<sub>s</sub>:
IRP: Internal Reversible Pollutant, causing R<sub>r</sub>:
IIRP: Internal Irreversible Pollutant, causing R<sub>i</sub>:

Fig. 4. Membrane fouling resistance with/without coagulation

(3) Influence of de-fouling strategy on membrane anti-fouling propensity

Fig. 5. Selection of backwash solution influenced membrane anti-fouling performance: (a) change of TMP with filtration time; (b) change of membrane fouling rate with filtration time (the FeCl3-C-FSCMF procedure, flux of 1.0 m/d, aeration of 0.1 LPM)

Conclusions

- The C-FSCMF hybrid procedure could produce the filtrate with low organics loading, and we could obtain the concentrated sludge with rich organics and P for further waste-to-resource recovery.
- Operation of the C-FSCMF hybrid procedure could be stably operated with high flux up to 1.0 m/d.
- The external attached foulants on membrane surface was found to cause the main resistance, accounting for approximately 76.2-80.9% of total resistance.
- The fouled membrane could be initially regenerated by physical cleaning methods, followed by chemical cleaning after long-term system operation. In real application of ceramic membranes, long-term stability of ceramic membranes and up scaling is needed.
Chemically Enhanced Primary Sedimentation and Acidogenesis of Organics in Sludge for Enhanced Nitrogen Removal in Wastewater Treatment

Xiao-yan Li*, Ying-yu Li

Department of Civil Engineering

**INTRODUCTION**

- With the decreasing COD/N ratio in the municipal wastewater in the recent year, external organic carbon source has been added into the secondary biochemical treatment process to improve N removal.
- The ferric iron-based chemically enhanced primary sedimentation (CEPS) is widely used in Hong Kong. With the reduced amount of organics flowing to the downstream process, organic load and sludge yield on biological wastewater treatment dramatically decreased. However, nitrogen cannot be removed in the CEPS process.
- There are over 800 tons of CEPS sludge produced by WWTPs in Hong Kong. Nowadays, incineration and landfilling are the main sludge disposal methods for the sludge.
- The Fe-based chemically enhanced primary sedimentation sludge can be converted into volatile fatty acids (VFAs) by hydrolysis and acidogenesis. The CEPS fermentation supernatant can be used in the heterotrophic denitrification process to make up carbon deficit for denitrification.

**METHODOLOGY**

- Denitrification performance of CEPS sludge fermentation supernatant (compared with methanol, NaAc and NaPr): denitrification rate, denitrification potential, sludge yield and nitrous oxide emission rate;
- Nitrate uptake rate (NUR) test was conducted for the denitrification performance assessment of a complex carbon source.

**OBJECTIVES**

- The aims of the research were to (i) investigate the composition of the CEPS-FL after CEPS sludge fermentation; (ii) determine the denitrification performance of CEPS-FL relative to the typical commercial carbon; (iii) investigate the influences of various carbon sources on the microbial communities and N₂O yield in the denitrification reactors; and (iv) analyze the system for carbon and nitrogen flow and related cost.

**RESULTS & DISCUSSION**

1. **Composition of CEPS sludge during fermentation:**

2. **Denitrification performance of CEPS-FL in comparison with typical commercial carbon sources:**

3. **Material flow and mass balance of C and N through CEPS-fermentation-denitrification combination:**

**CONCLUSIONS**

- The CEPS-fermentation-denitrification combination is an effective, chemical-saving, and energy-efficient process for carbon recovery and nutrient removal;
- Nearly 20% of the organics in the raw wastewater can be recovered by fermentation of CEPS sludge;
- CEPS-FL had a higher denitrification rate (410.3 g N/kg VSS/d) and a lower N₂O emission (1.14%) than that of methanol;
INTRODUCTION

- Wastewater treatment produces a large amount of sewage sludge every day, and the sludge contains quantities of organics as the aggregates of microorganism. The difficulty to recover these biodegradable resources is to thoroughly break down cell walls but not to exhaust the target objectives.
- By thermal hydrolysis, heating is applied under high pressure to break down microbial cells and particulate organics in sludge to smaller organic compounds. This process can effectively dissolve and hydrolyze large portions of solid organics into liquid phase with a highly improved biodegradability.
- The hydrolysis efficiency is different based on apparatus with different container scales, heating strategies, and gas tightness. But the release of organics and their biodegradability are most significant indicators for both the treatment efficiency and the prospective in the further application.

OBJECTIVES

- Laboratory treatment of waste sludge by thermal hydrolysis for organics release under different conditions.
- Determination of the hydrolysis efficiency and characterization of the soluble organics.
- The optimization and explanation between biodegradability and different treating conditions.

METHODOLOGY

- Thermal hydrolysis is implemented with 30-120 minutes, 140-180°C, to excess sludge, respectively.
- Efficiency of organics release and biodegradability are investigated by change of COD and BOD, respectively.
- Molecular weight distribution and excitation-emission matrix spectroscopy are to explain the change of organics.

RESULTS AND DISCUSSION

(1) Organics release via thermal hydrolysis

Fig. 2. (a) The sketch of thermal hydrolysis and (b) the hydrolysis efficiency under different treating time and temperature scale.

(2) Biodegradability of sludge liquor

Fig. 3. (a) Biodegradability of sludge liquor after treatment by different temperature and (b) the organics profiles in the liquor.

(3) Transformation of organics

Fig. 4. (a) Molecular weight distribution of sludge liquor and (b) excitation-emission matrix profiles after thermal hydrolysis.

CONCLUSIONS

- With the increase of treating time and temperature, solubilization of organics gets increase from 20% to 40%, even 50%, compared with the original total organics concentration.
- The biodegradability (BOD₅/COD) is generally higher than 0.5, which means easy degradation, but the temperature higher than 180°C promotes the production of new macromolecular organics. 150-160°C is comparatively better for both solubilization and biodegradation.
- Higher temperature also gives out more humic-acid like organics, which has poor biodegradability.
INTRODUCTION

- Removal of pollutants in conventional wastewater treatment processes produces a large amount of sludge, and disposal of sludge is one of the most challenging environmental problems for large cities.
- Sludge contains high concentrations of organics, which can be recovered in forms of value-added products instead of being degraded or wasted.
- Thermal hydrolysis has proved to be a promising technology for sludge disposal. During thermal hydrolysis, sludge is heated and pressurized to release organics from solid phase to liquid phase, and the settleability and dewaterability of sludge can be greatly improved.
- Thermal hydrolyzed sludge liquor with high contents of organics are currently treated by anaerobic digestion. But the purity of methane is too low to be used directly, and the value of methane has been greatly reduced with the large-scale development of shale gas and other fuels.
- To remove organics in thermal hydrolyzed sludge liquor and recover fungal biomass as a valuable resource, filamentous fungi were used in this study to treat thermal hydrolyzed sludge liquor, and the resulted fungal mycelia can be used as raw materials for single-cell proteins or fibrous carbon materials.

METHODOLOGY

Thermal hydrolysis: Excess sludge was thermal hydrolyzed in a high-pressure reaction vessel at 160 °C for 1 h. The liquid components and residual solids were separated by filtration.

Fungal species: The thermal hydrolyzed sludge liquor was inoculated with fungus species of Aspergillus niger (A. niger) or Rhizopus oryzae (R. oryzae).

Fungal fermentation: The inoculated sludge liquor was incubated in a environmental shaker at 30 °C with 150 rpm.

Fungal biomass recovery: After fungal fermentation, the enriched fungal pellets can be easily separated from the treated sludge liquor by sedimentation or filtration.

RESULTS AND DISCUSSION

(1) Treatment of thermal hydrolyzed sludge liquor by fungal fermentation

(2) pH optimization for organic removal and fungal biomass growth

(3) Fungal mycelia recovery and utilization

CONCLUSIONS

- Thermal hydrolyzed sludge liquor with high organic contents can be treated by fungal fermentation, and fungal biomass can be accumulated and recovered from this process.
- COD removal and fungal growth were significantly affected by pH. A. niger showed maximum COD removal of 41% and biomass of 1290 mg/L with the initial pH of 2. The biomass yields of A. niger and R. oryzae after 3 days were 0.33 and 0.53 g-biomass/g-COD, respectively.
- The recovered fungal mycelia can be used as the raw materials of single-cell proteins or fibrous carbon materials.
Interaction of plastic hinges in PC bridges with corrugated steel webs

Francis T.K. Au and Team

Department of Civil Engineering

INTRODUCTION

PC bridges with corrugated steel webs

Advantages:
• Lower self-weight;
• High buckling strength;
• No need for stiffeners;
• Efficient prestressing, etc.

Problems:
• Lower shear stiffness; and
• Invalid assumption that plane sections remain plane.

RESEARCH OBJECTIVES AND KEY COMPONENTS

Key components of research
• Practical yet reliable beam models
• Ductility and deformability analysis
• Nonlinear section analysis

EXPERIMENTAL PROGRAMME

Experimental and numerical investigation

1. Experimental work
2. Numerical analysis using commercial finite element package and self-developed finite element programme

Methodology

1. Experimental work
2. Numerical analysis using commercial finite element package and self-developed finite element programme

Programme for full-range nonlinear analysis of prestressed concrete members

Focus of this project

Key components of research

• Practical yet reliable beam models
• Ductility and deformability analysis
• Nonlinear section analysis

EXPERIMENTAL PROGRAMME

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Span (mm)</th>
<th>Beam depth (mm)</th>
<th>Flange Thickness (mm)</th>
<th>Web Thickness (mm)</th>
<th>Intermediate diaphragm thickness (mm)</th>
<th>Effective prestress force (kN)</th>
<th>No. of fixators</th>
<th>Loading point(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>3600</td>
<td>360</td>
<td>80</td>
<td>5</td>
<td>200</td>
<td>-</td>
<td>268</td>
<td>Mid-span</td>
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<tr>
<td>B-2</td>
<td>3600</td>
<td>360</td>
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<td>5</td>
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<td>70</td>
<td>252</td>
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<td>360</td>
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<td>5</td>
<td>200</td>
<td>70</td>
<td>102</td>
<td>Mid-span</td>
</tr>
</tbody>
</table>

Full-range structural behaviour

• Curvature along span
• Measured load-deflection curves & curvature
• Plastic hinge zones

INTERACTION BETWEEN FLANGE PLASTIC HINGES AND FULL-DEPTH PLASTIC HINGE

• Equivalent interactive plastic hinge length \( l_p \)

SIMPLIFIED METHOD FOR PREDICTION

Flowchart for simplified method to predict full-range behaviour

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Span (mm)</th>
<th>Beam depth (mm)</th>
<th>Flange Thickness (mm)</th>
<th>Web Thickness (mm)</th>
<th>Intermediate diaphragm thickness (mm)</th>
<th>Effective prestress force (kN)</th>
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<td>0</td>
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<tr>
<td>B-4</td>
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<td>360</td>
<td>80</td>
<td>5</td>
<td>200</td>
<td>70</td>
<td>102</td>
<td>Mid-span</td>
</tr>
</tbody>
</table>

CONCLUSIONS AND DESIGN RECOMMENDATIONS

• Flange plastic hinge and full-depth plastic hinge may both form and interact with each other.
• The equivalent interactive plastic hinge length, critical region length and plastic behaviour are governed by the formation of flange plastic hinge.
• Based on the equivalent interactive plastic hinge length, a simplified method is proposed to predict the full-range structural behaviour.
• To estimate the ultimate displacement and load, it is conservative to assume the plastic hinge to form only on one side of the critical section.
• The critical region length \( l_c \) in the upper flange is about twice the flange thickness.
Collapse mechanism and robustness of precast segmental bridges
Francis T.K. Au, Albert K.H. Kwan and team
Department of Civil Engineering

Introduction

- The collapse of MacArthur Maze near San Francisco after fire in 2007 illustrates the need for structural robustness.

- Eurocode EN 1991-1-7 states, “Robustness is the ability of a structure to withstand events like fire, explosions, impact or the consequences of human error, without being damaged to an extent disproportionate to the original cause.”

In-situ concrete stitches and potential weakness

- The in-situ concrete stitches in precast segmental bridges erected by balanced cantilever method are potential weaknesses.
- In an extreme event, progressive collapse is a constant threat.

Method of analysis to simulate extreme event

An imposed displacement is added at mid-span of Span 3 (M3) to simulate an accidental load in an extreme event.

Three scenarios are examined:
A. Moment capacities at Pier Sections C and D are not reached.
B. Moment capacities at Pier Sections C and D are reached.
C. Moment capacities at multiple critical sections are reached.

Results of numerical simulation

Scenario A – Original configuration
- 5 plastic hinges form in 3 stages.
- However it does not collapse despite the large deformations.
- It is said to have superb robustness.

Scenario B – Hogging moment capacities in pier sections reduced to 70% of original
- 7 plastic hinges form in 4 stages.
- Only the loaded span collapses.
- It is said to have adequate robustness.

Scenario C – Hogging moment capacities in pier sections reduced to 50% of original
- 13 plastic hinges form in 6 stages.
- The loaded span and two adjacent spans collapse, resulting in progressive collapse.
- It is said to have inadequate robustness.

Conclusions and design recommendations

- Assessment of robustness can be carried out by numerical simulation of displacement-controlled loading test to investigate the collapse mechanism.
- To achieve superb or adequate robustness, any span should be designed for the deck moments after the adjacent span has collapsed as if the remaining span has become a new end span.
- Nominal external tendons should be provided across in-situ stitches for new construction and retrofitting of existing bridges of insufficient robustness.

Acknowledgements
The study is supported by Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. HKU 710807E), and the Small Project Funding and the HKU SPACE Research Fund of The University of Hong Kong.
Dam development in the past, present and future

Dr. Ji Chen (陳骥)

jichen@hku.hk

Department of Civil Engineering

Background

- Water is the key factor in consideration of its various utilizations, e.g., drinking, irrigation, and hydropower.

![Global water availability by 2010 and global reservoir capacity by 2010](Image)

Dam Development

- Analysis of 32734 dams (related reservoirs and hydropower stations) from 1900 to 2010.

![Number of dams completed per year vs. Total reservoir capacity per year](Image)

- Total installed capacity per year (GW)

- Accumulated reservoir capacity of different levels of development

Population Growth

**Growth rate**

- Developed countries: steady and low
- The LDCs: steady but high
- Developing countries: between the above two

![Population, water consumption, number of dams, energy consumption, reservoir capacity, and food consumption](Image)

Water, Food and Energy Consumption Growth

- There were 2815 large dams are selected by storage capacity (> 0.1 km³) and height (> 10 m).

![Relation between Large Dam Number and GDP](Image)

Future Large Dam Prediction

![Predicted locations](Image)

Publications

Hydrological Processes and Reservoir Operation [1]

Comparison of the reservoir simulations of the XFJR storage from three schemes with the observations at a monthly time step from 1 Jan 1965 to 31 Dec 1984.

Hydrological Processes and Soil Erosion [2]

Spatial distribution of annual average soil erosion at (a) the HRU and (b) the sub-basin.

Multi-year average monthly net depositions of the channel segments.

Hydrological Processes and Pollution [3]

Study Area: point source pollution locations, two major gage stations and land use types.

Pollution, precipitation and water yield.

Annual average nutrient loads at the basin outlet (BL) under two scenarios (with and without point source pollution loads).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>min-N</th>
<th>min-P</th>
<th>org-N</th>
<th>org-P</th>
<th>TN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>NPS only ($10^3$ t/yr)</td>
<td>27.4</td>
<td>0.35</td>
<td>65.7</td>
<td>9.4</td>
<td>93.2</td>
<td>9.8</td>
</tr>
<tr>
<td>B</td>
<td>PS and NPS ($10^3$ t/yr)</td>
<td>29.2</td>
<td>0.70</td>
<td>68.7</td>
<td>9.7</td>
<td>95.9</td>
<td>10.4</td>
</tr>
<tr>
<td>A/B</td>
<td>Percentage of NPS (%)</td>
<td>94</td>
<td>50</td>
<td>99</td>
<td>97</td>
<td>97</td>
<td>94</td>
</tr>
</tbody>
</table>

Publications


Exploration of Severities of Rainfall and Runoff Extremes in Ungauged Catchments

Dr. Ji Chen (陳骥)
jichen@hku.hk

Department of Civil Engineering

Lai Chi Wo Catchment

It is designated as a Site of Special Scientific Interest (SSSI) in 1979.

Catchment Analysis

Drainage network and boundary Elevation and equipment's locations

Equipment Installation

Weather station Rain gauge Water level sensor Installed turbidity sensor and a new rain gauge, and collected water quality data

Field Data Collection

➢ The long period rainfall, water level data were recorded.


Discharge Simulation

TOPMODEL simulation using the rainfall and runoff data

The relationship between the frequencies and discharges of the floods in the Lai Chi Wo catchment.

Analysis of Rainfall and Runoff Extremes


Publication
Cross-diffusion formulation

“*All is flux*” -- Heraclitus

- **Consider a concurrent** scenario of primary and secondary consolidation processes in a porous viscoplastic medium[1]:

<table>
<thead>
<tr>
<th>1-D Hydro-Poro-Mechanics based on thermodynamics</th>
<th>Thermodynamic Force (1-D)</th>
<th>Thermodynamic Flux (1-D)</th>
<th>Conservation Law (no cross-diffusion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>$F_H = \frac{\partial \rho_t}{\partial x}$</td>
<td>$q_H = -\frac{\partial p_t}{\partial t}$</td>
<td>$\frac{\partial p_t}{\partial x} = \frac{D_H}{D_M} \frac{\partial ^2 \rho_t}{\partial x^2} + r^f_H$</td>
</tr>
<tr>
<td>M</td>
<td>$F_M = \frac{\partial \rho_s}{\partial x}$</td>
<td>$q_M = -\frac{\partial p_s}{\partial t}$</td>
<td>$\frac{\partial p_s}{\partial x} = \frac{D_M}{D_M} \frac{\partial ^2 \rho_s}{\partial x^2} + r^M_M$</td>
</tr>
</tbody>
</table>

- **H**: the diffusion of pore fluid pressure (e.g. melt in partially molten rock) – Darcy’s law, and hence $D_M$ depends on matrix permeability and melt viscosity;
- **M**: the compaction of the viscoplastic solid matrix after yield. Perzyna’s overstress model is adopted: $\tilde{\sigma} = (\sigma^2 - p_f)$
- The (M) conservation law in the creeping regime is described as a diffusion wave equation[2](no inertia) travelling at a wave velocity $v = \frac{D_M}{D_M}$.

- **How to manifest** the possible time-dependent interactions “around” the solid-fluid interface in the above thermodynamic framework?

- **Cross-diffusion** in a complex system: the phenomenon when a generalized thermodynamic force induces a generalized thermodynamic flux of another kind.

$\frac{\partial \rho}{\partial t} = \frac{\partial}{\partial x} \left( \frac{\partial \rho}{\partial x} \right) + r^f$

$\frac{\partial \rho}{\partial t} = \frac{\partial}{\partial x} \left( \frac{\partial \rho}{\partial x} \right) + r^M$

$\frac{\partial \rho}{\partial t} = \frac{\partial}{\partial x} \left( \frac{\partial \rho}{\partial x} \right) + r^f + r^M$

- Relaxing the adiabatic constraints on the reaction part of the system:

$\mathbf{D} = \left[ \begin{array}{c} D_H \\ D_M \end{array} \right] + \left[ \begin{array}{c} h_1 \\ h_2 \end{array} \right]$

- Detailed derivations on connecting pore scale to wave-sampling scale can be found in [1].

An extension of the standing cnoidal waves

**Standing waves**: KdV eq. featuring periodic stress localization in the weak phase.

**Hydro-Poro-Mechanical cross-diffusion wave instability**

- **A)** X-ray microtomography of density distribution around a CB (light area); **B)** Black-scattered SEM image showing crushed grains and loss of porosity (black pixels).

- **Apply a small plane wave perturbation** to the system:

$\frac{\partial \rho}{\partial t} = \frac{\partial}{\partial x} \left( \frac{\partial \rho}{\partial x} \right)$

- **Onset of instability**, i.e., $\Delta < 0$, requires

$D_H - D_M = \frac{\lambda}{6k^2} + 2h_1b_2 < 0$, $\Rightarrow$ The cross-diffusion coefficients $h_1$ and $h_2$ be non-zero and of opposite sign.

Field/Laboratory examples of cross-diffusion waves

- **Left**: Melt extraction channels in a partially molten metamorphic rock from the Sikkim Higher Himalaya Migmatite gneisses. **Right**: AE indications of compaction fronts in porous sandstone[3]

**Conclusions**

- We propose a new quasi-soliton type of cross-diffusional wave instability induced by possible time-dependent processes of inter-constituent mass transfer (dissolution, precipitation, melting, fluidization, solidification, etc.);
- The proposed approach considers an open system and allows local negative entropy, using a simple mathematical framework that captures a fundamental physics/chemistry-based perspective of pattern formation in Hydro-Poro-Mechanical materials.

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Sustainable development against landslide hazards

Dr Clarence E. Choi

Faculty of Engineering

Department of Civil Engineering

Research areas

Flow-structure interaction

Currently, the design of physical barriers against debris flows is empirical in nature. The problem with empiricism is that it is not possible to discern whether a design is insufficient, adequate, or over-conservative. We are currently looking to reveal fundamental impact mechanisms, to develop analytical approaches and to translate findings to design guidelines that practitioners can use.

Disaster preparedness

In an effort to enhance the preparedness and resiliency of communities situated in mountainous regions against Geohazards, engineers and scientists will need to embrace technology such as event-driven sensors and artificial intelligence. By adopting new technology, the processes of managing, reporting, and responding to landslides hazards can be streamlined.

Submarine landslides

We still have only a very limited understanding of what happens under the sea. Answering questions about submarine geomorphology is essential for sustainable offshore development. As development moves offshore, platforms, pipelines, and cables will become more susceptible to landslide hazards. Therefore, improving our understanding of initiation, transportation, and deposition mechanisms of submarine landslides will lead to safe and economical submarine engineering.

Climate change and frost geotechnics

With global warming, glaciated areas at all elevations are expected to retreat. This process will increase both sediment and water to catchments, thereby amplifying geohazards in mountainous areas. One of these critical challenges is dealing with the effects of periglaciation on landslides.

International collaborators and committees

• Chair of Debris Flow and Steep Creek hazards Committee of the Association of Geohazard Professionals (AGHP)
• Chair-nominated member of TC208 (Slope Stability) of International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE)

Relevant funded projects

• 2016 – ongoing: Smart landslide information system, The Hong Kong Jockey Club Disaster Preparedness and Response Institute (HKJCDPRI); Project No: HKJCDPRI17 (PI)
• 2016 – ongoing: Submersible model to study submarine debris flow impact on deep sea structures, Research Grants Council (RGC) of Hong Kong; Project No: IGN15EG03 (PI)
• 2018 – ongoing: Mechanisms of interaction between debris flow and baffles, General Research Fund (GRF) of the RGC of Hong Kong; Project No.: 16209717 (PI)
• 2018 – ongoing: Multi-scale modelling strategies for debris-flow; a new technique for hazard assessment combining numerical modelling and physical experiments, Politecnico Di Torino, Italy: Joint research projects with top universities (PI)
• 2018 – ongoing: Smart landslide barriers, HKJCDPRI; Project No.: HKJCDPRI18 (PI)
• 2019 – ongoing: Impact of geophysical flows on rigid barriers with and without cushioning materials, GRF of RGC Hong Kong; Project No.: 16212618 (PI)
• 2018 – ongoing: Interaction mechanisms between debris flows and multiple barriers, The National Natural Science Foundation (NSFC) of China; Project No.: 5170910939 (PI)
• 2020 – 2023: Impact mechanisms of debris flows on erodible bed against multiple flexible barriers: large-scale physical modelling, GRF of RGC Hong Kong; Project No.: 16210219 (PI)
The ability to control, manipulate and design materials to prevent environmental pollution and also to recover valuable resources will be a major technological challenge in the wastewater industry in the 21st century. For example, struvite (MgNH_4PO_4•6H_2O) is a phosphate phase that can be precipitated from wastewater to simultaneously provide P and N for plants as a slow-releasing fertilizer. Therefore, its product quality generated from the waste streams requires further evaluation and control. We have first demonstrated the capability of quantitative X-ray diffraction (QXRD) technique in evaluating and assisting the control of phosphorus-phases precipitated from solution.

**METHODOLOGY**

**Solution Precipitation**

Common Methods
- Qualitative XRD
- Chemical Elemental Analysis (IC, ICP-OES)
- Scanning Electron Microscope (SEM)

**Sample Preparation**

**Quantitative XRD**

**FIRST QUANTITATIVE XRD ANALYSIS**

Struvite is the only crystalline phase in the precipitates, and the other precipitated P existed in amorphous content. Struvite phases decreased as the initial solution Ca/Mg molar ratio increased. When the concentration of Ca was double than that of Mg in solution, the crystallization of struvite was nearly completely hindered by Ca ions.

The quantitative results showed that the struvite crystallization was significantly inhibited by calcium ions, particularly at high pHs (i.e., pH ≥ 10.0). The struvite contents in the precipitates were generally below 50 wt.% when the Ca/Mg molar ratio was 1:1 or higher. Moreover, a good linear correlation was found between the struvite weight content and the Ca/Mg molar ratio.

**CONTROL AMORPHOUS PHASE**

Combined with the elemental analysis by energy dispersive spectroscopy (EDS) in SEM technique, the results suggested that calcium phosphates were the major phases in the products precipitated from high pH solutions, but they were in the form of amorphous calcium phosphates.

**CONCLUSIONS**

◊ Struvite crystallization was significantly inhibited by the co-existence of calcium ions and the prohibiting effect was found to be with a negative linear correlation.

◊ This work shows the quantitative X-ray diffraction technique can greatly assist the quality control of phosphorus resource recovered from wastewater streams.
INTRODUCTION

Organic compounds in wastewater are one of the major treatment targets and also largely affect the membrane fouling tendency. Advanced oxidation processes (AOPs) based on highly reactive oxygen species (ROS) have shown great potential in wastewater treatment technology. The high thermal and chemical stability of flat-sheet ceramic membranes renders its surface properties easily tunable by various chemical modification processes. Using catalytically functional flat-sheet ceramic membranes can conduct forced filtration and chemical oxidation processes at the same time to simultaneously achieve high pollutant removal efficiency and membrane fouling propensity.

METHODOLOGY

The catalytic ceramic membranes can be fabricated using a modified sol-gel method: A ceramic membrane matrix was immersed into the Co-Fe sol for several times and then calcinated at 400 °C for 2 h.

CONCLUSIONS

◊ Substantial CoFe₂O₄ crystals were successfully anchored onto this new catalytically functional membranes to be highly efficient in removing organic pollutants in wastewater.
◊ The fabricated catalytically functional ceramic membranes showed good reusability in maintaining their catalytic reactivity after multiple treatment cycles.

NOVEL MEMBRANE PRODUCTS

UNIQUELY CATALYTIC FUNCTION

REUSABILITY ASSESSMENT

Stable treatment (bisphenol A) cycles with catalytic ceramic membrane
INTRODUCTION

Significant amounts of industrial and environmental treatment sludge and ash residues are generated in highly industrialized and urbanized areas. These materials include a wide variety of industrial processing waste, sewage sludge, and incinerated ashes. With the majority of them now disposed in landfill, the fact should be realized that considerable quantity of valuable resources are misplaced and a “Waste-to-Resource” strategy should be developed to close the loop for a more sustainable waste management framework. This work aims at reliably realizing the goal of beneficially and safely turning these waste residues into construction materials.

METHODOLOGY

Minerals (alumina, kaolinite, iron oxide, mullite) were mixed with nickel residue for ceramic sintering.

The phase formation mechanisms and kinetics were quantitatively investigated by X-ray diffraction (XRD) technique with Rietveld refinement. Field emission scanning electron microscopy (FESEM), high resolution transmission electron microscopy (HRTEM), and prolonged leaching experiments were employed to characterize the material properties of the products.

EFFICIENT STABILIZATION MECHANISM

Nickel spinels were identified as the phases of stabilizing nickel in ceramic products, and all tested precursors showed high nickel incorporation capability (> 90%) after a short 3-hr sintering at above 850°C.

RELIABLE AND SAFE PRODUCTS

Prolonged leaching experiments for spinels confirmed the effectiveness of preventing nickel leaching, and the observation of microstructures indicated the potential of mechanical robustness of the ceramic products.

CONCLUSIONS

◊ Mechanistic study in metal stabilization reveals, quantifies and controls the fate and transport of metals in beneficially using the waste materials for construction purposes.

◊ Safe and reliable “Waste-to-Resource” strategies can be realized by the state-of-the-art environmental materials research.
Driving Simulator Research Projects  
Prof. S.C. Wong (黃仕進) Team

Introduction

Driving simulator experiments have increasingly been used to safely and ethically model the relationship between traffic safety and driver behavior, especially prohibited behavior in hazardous situations.

Apparatus And Materials

Desktop-based XP-300 driving simulator (XPI Simulation Ltd., UK)

To measure the driving performance, e.g., vehicle position, speed, acceleration and braking, and angle of the steering wheel.

Driving Performance Measures

**Reaction time** The time interval between the appearance of the leading vehicle's brake light and the time at which the test vehicle driver applied the brake.

\[ \text{RT} = T_{\text{Brake}} - T_{\text{Event}} \]

- **Notes:**
  - \( T_{\text{Event}} \) = Time when braking event appeared
  - \( T_{\text{Brake}} \) = Time when brake is applied
  - \( V_{\text{Limit}} \) = Speed limit (50 or 80 km/h)

**Standard deviation of lateral position & speed**

Measurements of the lateral position and vehicle speed within the period between \( T_{\text{Limit}} \) and \( T_{\text{Limit}+10} \) were extracted from the dataset to calculate the variation in lateral position and speed

\[ \text{LANE} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}}, \text{ for } n = 1, 2, ..., 300 \]

\[ \text{SPEED} = \sqrt{\frac{\sum_{i=1}^{n}(V_i - V_{\text{Limit}})^2}{n-1}}, \text{ for } n = 1, 2, ..., 300 \]

Key Simulation Research Projects

- **Alcohol Impaired Driving Study**
  - Drager Alcotest 9510

- **Driving Distraction of Mobile Devices**

- **Fatigue Driving of Taxi Drivers**

Reference

Introduction

Area-wide Macroscopic Traffic Flow (MTF) Models

Research Gap: No Unbiased Model Estimation Methods

- To identify the sources of biases in the direct model estimation based on linearly projected data
- To develop methods to efficiently remove or reduce such biases
- To identify the primary network topological metrics governing the shapes of these MTF models
- To establish the spatial variable MTF models

Methodology

Sources of Biases

Parameters:
\[ E(\mathbf{G}(\mathbf{\beta}; x)) = G\left( \mathbf{\beta}, \sum_{i=1}^{n} x_i \right) \]

Standard Errors:
\[ \text{var}(\mathbf{y}|\mathbf{x}) = \sigma^2 \sum_{i=1}^{n} \frac{\partial g(\mathbf{f})}{\partial y} + \alpha^2 \]

Unbiased Model Estimation Methods

Network Topological Effects on MTF Models

Data: Taxi GPS Big Data; Fixed Detector Data; Map

Step 1

Unbiased MTF Model Estimations using the developed methods

Step 2


Contact and Fracture mechanics of FGM

Prof. Zhong-qi Quentin YUE’s Team

Department of Civil Engineering

Contact force law of FGMs coated materials

Functionally graded material (FGM) is a special composite material with the gradual variation of composition and microstructure along a specific direction. The grading changes of the material properties enable the FGM possesses many unique features such as reducing stress concentration, increasing fatigue life, preventing crack initiation and interfacial delamination of contacting bodies. This project analytically examines important contact and fracture problems encountered in applications of FGM.

Extended Hertz’s solution

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Elementary and explicit nonlinear force law is developed for FGM coated substrate

Extended GW’s model and solution

A statistic model is developed to simulate the contact of FGM coated rough surface. It is a combination of the GW’s model and the contact force law for FGM coated substrate

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Crack tip plasticity of fracture in FGMs

A multi-layer model to simulate the arbitrarily graded interface

A multi-layer model to simulate the arbitrarily graded interface

Results of Mode I SIF by using the multi-layer model

Results of Mode I SIF by using the multi-layer model

Typical value of coating thickness

Variation of normalized total contact force

W/Ω as function of dimensionless separation

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Extended GW’s model and solution
Learning More Lessons from a Catastrophic Man-made Slope Failure Disaster in Shenzhen

Prof. Zhong-qi Quentin YUE’s Team
Department of Civil Engineering

Introduction

20 December 2015 is the important date for Shenzhen because there was considerably huge landslide disaster at dumpsite near Hengtaiyu Industrial Park, Guangming Province, Shenzhen, People’s Republic of China. A possible energy source of fluid (gas) layer to induce the landslide is investigated in this project funded by RGC under GRF. Here several highlights:

- Land before failure volume of 6.27 million m³
- Land failure volume of 2.7 million m³
- Land failure area ~267,750 m² or nearly 60 times standard FIFA Soccer Field with long run-out 630 m
- Slope angle range 9° ~ 15° (Less than minimum angle for registration as potentially dangerous fill slope in Hong Kong Slope Safety System of 16°)
- Occurred in Dry season
- 33 building collapsed
- 73 fatalities, four missing and 17 injured
- Direct economic losses of ¥880 million (Zhan et al. 2018)

Model A (Longitudinal section at terrace area)

Model B (Longitudinal section entire area)

Before and After Failure entire area

Longitudinal section at Terrace Area

- CLAY 7% by weight
- Ps=23-25%
- LL=30-32%
- Pe=7-
- wtm=20%

Longitudinal cross-section M

- Top FILL
- Bottom FILL
- Central Gas Pipeline

Longitudinal cross-section Q

- Deposition zone
- Source zone

Geometric Scale 1:900

Preliminary findings of the laboratory model tests
Effect of micro-gas inclusions on delayed behaviour of rockburst

Prof. Zhong-qi Quentin YUE’s Team

Department of Civil Engineering

Introduction

In-situ intact rocks surrounding excavations do have some abnormally delayed mechanical behavior such as rockburst. The rockburst involves the implosion of the intact rock into the excavated tunnel with the release of significant amounts of energy, which often causes disasters. The rockburst is still an unexpected, unpredicted and undescribed phenomenon with the current theories of applied mechanics and rock mechanics. A possible energy source of fluid (gas) inclusions to induce the rockburst is investigated in this project funded by RGC under GRF.

Gas-driven fractures of rock-like materials

Energy components during gas-driven fragmentation

Fracture and fragmentation of coal briquettes

Schematic diagram of gas-driven fractures

Intensity of outbursts after gas decompression

Effects of the decompression rate of gas on outbursts

Fracture of rock-like solids caused by compressed gas

A combination of the compaction method and adding gas entraining agent in cement-based solid is first proposed and used. The gas can be compressed and confined in micro-voids of the cement-based solids. The expansion of the compressed micro-gas can act as the energy source and internal force to fracture solids.

Eruption of cement paste by its chemical reacting gas

Oxygen gas \( O_2 \) is being generated by chemical reaction in cylinder. The sealing piston can be ejected due to the increasing and expanding of chemical gas in liquid paste.
The boundary element method (BEM) is an efficient and accurate numerical method which is ideally suited for the analysis of elastic solid materials occupying either fullspace or halfspace. The analytical solutions of homogeneous layered fullspace and transversely isotropic bi-material fullspace proposed by Prof. Yue have been applied as the fundamental solutions to BEM. In the past 20 years, the proposed method has been successfully applied to stress field analysis, fracture mechanics and contact problems.

### Elastic fields in homogeneous non-horizontally layered halfspaces

**Displacement boundary integral equation**

\[ c_i (P) u_i (P) + \int_{S_p} \frac{1}{r} (P, Q) u_j (Q) dS (Q) = \int_{S_p} \frac{1}{r} (P, Q) \tau_j (Q) dS (Q) \]

A square footing acting on a bi-material elastic halfspace with an arbitrarily inclined interface plane

### Elastic fields in transversely isotropic bi-material halfspaces

A square footing acting on a transversely isotropic elastic bi-material elastic halfspace with (a) an arbitrarily inclined (b) horizontal interface plane

### Three-dimensional cracks in layered and graded halfspaces

**Displacement boundary integral equation**

\[ c_i (P) u_i (P) + \int_{S_p} \frac{1}{r} (P, Q) u_j (Q) dS (Q) + \int_{S_p} \frac{1}{r} (P, Q) \tau_j (Q) dS (Q) \]

(a) A penny-shaped crack located at the interface between a graded layer and a homogeneous halfspace under a uniform compressive stress on the crack surface and (b) the normalized SIFs KI of it
Drilling Process Monitoring (DPM) is a new technique for digitizing, recording and analyzing drilling information. Since 2000, Prof. Yue and his research team have identified, developed and carried out the research project for real-time digital monitoring and recording of the drilling process in ground investigation and construction. The research team invented DPM system with the following features (Yue et al. 2003).

- DPM is a portable digital device;
- DPM can be mounted onto a conventional pneumatic rotary-percussive or hydraulic rotary drilling machine;
- DPM can digitize and record the drilling parameters in real time when drilling hole is being formed by the drilling machine in ground.

**Methodology and Discovery**

- Time-series analysis algorithm;
- The curve of the drill bit advancement depth versus the net drilling time is a set of connected linear lines;
- Each linear line zone has a constant slope gradient representing the constant drilling rate of a homogeneous geo-material seam;
- The connection depth of two linear line zones represents a discontinuity position of two homogeneous geo-materials.

**Application**

DPM are used in many projects for digital geotechnical engineering. It upgrades existing or new drilling machines as in-situ digital ground investigation and exploration tools. It can quantify the strength profile of soils and rocks along the drilling hole quantitatively and promote development of intelligent engineering.

**Uniaxial Compressive Strength with DPM**

**Concluding Remark**

DPM is an innovative technique for automatically, objectively and quantitatively monitoring the whole drilling process with the fast and direct time-series analysis of DPM data. DPM can offer a new measurement method and many factual data for digitizing, refining and upgrading strength of geomaterials and rock mass quality classification in geo-engineering.
AMR surveillance and ARGs Host Tracking
The abundant ARGs were usually associated with the extensively used antibiotics. The abundance of ARGs increased with the influence of anthropogenic activities.

Minimize AMR in the Environment
A practical method to combat AMR is to remove antimicrobial residues by degradation.

Welcome to ARGs-OAP Galaxy!
ARGs-OAP
Online analysis pipeline for ARGs detection from metagenome data using an integrated structured ARG database. SARGFAM
A function module in ARGs-OAP v2.0, supporting sequence retrieval strategy for detecting novel genes.
ARGPORE
Online tool to identify ARGs for third generation sequencing nanopore reads and identity the ARGs host.
ARGs-OSP
A source-tracking platform using machine-learning classification with ARG abundance profiles.
I-VIP
Integron visualization and identification pipeline.

Antimicrobial resistance genes (ARGs)
Antimicrobial resistance in the microorganism is conferred by ARGs. ARGs-carrying microorganisms were found in waters, soils, human and animal wastewaters. The spread of ARGs among microorganims has been sped up by antimicrobial residues in the environment. ARGs was listed as a top emerging environmental issue in United Nations Environment Programme (UNEP) report, Frontiers 2017.

Online Metagenomic Analysis of ARGs (ARGs-OAP)
Metagenomic approaches can provide broad-spectrum profiles of ARGs in environmental samples, but the detection and classification of ARGs-like DNA sequences are time consuming. We sought to accelerate quantification of ARGs in metagenomic datasets of environmental samples, and developed an online tool for fast annotation and classification of ARGs-like DNA sequences from metagenomic datasets called ARGs-OAP.
Activated sludge (AS) has been in use over a century to treat a large variety of municipal and industrial wastewaters. The understanding of the microbiome in AS (i.e., composition) is of significant importance for a stable wastewater treatment.

**Activated sludge process**

Rarefaction curves of OTUs in 15 AS samples from 14 sewage treatment plants.

Zhang, T., et al. ISME J., 2012, 6(6)

Occurrence-abundance plot of each genus in the 21 municipal and 29 industrial AS samples.


**Prokaryotic community of AS**

Gammaproteobacteria

Alphaproteobacteria

Betaproteobacteria

Acidobacteria

Planctomycetes

Verrucomicrobiota

Actinobacteria

Bacteroidetes

Chloroflexi

Bdellovibrionota

Halobacterota

Deinococcota

Chloroflexota

Bacteroidota

Planctomycetota

Spirochaetota

Armatimonadota

Hermonobacteria

Proteobacteria

**Microbial community assembly of AS microbiome**

Protein-sharing network for 8,728 metagenomic viral contigs (mVCs).


Metabolic feature of functional bacteria in AS

Genome tree of newly recovered bacterial and archaeal metagenome-assembled genomes (MAGs).

Wang, Y., et al. Under preparation

**Virome in AS**

Metabolism and gene expression of a newly recovered polyphosphate accumulating organism.

Application of Nanopore Sequencing

Prof. Tong Zhang (張彤) Team
Department of Civil Engineering

Nanopore sequencing technology

Oxford Nanopore sequencing technology offers real-time, scalable, direct DNA and RNA sequencing. The nano-scale Nanopores pass current through the hole and measure the changes in current when DNA or RNA molecules pass through the nanopore. The current can be used to identify the molecule (Figure 1). The longest read generated by Nanopore sequencing is up to 2.27 Mb.

Genetic analysis of resistome in WWTPs

we used Oxford Nanopore metagenomics sequencing to comprehensively uncover the resistome context of influent, activated sludge and effluent of WWTPs (Figure 2).

The results showed that most of the ARGs detected in all compartments of the WWTPs were carried by plasmids. Transposons and integrons also showed higher prevalence on plasmids than on the ARG-carrying chromosomes (Figure 3). A broad spectrum of ARGs carried by plasmids (29 subtypes) and ICEs (4 subtypes) was persistent across the WWTPs (Figure 4).

Rapid deciphering of antimicrobial resistant pathogen

Host tracking showed a variety of antibiotic-resistant pathogens in the effluent, suggesting the high potential for their dissemination into receiving environments (Figure 5).

High-quality bacterial genomes and plasmids assembly

Nanopore and Illumina sequencing were performed to assemble the bacterial genomes as well as their plasmids. Twelve bacteria were pooled with barcodes and sequenced together using one flow cell. The results showed that the long reads generated by Nanopore sequencing greatly facilitated the assembly results compared with the Illumina sequencing.
**Background**

MegaHIT is the first practical solution for large-scale metagenomic assembly, which is an important step in the study of unknown microorganisms in different environments. MegaHIT has remained widely used since the release of its first version and was recently awarded with the Faculty Research Output Prize.

Metagenomic assembly refers to the computational process of assembling the genome sequences of many (up to tens of thousands) different microbes directly from the NGS data of a microbial sample (e.g., soil, human guts). The data volume and computational resources could be tremendous. For example, the Great Prairie Soil Metagenome Grand Challenge includes datasets with a few hundred billion bases and the assembly process would typically require Terabytes of memory and weeks to months (if it could finish). MegaHIT, exploiting advance compressed data structures and parallel algorithms, was the first solution to complete the assembly of such soil data in a superior time-and-memory efficient manner. More importantly, MegaHIT has achieved a much better assembly quality when compared with previous solutions.

MegaPATH is bioinformatics software supporting real-time comprehensive pathogen detection in human specimen based on NGS. It has been used in hospital and microbiology laboratory. It exploits MegaHIT as well an SIMD-accelerated alignment algorithm (AC-Diamond) and an enhanced seeding strategy based on maximum-exact-match prefix to achieve superiois efficiency & accuracy. Furthermore, MegaPath can detect microbes without similar references.

**Workflow of MegaHIT**

**Succint de Bruijn graph (SdBG):** Convert a de Bruijn graph (≥20 bits per edge) into an bit array (<7 bits per edge)

**Parallel SdBG construction using GPU or SIMD:** partitions k-mers and performs radix-sort independently and in parallel.

### Performance of MegaHIT on soil metagenomic data

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Iowa (257 Gbp)</th>
<th>Kansas (484 Gbp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>6.7 Gbp</td>
<td>1.5 Gbp</td>
</tr>
<tr>
<td># of contigs</td>
<td>9.2 M</td>
<td>3.1 M</td>
</tr>
<tr>
<td># of contigs &gt; 1kbp</td>
<td>1.3 M</td>
<td>0.1 M</td>
</tr>
<tr>
<td>Average length</td>
<td>727 bp</td>
<td>485 bp</td>
</tr>
<tr>
<td>N50</td>
<td>807 bp</td>
<td>471 bp</td>
</tr>
<tr>
<td>Longest contig</td>
<td>313,620 bp</td>
<td>9,379 bp</td>
</tr>
<tr>
<td>Reads coverage</td>
<td>61%</td>
<td>11%</td>
</tr>
<tr>
<td>Memory</td>
<td>167 GB</td>
<td>287 GB</td>
</tr>
<tr>
<td>Time</td>
<td>46 hours</td>
<td>&gt;488 hours</td>
</tr>
</tbody>
</table>

**References**

Third Generation Sequencing (TGS) Platform

Affordable Precision medicine for all patients

Suitcase-sized Enabling precision medicine in remote areas

Easy to use Limited wet-lab operations required

Disadvantage Lack of algorithms and analytics

AI/DL algorithms and analytics for TGS

Clairvoyante: Small Variant Detection

Skyhawk: Clinically Significant Variant Validation


Biomedical Literature Mining

RENET: Gene-Disease Association Extraction

**Classifier**

**Document Representation**

**Document Composition**

**Sentence Representation**

**Sentence Composition**

**Word Representation**

<table>
<thead>
<tr>
<th></th>
<th>PRECISION</th>
<th>RECALL</th>
<th>F-SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeFree</td>
<td>48.2%</td>
<td>74.1%</td>
<td>58.4%</td>
</tr>
<tr>
<td>DTMiner</td>
<td>47.3%</td>
<td>78.4%</td>
<td>59.0%</td>
</tr>
<tr>
<td>RENET</td>
<td>85.2%</td>
<td>81.8%</td>
<td>83.5%</td>
</tr>
</tbody>
</table>


Chinese Genome Database (CGDB)

Human Leukocyte Antigen (HLA) Type Distribution

Acknowledgement

- Innovation and Technology Commission, HKSAR
- Research Grants Council, HKSAR
- Center of Computational Biology, Johns Hopkins
- Li Ka Shing Faculty of Medicine, HKU
- Novogene, Beijing
Crowdsourcing Big Data
Dr. Reynold C. K. Cheng (ckcheng@cs.hku.hk)
PhD Students: Caihua Shan, Yudian Zheng

Crowdsourcing and Platforms
- A New Computation Model: Coordinating the crowd (Internet workers) to solve computer-hard problems
- Voluntary Platforms:
  1. Wikipedia: Collaborative knowledge
  2. reCAPTCHA: Digitalizing newspapers
  3. Foldit: fold the structures of selected proteins
  4. Yahoo! Answers: community-driven question-and-answer (Q&A) website

Incentive-based Platforms:

Research Problems
- Crowdsourcing Workflow:
  - Requester deploys tasks and budget on crowdsourcing platform (e.g., Amazon Mechanical Turk).
  - Workers interact with platform (2 phases) (1) when a worker comes to the platform, the worker will be assigned to a set of tasks (task assignment); (2) when a worker accomplishes tasks, the platform will collect answers from the worker (truth inference).

- Truth Inference: Given different answers of tasks collected from workers, the goal is to infer the truth of each task.
- Task Assignment: Given a pool of n tasks, when a worker comes to answer tasks, which set of the k tasks should be batched and assigned to the coming worker?

Research Output

Research Accomplishments
- QASCA: A Quality-Aware Task Assignment System for Crowdsourcing Applications [1]
  - Our Target: Evaluation Metric → Task Assignment

- Problem: When a worker comes, given the evaluation metric, which k tasks are selected to maximize the quality improvement?

- Problem: What are the similarities and differences in existing truth inference algorithms? Any suggestions to use in practice?

- A Crowdsourcing Framework for Collecting Tabular Data [3]

- Result: T-Crowd outperforms state-of-the-art methods, which improves 5% quality of results and coverages much faster in average.

- Problem: Given a table with missing values, how to design an effective crowdsourcing framework to fill in the table?

- Result: T-Crowd outperforms other systems >8% improvement in quality when all HITs are completed.
Heterogeneous Information Networks

Supervisor: Dr. Reynold C. K. Cheng (ckcheng@cs.hku.hk)
Postdocs: Dr. Tobias Grubenmann and Dr. Edison Chan
Students: Zhipeng Huang (PhD) and Zichen Chen (MPhil)

Computer Science

Heterogeneous Information Networks

A Heterogeneous Information Network (HIN) is a directed graph with multiple node types and edge types. It can capture various different (heterogeneous) kind of information:

- **Meta-Path Discovery**: Identifying paths made of node types and edge types:
  \[ P_1: \text{Author} \xrightarrow{\text{affiliation}} \text{Author} \]
  \[ P_2: \text{Author} \xrightarrow{\text{write}} \text{Paper} \xrightarrow{\text{publish}} \text{Author} \]

- **Meta-Structures**: An extensions to meta-paths which allows us to capture more complex structures [1]:
  \[ S: \text{Author} \xrightarrow{\text{write}} \text{Paper} \xrightarrow{\text{published by}} \text{Publisher} \xrightarrow{\text{publish}} \text{Author} \]

- **Top-k meta-path retrieval**: Identifying the k most important meta-paths connecting two entities:

<table>
<thead>
<tr>
<th>Meta Path</th>
<th>Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$: Author $\xrightarrow{\text{affiliation}}$ Author (A $\rightarrow$ A)</td>
<td>common</td>
</tr>
<tr>
<td>$P_2$: Author $\xrightarrow{\text{write}}$ Paper $\xrightarrow{\text{publish}}$ Author (A $\rightarrow$ A)</td>
<td>rare</td>
</tr>
</tbody>
</table>

**Funding Sources**

- **HINCare**: A Heterogeneous Information Network for Elderly-Care Helper Recommendation, ITF, MRP/029/18, 2019-21, HKD 4M.
- **Modelling of Artificial Neural Networks, Distributed System with High Reliability for Intelligent Data Management System (IDMS)**, contract research, 2019-20, ASTRI, HKD 900K.
- **Discovering and Querying Meta-Graphs in Large Heterogeneous Information Networks, RGC GRF, 17229116, 2016-18. HKD 675K.**
- **Motif Discovery in Heterogeneous Information Networks, RGC Germany/HK Joint Research Scheme 2018/19, G-HKU706/18, HKD 89K.**

**Challenges**

Our research focuses on the following challenges:

- **We propose a new Minimum Instances Support (MNIS) for top-k meta-path retrieval, which considers support (number of instances), rarity, and length of the meta-path [2]**.
  
  \[ \text{supp}_{P_k} (P) = \left( \prod_{\text{min}(\text{length}(P), \text{length}(p_1 + \text{length}(p_2)))}^{\min_{i < j < k} |\{p_i: p_j \in \text{P}_{k,i} \}|} \right) \times \text{min} \left( \frac{|p|}{P} \right) \]

  \[ \text{rare}(p, D) = \log \left( \frac{|\{p: p \notin D\}|}{|\{p: p \in D\}|} \right) \]

  \[ \text{Penalty}(P) = \beta^{|P|}, \beta \in (0, 1) \]

**We exploit meta-paths in combination with a Knowledge Base to improve query recommendation [3]**.

**HINs in Practice**

In our project, **HINCare**, we use an HIN to model elderly people in need. The rich semantics of HINs allows us to model the context of an elderly person and improve matching between elderly and helper:

**References**

Querying Big Uncertain Graphs
Supervisor: Dr. Reynold C. K. Cheng (ckcheng@cs.hku.hk)
Postdocs: Edison Chan and Tobias Grubenmann
PhD students: Xiaodong Li and Chenhao Ma

Big Graph Queries & Analytics
- Efficiency
- Fast online query for real-time response
- Accuracy
- Important for extracting insights
- Scalability
- Queries can be slow in Big Graphs

Methodology
- Possible world semantics
  - Exponential number of possible worlds!

Querying Big Uncertain Graphs

Data Uncertainty
- 0.8 Edge existence probability
- Protein-protein interaction networks
- Knowledge bases
  - Social networks
  - Traffic Networks
  - Wireless Sensor Networks

Empirical Results
- Indexing Cost VS. Query Time [TODS 2017, EDBT 2018]
  - 75% query time is reduced with 23% more space cost.
  - Good scalability for various real and synthetic datasets.

References and Funding
Quantum Information Science
Harnessing the power of quantum systems

Quantum information science turns the counterintuitive behaviour of quantum particles into a powerful resource for information and communication technologies. At the same time, it sheds new light on the mysteries of quantum mechanics, and provides a new foundation for our understanding of the quantum world.

Quantum Communication Networks

Quantum communication networks connect distant users through the transmission of quantum particles. They offer enhanced security and boost the performances of sensor networks and distributed computing.

Highlights:
- We developed a new model of quantum communication network where the information carriers can travel simultaneously along multiple trajectories.
- We extended quantum communication to new spacetime scenarios where the order of events can be in a superposition.
- We developed a technique to detect the presence of communication links in an unknown quantum network.

Learn more: Chiribella and Kristjánsson, Proceedings of the Royal Society, 2019
Yang, Salek, and Chiribella, Physical Review Letters, 2018

Quantum Data Compression

The efficient transmission of quantum data in quantum network requires compression protocols that encode information in the smallest amount of quantum bits.

Highlight: We developed quantum data compression protocols that store quantum data into an exponentially smaller memory. Our protocols can be used to store information collected by quantum sensors using the minimum amount of memory.

Learn more: Yang, Chiribella, and Ebler, Physical Review Letters, 2016
Yang, Chiribella, and Hayashi, Physical Review Letters, 2016
Yang, Bai, Chiribella, and Hayashi IEEE Transactions on Information Theory, 2018

Quantum Sensors

Quantum sensors exploit quantum features of coherence and entanglement to design the most accurate measurement devices.

Highlight: We designed a quantum stopwatch that measures the total duration of a sequence of events with the ultimate accuracy allowed by quantum mechanics.

The quantum stopwatch transfers time information from a quantum clock to a quantum memory, outperforming every classical stopwatch.


Quantum Cryptography

Quantum cryptography exploits quantum entanglement to generate secret keys and random numbers, both of which are crucial in modern communications and e-commerce.

Highlight: We developed a randomness amplification technique that generates nearly perfect, cryptographically secure random bits from arbitrarily weak sources.

- Security is proven against computationally unbounded adversaries, only constrained by the fundamental laws of physics.
- Users do not need to trust the internal workings of their devices. Security can be verified based solely on the input-output statistics.
- Our protocol can be realized with current technology.


Verification of Quantum Devices

The construction quantum devices requires new procedures for testing their performance and verifying their functionality.

We designed experimental setups that test quantum devices on infinitely many states in one go.

Learn more: Bai and Chiribella, Physical Review Letters, 2018, Editors’ Suggestion.

Quantum Foundations

Quantum technologies are the practical outcome of a deeper investigation into the foundations of quantum mechanics.

Highlight: We derived the framework of quantum theory from six basic principles of information-theoretic nature.

We explored how the theory of relativity constrains the correlations between quantum particles.

Learn more:

Credits to Ge Bai and Yin Mo for contributing to the design of this poster.
A human-compatible machine should be:
• Empathetic: understand human’s intention
• Polite: follow human’s etiquette rules
• Dexterous: help with human’s tasks

Empathetic machine intelligence:
understand human’s intention by analyzing human’s perceptual input signals and physiological/physical output signals collected from self-developed sensors

Magnet-based sensor to measure human’s tactile information.

Polite machine intelligence:
understand human’s etiquette rules in the team and during the work; transfer the human’s etiquette rules to the machine’s personal and crowd behavior

Dexterous machine intelligence:
Understand human’s dexterity from the perspective of anatomical structure and brain intelligence; transfer the human’s dexterity to machine using artificial intelligence and mechanical optimization.
Introduction

Big-data frameworks (e.g., Spark) enable computations on tremendous data records generated by third parties, causing various security and reliability problems such as information leakage and programming bugs. Information Flow Tracking (IFT) is a conventional approach for precise information control. However, extant IFT systems are neither efficient nor complete for big-data frameworks, because these frameworks are data-intensive, and data flowing across hosts is often ignored by IFT.

This paper presents Kakute, a precise and fine-grained information flow analysis system for big-data. Our insight on making IFT efficient is that most fields in a data record often have the same IFT tags, and we present two new efficient techniques called Reference Propagation and Tag Sharing.

Runtime Optimization

Kakute Can support using both int and object as tags. To optimize performance, we propose Reference Propagation and Tag Cache.

Conclusion

This paper presents Kakute, a fine-grained information flow analysis system for big-data. Kakute has the following benefits:

• Precise and Fine-grained Information Flow Tracking
• Transparent, no modifications to programs
• Moderate performance overhead
• Flexible APIs for information flow analysis

System Architecture

Kakute adds 5 components in Spark to do IFT transparently, so that people who write UDFs do not need to be aware of Kakute.

Evaluation

Our Evaluation mainly focus on precision, performance overhead and scalability.

<table>
<thead>
<tr>
<th>App Name</th>
<th>Titian</th>
<th>Kakute</th>
<th>Precise</th>
</tr>
</thead>
<tbody>
<tr>
<td>TwitterHot</td>
<td>2.75 × 10^5</td>
<td>520</td>
<td>520</td>
</tr>
<tr>
<td>ConnectedComponent</td>
<td>1.4 × 10^6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>MedicalGroupBy</td>
<td>1.99 × 10^7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MedicalGroupSort</td>
<td>2.56 × 10^7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TentativeClosure</td>
<td>1.31 × 10^3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>WordCount</td>
<td>6.03 × 10^4</td>
<td>6.03 × 10^4</td>
<td>6.03 × 10^4</td>
</tr>
<tr>
<td>WordGrep</td>
<td>1.37 × 10^5</td>
<td>1.37 × 10^5</td>
<td>1.37 × 10^5</td>
</tr>
</tbody>
</table>

Figure 3: Backward Tracing Record of Kakute and Titian.
Classic VM replication – primary/backup approach

Pros
- Automatically handle non-determinism

Cons
- Split-brain problem
- Unsatisfactory performance due to transferring large amount of state

PLOVER: Combining SMR and primary/backup

Simple to achieve by carefully designing the consensus protocol
- Step 1: Use Paxos to ensure the same total order of requests for replicas
- Step 2: Invoke VM synchronization periodically and then release

Combines the benefits of SMR and primary/backup
- Step 1 makes primary/backup have mostly the same memory (up to 97%), then PLOVER need only copy and transfer a small portion of the memory
- Step 2 automatically addresses non-determinism and ensures external consistency

Limitations of periodic synchronization
- Large amount of divergent state
  - throughput drops due to longer suspended state
- Automatically adjusted synchronization interval

Evaluation Setup
Evaluated 12 programs, grouped into 8 services
- Three replicas within the LAN, each has 24 cores with hyperthreading
- Varied number of clients until throughput of unreplicated execution is saturated
- Compared with three state-of-the-art VM fault tolerance systems: COLO (SoCC’13), Remus (NSDI’08), STR (DSN’09)

Performance of PLOVER

SMR: A Powerful Fault-tolerance Technique

Pros
- Good performance by ensuring the same execution states
- Solve the split-brain problem

Cons
- Hard to handle non-determinism

Bandwidth consumption of PLOVER

Conclusion and Ongoing Work
PLOVER: efficiently replicate VM with strong fault tolerance
- Low overhead, low network bandwidth consumption, robust to replica failures
Collaborating with Huawei for technology transfer
- An award from Huawei Innovation Research Program 2017
https://github.com/hku-systems/plover
Data-driven Auction Design: Theoretical Foundations
Dr. Zhiyi Huang
Computer Science

WHAT IS DATA-DRIVEN AUCTION DESIGN?

Data
- Past user bids
- Market survey
- Etc.

Auction
- Decide winner and price from user bids
- Maximize revenue

PART 1: SAMPLE COMPLEXITY MODEL

Model:
- Bidders’ values follow a Bayesian prior
- Data are iid samples from the prior
- What is the fewest samples needed to get an $1 - \epsilon$ approximation (e.g., 99% optimal) in revenue?

Related Publications:
[2] Huang, Mansour, Roughgarden, *Making the most of your samples*, SICOMP, 2018

PART 2: ONLINE LEARNING MODEL

Model:
- Post a price against a new bidder every day
- No distributional assumption on values
- Maximize cumulative revenue over time

Related Publication:
[4] Bubeck, Devanur, Huang, Niazadeh, *Multi-scale online learning: theory and applications to online auctions and pricing*, JMLR, 2019

PART 3: (TRULY) STRATEGIC BIDDERS

Model:
- The same bidder may come on multiple days
- She’s aware future prices depend on her bid today
- She acts strategically accordingly
- Can we still learn from data?

Related Publication:

LOOKING FORWARD

Targeted Samples:
- Actively retrieve “more important” samples, e.g., those in the top 10%
- Can we learn using much less data?

Back to Learning Theory:
- New techniques have been developed for learning auctions from data
- Do they generalize to other learning problems?
Understanding Texts and Languages in an Open World

Dr. Ping Luo
Ph.D student: Enze Xie
Department of Computer Science

Reading Text in the Wild
- Text as a Carrier of High Level Semantics
- Text as a Cue in Visual Recognition

Research Areas
- Arbitrary Shape Text Detection
- Arbitrary Shape Text Recognition
- Visual Question Answer

Problem Define
Scene text detection is the process of predicting the presence of text and localizing each instance, usually at word or line level, in natural scenes.

Two works on Arbitrary Shape Text Detection
- Scene Text Detection with Supervised Pyramid Context Network.
- Shape Robust Text Detection with Progressive Scale Expansion Network

Applications
- Card Recognition
- Product Search
- Geo-location
- Instant Translation
- Self-driving Car
- Industry Automation
Deep Learning for Autonomous Driving

Dr. Ping Luo
Ph.D students: Mingyu Ding
Department of Computer Science

CamNet: a coarse-to-fine retrieval-based deep learning framework

<table>
<thead>
<tr>
<th>Category</th>
<th>Method</th>
<th>RGB</th>
<th>3D</th>
<th>Seg</th>
<th>Generalized</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D-3D matching</td>
<td>DSAC [35], Active Search [39], SfMLearner [38]</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Absolute pose</td>
<td>PoseNet [15, 16], MapNet [17]</td>
<td>✓</td>
<td></td>
<td></td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Relative pose</td>
<td>NN-Net [13], RelNet [13]</td>
<td>✓</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>Ours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>High</td>
</tr>
</tbody>
</table>

Video segmentation & Optical flow

A major challenge for video semantic segmentation is the lack of labeled data. The optical flow encode the temporal consistency, to improve the video segmentation.

CamNet

Three modules including an image-based coarse retrieval module (ICR), a pose-based fine retrieval module (PFR), and a precise relative pose regression module (PRP).

The blue line shows the training flow of our retrieval module, and the orange line shows the training flow of our precise relative pose regression.

Data distribution of two modules

The training data distribution on 7-Scenes dataset. The PFR module and the PRP module are displayed in red and green.

Results

Camera localization results on the 7-Sevenscenes dataset. The ground truth camera trajectory is the green line and the red lines show the camera pose predictions.
Deep Learning for Comprehensive Fashion Image Analysis

Dr. Ping Luo
Ph.D Student: GE, Yuying
Department of Computer Science

DeepFashion2 Dataset

We build a large-scale clothes dataset named DeepFashion2. It is the most comprehensive benchmark of its kind to date.

- DeepFashion2 contains 491K images of 13 popular clothing categories.
- It has 801K clothing items where each item has rich annotations such as style, scale, viewpoint, occlusion, bounding box, dense landmarks and masks.
- There are 873K commercial-consumer clothes pairs.

Benchmarks for Fashion Understanding

Match-RCNN is an end-to-end training framework that jointly learns clothes detection, landmark estimation, instance segmentation, and consumer-to-shop retrieval.

Results of (a) Clothes detection and segmentation (b) Landmark and pose estimation (c) Clothes retrieval.

GANs for Fashion Images

The above clothes images are produced by Generative Adversarial Networks (GANs).

Three-dimensional Annotation in Fashion

We establish dense correspondences from 2D fashion images to surface-based representations of the clothes. 3D clothes surface is partitioned and parameterized by UV coordinates.

Point on 2D clothes image is shown in 3D clothes model from different views.

Future Work

Producing clothes images with GAN
Mapping clothes pixels of generated image to the 3D surface of the clothes model
3D clothes reconstruction
Visual try-on
Overview

Task:
- The problem of grounding referring expressions is defined as locating the object in an image referred to by a given expression.
- The referring expressions usually describe the objects as well as their attributes and relationships with other objects.

Framework:
- **Cross-Modal Relationship Inference Network**
  - **Spatial relation graph** $G^S = (V, E, X^S)$.
  - **Language-Guided Visual Relation Graph** $G^S = (V, E, X^S, P^V, P^e)$.
    - Classify the words $(h_0, h_1, \ldots, h_T)$ in the expression into four types (i.e., entity, relation, absolute location and unnecessary word).
    $m_t = \text{softmax}(W_{t1} \sigma(W_{10} h_t + b_{10}) + b_{t1}),$
    $h_t = \sum (m_t^{(0)} + m_t^{(1)} + m_t^{(2)}) h_t.$
  - Attend the words over the vertices and edges of graph $G^S$.
    $\alpha_{t,i} = W_h \text{tanh}(W_v x^S_i + W_h h_t),$
    $\lambda_{t,i} = m_t^{(0)} \exp \left( \alpha_{t,i} \right) / \sum_i \exp \left( \alpha_{t,i} \right),$
    $c_t = \sum \lambda_{t,i} h_t,$
    $P^e = \sum \lambda_{t,i},$
    $w^e = \text{softmax}(W_{e1} \sigma(W_{e0} h_t + b_{e0}) + b_{e1}) m_t^{(1)},$
    $P^e = \sum w_{t,i}.$
  - **Multimodal Relation Graph** $G^m = (V, E, X^m, P^V, P^e)$.
    $x^m = [x^S_i, c_t].$
  - **Gated Graph Convolutional Network.** Obtain semantic contexts representing multi-order relationships through message passing on $G^m$.

Motivation:
- Adaptively extract and represent information (i.e., objects and the relationships among them) in both language and vision modes for unpredictable and flexible expressions.
- Consistently represent contexts with **multi-order relationships** in the referring expression and object proposals.

Fusing and propagating information in the graph

Cross-Modal Relationship Extractor

Results

<table>
<thead>
<tr>
<th>Methods</th>
<th>RefCOCO</th>
<th>RefCOCO+</th>
<th>RefCOCOg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>val</td>
<td>testA</td>
<td>testB</td>
</tr>
<tr>
<td>VeriContext</td>
<td>-</td>
<td>78.98</td>
<td>82.35</td>
</tr>
<tr>
<td>AccumulateAttn</td>
<td>81.27</td>
<td>81.17</td>
<td>80.01</td>
</tr>
<tr>
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<td>80.81</td>
<td>81.32</td>
</tr>
<tr>
<td>MattNet</td>
<td>80.94</td>
<td>79.99</td>
<td>82.30</td>
</tr>
<tr>
<td>Ours CMRIN</td>
<td>84.02</td>
<td>84.51</td>
<td>82.99</td>
</tr>
<tr>
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<td>85.65</td>
<td>85.26</td>
<td>84.57</td>
</tr>
<tr>
<td>Ours CMRIN (ResNet)</td>
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<td>87.63</td>
<td>84.73</td>
</tr>
</tbody>
</table>

- CMRIN accurately captures the language-guided contexts, which are conducive to grounding referring expressions.

Task:
- The problem of grounding referring expressions is defined as locating the object in an image referred to by a given expression.

Motivation:
- Adaptively extract and represent information (i.e., objects and the relationships among them) in both language and vision modes for unpredictable and flexible expressions.

Attention & Graph
- Consistently represent contexts with **multi-order relationships** in the referring expression and object proposals.

Fusing and propagating information in the graph

Cross-Modal Relationship Extractor

Results

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<td>84.73</td>
</tr>
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- CMRIN accurately captures the language-guided contexts, which are conducive to grounding referring expressions.
Face Analysis with Deep Learning
Dr. Kenneth Kwan-Yee Wong

Face Analysis with Deep Learning

Introduction: Face Analyses

The analysis of face is one of the most important topics in computer vision, and it has many real-world applications. There are two important problems in face analysis:

- Face image processing, such as face super resolution and face sketch synthesis.
- Face recognition.

These two problems are usually closely related. For example, face super resolution can help to recognize small faces, and face sketch synthesis can help to recognize hand drawn faces.

Our research focuses on face image processing and how to exploit image processing techniques to improve face recognition performance.

Research Topics

<table>
<thead>
<tr>
<th>Face Sketch Synthesis:</th>
<th>Face Super Resolution:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face sketch synthesis targets at generating a sketch from an input face photo. It has many useful applications. For instance, police officers often have to rely on face sketches to identify suspects. Artists can also employ face sketch synthesis to simplify the animation production process.</td>
<td>Face super-resolution (SR), also known as face hallucination, refers to generating high resolution (HR) face images from the corresponding low resolution (LR) inputs. Since there exist many low resolution face images (e.g., faces in surveillance videos) and face-related algorithms (e.g., face recognition) often perform poorly on such images, there is a growing interest in face SR.</td>
</tr>
</tbody>
</table>

Occluded Face Recognition:

In real-world scenarios, face recognition systems often suffer from degradation of accuracy due to occlusions such as sunglasses, masks, scarfs, etc. Different type of occlusions may appear at different locations and have different appearances, making it difficult to recognize occluded faces. We develop new methods based on neural networks for this challenging problem.

Methodology and Results

Face Sketch Synthesis:

- Face sketch synthesis: generating a sketch from a face photo.
- Face super-resolution: generating high resolution face images from low resolution inputs.

Face Super Resolution:

- Input: low resolution face images.
- Result: high resolution face images.

Occluded Face Recognition:

- Occlusion: different types of occlusions (e.g., sunglasses, masks, scarfs).
**Photometric Stereo** is a technique to estimate the surface normal of a static object from a set of images captured by a fixed viewpoint under varying light directions.

Based on the availability of known lighting conditions, photometric stereo can be categorized into *calibrated* and *uncalibrated* photometric stereos.

### Problem Formulation

**Assumptions:** Orthographic camera with linear radiometric response and directional lighting.

- Distant point light source
- Orthographic Camera

**Image formation model:**

$$m = e \rho(n, l, v) \max(n^T l, 0) + e$$

- $m \in \mathbb{R}$: measured intensity
- $e \in \mathbb{R}$: light intensity
- $\rho(n, l, v)$: BRDF
- $n \in \mathbb{R}^2$: surface normal
- $l \in \mathbb{R}^2$: light direction
- $v \in \mathbb{R}^2$: viewing vector
- $\max(\cdot, 0)$: attached shadow
- $e$: global illumination effects and noise

### Calibrated and uncalibrated photometric stereo:

- **Calibrated Photometric Stereo**
- **Uncalibrated Photometric Stereo**

**Methodology and Research Accomplishments**

**Synthetic dataset for training**

- (a) Blobby dataset
- (b) Sculpture dataset

**Calibrated photometric stereo (PS-FCN, ECCV 2018)**

**Feature visualization:**

- Different regions with similar normal directions are fired in different channels. Each channel can therefore be interpreted as the probability of the normal belonging to a certain direction.

**Uncalibrated photometric stereo (SDPS-Net, CVPR 2019)**

**Comparison with state-of-the-art methods:**

**Qualitative results on challenging real datasets:**

- Arya, Geometx, Science, Horse-Head, Space Ship, Apollo, Fish, Bacterial, Planet
Robust Scene Text Recognition in Natural Images

Dr. Kenneth Kwan-Yee Wong

Department of Computer Science

**Robust Scene Text Recognition**

**Scene text recognition** refers to recognising words that appear in various kinds of natural images. There are two main challenges for robust text recognition in natural images:

1. Arbitrary Geometric Distortions
   - Rotation
   - Perspective distortion
   - Artistic designs (characters along a curve)

2. Varying scales of characters

**Methodology**

**Scale Aware Feature Encoder** (SAFE, ACCV 2018)

- Multi-Scale Convolutional Encoder
- Backbone CNN
- Scale Attention Network
- Character-Level Attention
- LSTM-based Decoder
- Spatial Transformer
- CNN
- Recurrent RoI Warp Layer
- Character-Level Attention
- Word-Level Encoder

**Research Accomplishments**

By combining the scale aware feature encoder with the character aware neural network, we can simultaneously handle distortion and scale problems for robust text recognition in natural images.

<table>
<thead>
<tr>
<th>Method</th>
<th>HIT5K</th>
<th>SVT</th>
<th>ICDAR 2003</th>
<th>ICDAR 2013</th>
<th>SVTP</th>
<th>ICDAR 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhotoOCR [2]</td>
<td>78.0</td>
<td>-</td>
<td>87.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jaderberg et al. [3]</td>
<td>71.7</td>
<td>89.6</td>
<td>81.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jaderberg et al. [1]</td>
<td>80.7</td>
<td>88.7</td>
<td>90.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>R-2AM [4]</td>
<td>81.9</td>
<td>89.1</td>
<td>86.6</td>
<td>66.8</td>
<td>-</td>
<td>-</td>
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<tr>
<td>CRNN [5]</td>
<td>79.1</td>
<td>81.5</td>
<td>87.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>RANE [6]</td>
<td>81.9</td>
<td>89.1</td>
<td>88.6</td>
<td>71.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>STAR-Net</td>
<td>83.3</td>
<td>89.9</td>
<td>89.1</td>
<td>73.2</td>
<td>65.6</td>
<td>-</td>
</tr>
<tr>
<td>Scale Aware Char-Net</td>
<td>84.9</td>
<td>85.5</td>
<td>92.9</td>
<td>90.9</td>
<td>76.6</td>
<td>66.2</td>
</tr>
</tbody>
</table>

Note that all the outputs in * [1] are constrained to a 90K dictionary even when recognising without a pre-defined lexicon.
Deep Learning-based Job Placement in Distributed Machine Learning Clusters

Dr. Chuan Wu
PhD students: Yixin Bao, Yanghua Peng
Department of Computer Science

Deep Learning-based Job Placement
In a distributed machine learning job, the dataset is divided and trained by separate workers, which exchange calculated model parameters with each other through parameter servers to derive the global parameters.

The dataset is trained for multiple epochs until the model converges or a preset maximum number of epochs is reached.

Interference among Co-located ML Jobs

Co-located ML jobs on the same server may interfere with each other negatively and experience performance unpredictability.

The jobs share underlying resources such as CPU caches, disk I/O, and network I/O and buses.

Different levels of interference occur when different types of ML jobs are co-located, depending on the models being trained and behavior of the training programs written by the users.

Harmony: System Overview

- Existing schemes are not good enough to achieve high resource utilization and training speed at the same time.
- Performance interference is hard to identify and model.

Reward Prediction Model

- Address the challenge that it is difficult to collect enough traces to simulate interaction with the environment in DRL.
- Provide feedback for DRL and obtain reward by inference instead of running a set of jobs in a real cluster.
- Train the neural network using historical traces by supervised learning to minimize the relative error of the prediction and the label.

\[
L(c, c') = \frac{1}{N} \sum_{i=1}^{N} c_{i} - c'_{i}
\]

Methodology

Deep Reinforcement Learning
- State space: job type, resource demand, available resources, etc.
- Action space: place one more worker or parameter server of one job on one server
- Maximize the expected cumulative discounted reward
  \[
  J(\theta) = E[\sum_{t=0}^{\infty} r_{t} \gamma^{t}]
  \]
- Update by policy gradient method
  \[
  \nabla_{\theta} J(\theta) = \frac{1}{N} \sum_{i=1}^{N} \nabla_{\theta} \log(\pi_{\theta}(a_{i}|s_{i})) Q_{\pi_{\theta}}(s_{i}, a_{i})
  \]

Performance Evaluation

Baselines
- Load Balancing (LB) - Assign worker/parameter server to the server with the least load
- Tetris - Multi-resource bin packing to avoid resource fragmentation
- Least Interference First (LIF-Line, LIF-Quad) - Build a linear or non-linear interference model

We present a deep learning-based scheduler that addresses performance interference and minimizes average job completion time by efficient job placement in an ML cluster. We find that there is a big potential on improving resource efficiency in ML clusters. We believe that our reward prediction module design is general, and applicable to other DRL problems where historical traces are not sufficient.
Optimus: An Efficient Dynamic Resource Scheduler for Deep Learning Clusters

Dr. Chuan Wu
Ph.D students: Y. Peng, Y. Bao, Y. Chen

Optimus reduces job training time by 139% and 74% respectively in comparison to DRF and Tetris. The normalized CPU utilization shows that Optimus can utilize allocated resources more efficiently.
Blockchain is an emerging technology in Fintech. It lets people who have no particular confidence in each other collaborate without having to go through a neutral central authority.

Blockchain has a lot of interesting applications.

- Finance
- Supply Chain
- Sharing Economy
- Digital Rights Management
- IoT

1. Privacy-preserving Public Blockchain

Privacy-preserving cryptocurrencies, like Monero, Zcash and Dash, have a total market capitalization of over USD$3.5 billion as of May 2019.

There is room for improvement for the efficiency and the security of these cryptocurrencies.

2. Scalability in Blockchain

Layer 1 solutions: scale blockchains themselves, e.g., by improving the consensus algorithm.
Layer 2 solutions: move business logic to sub-chains, while the security of these sub-chains are guaranteed by a security deposit in the main chain.

Research Accomplishments

1. Blockchain Confidential Transaction

We propose the most competent blockchain ring confidential transaction protocol for protecting:

- Sender anonymity
- Recipient anonymity

For a typical 2-input transaction with a ring size of 1024, the ring signature size of our RingCT3.0 protocol is 97% less than the ring signature size of the original RingCT1.0 protocol used in Monero.

2. Anonymity Reduction Attacks

We discovered two new attacks targeting the anonymity in Monero system: (1) extension of the Monero Ring Attack, (2) exploits Payment ID to discover the real output of a mixin. We propose countermeasures to these attacks.

3. Scaling Blockchain by Trapdoorless Accumulator

We propose to use trapdoorless accumulator to replace Merkle tree in blockchain. It gives compact membership and non-membership proof.

```
Algorithm 2: Accumulator of Class Group

1. Fg Setup(1^l) : h
2. (1, g) = GGen(1^l) ;
3. Define H = \{ h \}
4. Return H = \{ h \}
5. Fg Acc\{ param, S \}
6. Return g = \{ h \}
7. Fg Memo\{ param, x, S \}
8. Return x = \{ h \}
9. Fg Mem\{ param, x, w, e \}
10. If e = w \{ h \} then
11. Stop with 1;
12. Stop with 6;
```

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Revisiting Opinion Dynamics with Varying Susceptibility to Persuasion via Non-Convex Local Search

Dr. Hubert Chan
Department of Computer Science

IV. Local Search with Irrevocable Flips

- Local search strategy (only $O(n)$ extreme points to try):
  1. Initialize $\alpha_i = u$, $\forall i \in V$ and compute $z$.
  2. While $\exists i \in V: s_i > z_i(\alpha)$ and $\alpha_i = u$ do:
  3. For all such $i \in V$, flip $\alpha_i = l$.
  4. Re-compute $z = [(I - (I - A)P)^{-1}A\alpha]$. where $A = \text{Diag}(\alpha)$.

Example: $s_i > z_i(\alpha)$, $\alpha_i = u$:

$\alpha_1 \leftarrow \alpha_2 \leftarrow \alpha_3 \leftarrow \alpha_4 \leftarrow \alpha_5 \leftarrow \alpha_6 \leftarrow \alpha_7 \leftarrow \alpha_8 \leftarrow \alpha_9 \leftarrow \alpha_{10}$

V. Optimistic Local Search on Large-scale Graphs

- Use $z^{(t)} = \alpha s + (I - A)Pz^{(t-1)}$ to approximate matrix inverse:

Using Neumann series, $z = [I - (I - A)P]^{-1}s = \sum_{j=0}^{\infty} (I - A)P^j s$, estimate error $e^{(t)} \geq |z_i - z_i^{(t)}|$: 

1. Conservative: update $\alpha$ when $|s_i - z_i^{(t)}| > e^{(t)}$ for all $i$.
2. Opportunistic: update $\alpha$ when $|s_i - z_i^{(t)}| > e^{(t)}$ for most $i$.
3. Optimistic: update $\alpha$ 

VI. Experiment Results on Large-scale Graphs

- LiveJournal user and group membership network on 10 million nodes:
  - The real network is utilized as an undirected graph and parameters ($s_i$, etc.) are generated randomly.
  - The red line represents the experimental result.

VII. Conclusion and Future Work

We have designed scalable local search algorithms solving the unbounded opinion susceptibility problem optimally on graphs with millions of nodes.

- Budgeted variant as future work: Given an initial resistance vector $\alpha$ and budget $k \in \mathbb{Z}^+$, we can only modify the resistances of at most $k$ agents.
Data-Based Dynamic Stability Assessment in Smart Grids

Prof. David J. Hill
dhill@eee.hku.hk
Laboratory of Power Network with High Renewable

Department of Electrical and Electronic Engineering, The University of Hong Kong

Future Grids: a Flood of Data

Big Data in Smart Grids
- Costumer Profiling
- Network Planning
- Demand Response
- Predictive control

Data Sources
- Data storage
- Centralized or cloud data center

Distribution and transmission system data
PMUs and AMIs data
Distributed generation data
Intelligence application related data

Big Data Characteristics
- Volume
- Variety
- Velocity
- Veracity

- Amount of data
- Terabytes
- Transaction
- Batch

- Large data types
  - Structured
  - Unstructured
  - Probabilistic

- Speed of data flow
  - Real-time
  - Near-real-time
  - Streams

- Data uncertainty
  - Authenticity
  - Origin
  - Availability

Main Methodology

- Spatial-Temporal Information Fusion
  - Electrical distances from system topology
  - Responsive trajectories during dynamic process

- 3D Convolution Neural Network
  - Translation invariance
  - Spatial-temporal correlations
  - 3D convolution and pooling

3D Convolution Neural Network

The structure of 3D Convolution Neural Network

\[ \text{Output} = \text{New Opportunities for Smart Grids} \]

- ConvLSTM
  - Good at capturing spatial-temporal correlations
  - Transfer learning
    - To solve the adaptability in different power networks

Objectives: to convert system information into time-series images and adopt learning techniques to realize online efficient and effective voltage stability assessment.

Case Study and Conclusions

Table I. Performance on Training and Test Set

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy(%) Training set I</th>
<th>Accuracy(%) validation set 100x10</th>
<th>Accuracy(%) test set I 100x10</th>
<th>Accuracy(%) test set II 600x5</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D-CNN</td>
<td>98.20</td>
<td>97.71</td>
<td>96.78</td>
<td></td>
</tr>
<tr>
<td>MLP</td>
<td>97.01</td>
<td>96.82</td>
<td>96.82</td>
<td>89.64</td>
</tr>
<tr>
<td>MLP</td>
<td>97.01</td>
<td>96.82</td>
<td>96.82</td>
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<td>96.82</td>
<td>89.64</td>
</tr>
</tbody>
</table>

Table II. Summary of Computational Efficiency

<table>
<thead>
<tr>
<th>Offline training</th>
<th>Online images generations</th>
<th>Online 3D-CNN prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>421.1030 s</td>
<td>0.2710 s</td>
<td>0.0016 s</td>
</tr>
</tbody>
</table>

Online continuous monitoring for long-term voltage stability

- Advantages w.r.t. MLP
  - More reasonable data modeling
  - Stronger feature representation
  - Higher assessment accuracy
  - Higher genericity
  - Adaptability to unknown scenarios
  - Highly efficient for online applications

3D-CNN

ConvLSTM

Structure of a LSTM neuron


Perspective Conversion

Monitoring of power systems (Miranda, 2017)

Each image records a moment of information. Just like frames in a film.

The dynamic of state variables in the time domain becomes the change from frame to frame.

New Opportunities for Smart Grids

- 3D Convolution Neural Network
  - Good at capturing spatial-temporal correlations
  - Transfer learning
    - To solve the adaptability in different power networks

New Opportunities for Smart Grids
Electric power system is a critical infrastructure, while its stability analysis and control are fundamental problems for the sake of secure operation. The research attention has been mainly paid to node dynamics in power systems, i.e., the impact of generator/load parameters. On the other hand, power system dynamics also evolve via the underlying power network. The role of network structure in stability and control deserve further investigation.

In this work we extend power system theory from a network science viewpoint, which exploits the features of power networks. It appears that the whole of the nearly 100-year old subject of power systems can be rewritten in the network-based paradigm to provide new insights. The results are also of potential interest to future grids where control burden is shifted from generation side to network and demand side due to high renewable penetration.

Unlike the traditional network-reduced model that comes up with a full graph with loads being eliminated, the structure-preserving model characterizes the system as a complex dynamical network with the original network structure and heterogeneous node dynamics. So it is a natural model for network-based analysis.

**Power Network Stability**

- **Rotor angle stability**
  - Local stability and the type of UEP are characterized by the power flow graph Laplacian and location of critical lines.
  - Intuitive interpretation of angle instability as the critical lines leading to negative effective conductance (indicating electrical antagonism) between some pairs of nodes.
  - New graph theory linking cutsets to cycles that explains why the loss of synchronism initiates from angle separation across the lines in some cutsets.
  - Improved cutset index that better measures the degree of vulnerability of cutsets, i.e. how close to being critical.

![Critical cutset](Figure from Song, Hill, Liu 2018 IEEE TCNS)

**Voltage stability**

- Static voltage stability modal analysis has been revisited in terms of state-in-mode versus mode-in-state analysis with new insights guiding system dispatch to improve voltage stability margin.
- Necessary and sufficient condition for static voltage stability of generic distribution systems in terms of a new concept namely the network-load admittance ratio, which extends the classical criterion that only applies to the single-load infinite-bus system.
- A novel voltage stability index that is highly linear with load increase and better estimates voltage stability margin.

![Figure from Song, Hill, Liu 2019 IEEE TPWRS](Figure from Song, Hill, Liu, Zheng 2017 IEEE TSG)

**Stability issues in microgrids**

- Linking algebraic connectivity to the dynamics of microgrids that theoretically foresees the decline of microgrid stability in case of tree-like connection topology for inverter-based distributed generators (DGs).

**Distributed stability evaluation**

- Stability evaluation algorithm based on a distributed protocol that only needs finite steps of communication between neighboring nodes and local eigen-computation at a pilot node.

**Distributed stability control**

- Stability enhancement algorithm via a few steps of sparse communication among a minority of DG nodes.
- Computationally efficient; flexible to DG plug-and-play and microgrid topology change.

**Acknowledgement**

1. Network-based Stability Analysis and Control of Future Power Grids, RGC GRF, finished
2. New Analytical Issues in Power Grid Voltage Stability, RGC GRF, ongoing
3. Stability Issues for Microgrids, RGC GRF, ongoing
4. Sustainable Power Delivery Structures for High Renewables, RGC TRS, ongoing
Sustainable Power Delivery Structures for High Renewables

The development of a truly sustainable electricity supply system, with diverse sources of renewable energy (RES), can make a large contribution to solving problems of pollution and climate change. Much higher use of RES makes the proper operation of a power grid (balancing, stability, control, recovery) much more difficult and ultimately determines the answer to the question about what percentage of RES levels are achievable.

While outstanding progress is being made in new technologies (PV, storage etc), most research at the systems level deals with small pieces of the overall problem and much lacks a serious scientific approach to address the key questions.

**Introduction**

The overall mission of the research is to derive a sustainable structure for the operation, control and protection of future energy networks delivering harvested renewable energy to consumers who themselves play a demand-side role in the overall system.

The key to delivering in the goals is maximizing synergy between the key areas of power systems, power electronics, ICT and control which are the areas of expertise of the project leaders (Hill, Hui and Li at HKU and Qiu at HKUST respectively).

More specific goals are summarized as:

1. Develop an integrated approach based on a novel ‘demand response’ balancing paradigm;
2. Develop electric springs into universal smart load controllers;
3. Integrate DC and IC strategies to study distributed control algorithms that can achieve the sustainable smart grid;
4. Incorporate requirements on energy efficiency and reliability of power system operation;
5. Enable increased consumer participation in with various financial considerations;
6. Establish a regional research and educational hub in sustainable grid technology.

The particular characteristics of power delivery in HK will be given special attention, e.g. high buildings.

**Objectives**

| Source of Funding: RGC TRS-R4 |
| Faculty of Engineering |

**Results**

The research highlights in the first year of the project have been:

1. The electric spring has been developed into a powerful local low voltage controller which can deal with power balancing, voltage control and frequency control with new real and reactive power control and some storage facility; results on its use in power system services have exceeded expectations;
2. The idea of granulated control has been proven in specific situations of voltage control and frequency control across two voltage levels; the next step is to fully granulate from kW to GW, but we feel confident that this can be achieved by about the middle of the project;
3. Several new and exciting ideas have emerged that add to those in the proposal; these include power flow routing and networked microgrids which will play key roles in the final structure;
4. The research teams have had strong collaboration with the strongest international groups such as at Caltech, ETH Zurich.

**Conclusions**

An architecture for a sustainable power grid is being built systematically in a multidisciplinary way.

Good progress has been achieved in all goals with more in 1-3 and a bit less in 4-5, which will be emphasized in later stages. Also further connection to industry will be a priority.

Rpg Students: 6 plus many associated
FPGA-based Reconfigurable Computing: from System to Application

Dr. Hayden Kwok-Hay So (hso@eee.hku.hk)
Department of Electrical & Electronic Engineering

Overview

Cell Image-based Cytometry

Interdisciplinary Application-specific Designs

Computer Architecture & System Research Group (CASR)

PACoGen: Posit Arithmetic

NCore: Non-linear HW Func

Micro-Architectural Innovations

QuickDough: FPGA Overlay

High-Speed Image-Based Cell Cytometry

Low Latency In-Situ Cell Classification

Quantized Convolutional Neural Network Training & Inference

Continuous Capture for offline process

In-situ Processing low latency machine intelligence

CPU/FPGA/GPU Offline Processing Accelerated machine learning

QuickDough: FPGA Overlay for Rapid Compilation

A high productivity compilation framework for high-level applications on CPU-FPGA computers.

- Compiles software and FPGA accelerator in a unified framework
- Overall SW-like compile speedup

GraVF: Distributed Graph Processing on FPGAs

- A hardware generator for distributed vertex-centric graph processing on multi-FPGA systems.
- User provide simple graph processing kernels
- GraVF produces all necessary hardware

Advanced Arithmetic Circuits

PACoGen: Posit Arithmetic Generator

NCore: Non-linear Arithmetic Functions Generator

Multimode Floating Point Circuits: Configurable multi-single, multi-double & quadruple floating point circuits

Acknowledgements

- Croucher Foundation (Croucher Innovation Award)
- Research Grant Council of Hong Kong (GRF, ECS, CRF)
- Micron Technology (Pico Computing) for HMC system

High-level source code

Reduce Accelerator Compile Time:

- hours
- seconds

K-mean

Steering diagram

Input Graph

User design

Auto Generated

Complete Single-Source Shortest Path FPGA implementation in 2 days

Cell sorter

Packet receiver

Storage

In-situ Processing

Convolutional neural network (CNN)

High speed ADC (2x6GSPS)

FPGA

8x 10Gb Ethernet

Cell Image-based Cytometry

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Distributed Control of Future Grids

Dr. Tao Liu
ttaoliu@eee.hku.hk
Laboratory of Power Network with High Renewable

Department of Electrical and Electronic Engineering, The University of Hong Kong

Future Grids: High Renewables

Hierarchical structure of power systems (Glover et al., Power System Analysis & Design, 2012)

Frequency Control with Energy Storage

- Synchronous generators
  - Energy unconstrained
  - Low ramping capacity
- Energy storage devices
  - Energy constrained
  - High ramping capacity

Response to an AGC signal by the system with three storage units and one ramp-limited generator

Non-Disruptive Load-Side Frequency Control

- Load-side control
  - System-level control effect
  - Non-disruptive for end-user
- Consensus-based control
- Switching control

G1 and G2 with AGC
10% controllable load
Bus 9 has a 30% load increase at t=100s

The modified WSCC 9-Bus System
System responses

Frequency Control in Networked Microgrids

Issues in microgrids
- Plug and play
- Privacy issues
- High R/X ratios (frequency and voltage)
- Limited operational flexibility

Networked microgrid system (Baken et al, 2011)

New Opportunities for Future Grids

- Big data & Artificial intelligence
- Game theory
- RT-based stability margin prediction and event detection. (Kezunovic et al, 2013)
Machine Learning and Signal Processing
Yik-Chung WU
Department of Electrical and Electronic Engineering

Gaussian Belief Propagation

- Factor graph representing a joint Gaussian distribution
- A distributed, low complexity message passing algorithm for computing the marginal distribution from a high-dimensional joint Gaussian distribution
- Challenge: no guarantee of convergence in loopy graphs
- Out contributions:
  - World's first
  - Sufficient and necessary condition for convergence
  - Study on the convergence of high-order Gaussian Belief Propagation
  - Proof on the form of pairwise factorization does not change convergence

Variational Inference

- In Bayesian machine learning, the posterior distribution usually do not have closed-form expression
- Variational inference finds a surrogate $Q(w)$ in a restricted family such that the KL divergence from the posterior distribution $p(w | y)$ is minimized
- Applications
  - Distributed network synchronization
  - Peer-to-peer rating
  - Image de-noising

Large-scale non-convex non-smooth constrained optimization

- Modern optimization problems can be very large in scale
- Problems with 10000 variables and/or constraints are very common
- If the cost function or constraints are non-convex or non-smooth or both, the problems are very challenging to solve
- General form of non-convex non-smooth constrained optimization
  - Major techniques employed:
    - Successive convex approximation
    - Dual-decomposition
    - Primal domain decomposition
    - Penalty decomposition
    - Acceleration using momentum
    - Acceleration in embedded manifold
  - These lead to various first-order algorithms

Applications

- IoT devices activity detection
- Magnetic resonance fingerprinting reconstruction
- Beamforming in cloud radio access network (C-RAN)
- Surveillance video background separation
- Smart grid research
- Robot path planning for data collection
- Future wireless communication
Electric Vehicle Technologies
Prof. K. T. Chau
PhD students: L. Cao, W. Liu
Department of EEE

Electric Vehicle (EV) Challenges and Solutions

- Either short driving range or huge battery pack
- Demanding driving performance
- Demanding reliability during cornering

Solutions

- Develop energy-encrypted move-and-charge
- Develop high-torque-density in-wheel motor
- Develop reliable magnetic differential

Energy Encryption for Move-And-Charge

- EVs perform wireless charging on electrified roadway where transmitter coils are buried beneath ground
- The rail-based transmitter enjoys much lower installation cost, but is unable to selectively charge authorized EVs
- By using energy encryption, only those authorized EVs which know the security key can decrypt the wireless energy for battery charging
- Those unauthorized EVs cannot pick up wireless energy

Harmonic-Shift Parallel-Hybrid-Excited Motor

- The outer rotor can be directly mounted with the tire rim to realize the in-wheel feature
- The inner stator space can fully accommodate PMs and DC-field winding, resulting in higher torque density
- The DC-field harmonics interact with the PM harmonics in the airgap to regulate the resultant effective harmonics
- The parallel flux paths of PM flux and DC-field flux can provide effective flux regulation capability

Magnetic Differential

- Mechanical differential is robust, but suffering from gear problems; whereas electronic differential is accurate and efficient, but suffering from reliability concerns
- Magnetic differential can provide accurate and efficient differential action while solving reliability concerns
- By using magnetic steering (MS) field to link two rotors, the MS-DRM can create flux-strengthening at one rotor while flux-weakening at another rotor during cornering
Why Go Wireless?

- Free from electrocution
- Free from messy cables
- Highly flexible and reliable
- Appliances can be totally sealed

Wireless Motors

Wireless Permanent Magnet DC (PMDC) Motors

- Multiple PM DC motors can be wirelessly powered by a single transmitter
- They can be controlled independently by using time-division multiplexing wireless power transfer (TDM-WPT)

Wireless Separately Excited DC (SEDC) Motor

- The SEDC motor can be wirelessly powered and controlled by a single transmitter
- It can perform both constant-torque and constant-power operations by using TDM-WPT

Wireless Switched Reluctance (SR) Motor

- The SR motor can be wirelessly powered and controlled
- It can be totally sealed and work at isolated environment
- It can perform speed control with bidirectional rotation by properly energising individual phases
- It can readily adopt position sensorless control

Wireless Ballastless Indoor Lighting

Wireless Ballastless Outdoor Lighting

Wireless Heating

Flexible Induction Heating

- Flexible induction heating (IH) utilizes magnetic resonant coupling (MRC) to compensate varying vertical distance and horizontal misalignment for various cooking styles
- Homogeneous IH utilizes MRC to boost the auxiliary coil current and heating effect at the cookware outer part
Resilience of Power Systems under New Energy Paradigm

Dr. Yunhe Hou (侯雲鶴) team:
10+PhD, 5 PostDoc
yhhou@eee.hku.hk

Dept. Electronic and Electrical Engineering

Background

- Recent catastrophic blackouts in North America, Europe, and India serve as powerful reminders that a reliable, resilient, and responsive power grid is vitally needed.

- By integration of state-of-the-art technologies on renewables, responsive loads, information, and communication, a smart grid promises development of a strategic defence system.

Mitigating Unfolding Sequential Events for Transmission systems

- Establishing proactive strategies to mitigate sequential extreme events with Markov decision. This method was used in realistic Guangdong system during typhoon Mujigae

Transmission System Restoration and Commercial Software

- An objective-driven systematic system restoration methodology: Generic Restoration Milestones (GRMs)

- A system restoration tool: System Restoration Navigator (SRN). It has been commercialized by Electric Power Research Institute of USA.

Enhance Resilience of Distribution Systems

- Proactive pre-dispatch and timely re-dispatch of response resources, achieving effective resilient response to natural disasters

Power-Electronics Interfaced Renewable Aided Restoration

- PE based devices enable renewables to provide blackstart resources

Supported by:
- RGC-General Research Fund (712410, 712411, 739713, 17202714, 17207818)
- The National Natural Science Foundation of China(51277155, 51677160)
- Electric Power Research Institute, USA (EP-P35424/C16059, EP-P39470/C1 7538, 00-10000550, 10004675, 00-10006150)
Large-scale renewable integration changes the current power system balance mechanism.

System flexibility: To maintain continuous service in the face of rapid and large swings in supply and demand, which is a critical requirement for mitigating variation and uncertainties of the renewables.

Quantify system’s flexibility and determinate the acceptable renewables penetration. Quantifying the frequency, magnitude, and intensity of insufficient flexibility.

Quantify the relationship between renewable penetration level, prediction accuracy, and system flexibility. Identify the bottleneck.

Risk-limiting Renewables Dispatch in Transmission Systems

- System flexible resource is coupled in multiple periods, and the prediction information is updated continuously.
- The sequential feature of prediction accuracy: increased when approaching the real-time.
- Risk-limiting UC vs. traditional UC in realistic Gansu system.

Enhance Flexibility of Distribution Systems

- dynamic network reconfiguration: loss reduction, service restoration, renewable integration, etc.
- Rely on expensive remote-controlled switches: identify critical switches

Flexibility Enhancement for Power-Electronics Enabled Systems

- PE based devices are employed to regulate frequency and voltage of distribution systems

Supported by:
- RGC-General Research Fund (17202714, 17207818)
- The National Natural Science Foundation of China(51677160)
- China Electric Power Research Institute (SGLNSY00FZJS1601337)
- National Key Research Program (973 Program, 2012CB215102)
Emerging Optoelectronic Devices Achieved by Robust Low-temperature Solution-Processes

Research Team 研發團隊
Wallace Choy (蔡植豪) Team:
10+ PhD students and 3 Postdoc
Department of Electrical and Electronic Engineering
the University of Hong Kong
Pokfulam Road, Hong Kong
chchoy@eee.hku.hk, (852) 2857-8485

Potential Application 潜在應用
Emerging Optoelectronic Devices Achieved by Robust Low-temperature Solution-Processes

Solar cells (green energy):
Instant sensors (food quality, safety monitoring, etc).
Flexible electronics (cell phones, wearable electronics).

Needs:
low cost, high throughput production, large area, light weight, mechanical flexibility.

How?
Abundant materials, simple formation process, stable, scalable, pre-/ post- treatment free for forming films in devices

Our Solutions:
oxide based semiconductors, solution process, low temperature (flexible) tunable function, well and easy film formation

Technology Advantage 技術優勢
A. Low-temperature Solution Processed Oxide Based Semiconductors
In HKU, we have been developing a library of n-type and p-type semiconductor oxides with our own approaches.

Form layer in different location of multilayered device structures: Smooth, pin-hole free In-situ tunable between p-type to n-type oxide-base semiconductor.
pre-/ post- treatment free Plasmon enhanced optical and electrical effects

Stable and easily reproducible.

9 patents (filed and under process)

Emerging Optoelectronic Devices Achieved by Robust Low-temperature Solution-Processes

B. Solution-processed Flexible Electrodes


C. Simple Ligand-promoted room-temperature formation of high quality perovskite films

Ligand vapor

PbI₂

Stage I: Ligand-induced formation of nanostructured films

CH₃NH₂ solution

PbI₂(ðL)₂

Stage II: perovskite film formation facilitated by ligand exchange reaction

CH₃NH₃PbI₃

D. All solution-proceeded, microfabrication-free perovskite/ organic grating

Gratings with periodicity of 300nm-1000nm by solid-liquid-solid phase transformation without any lithography process. The crystallization and optical properties improve.

E. Simple off-the-shelf post-device gas treatment to improve the stability and performance of perovskite solar cells: 900% Efficiency Enhancement

Development Status 開發階段

- 1) U.S. Patent No. 8,384,067.
- 7) US Patent 9,972,780.
- 9) US Provisional Application: 62/577,419
- 10) US Provisional Application: 62/702,088.

Device prototype in available in laboratory scale
Look for industrial partner for scaling up
Cardiovascular disease (CVD) remains the leading cause of death worldwide.

The Lee Ultrasound Imaging Laboratory at HKU develops **ultrafast functional ultrasound imaging** techniques to assess complex cardiovascular dynamics and properties.

- diverging wave model
- >1000 frames/sec
- High signal-to-noise ratio (SNR)
- High contrast
- Optimal spatial resolution achievable
- Functional information of the heart and the artery

### Ultrafast Ultrasound Imaging of the Heart

- The array probe is divided into M sub-arrays.
- T1-R1, T2-R2, T3-R3, and T4-R4 indicate the 1st, 2nd, 3rd, and 4th transmission-reception events.
- Spatiotemporally encoded waves
- Temporal Decoding
- Spatial (Hadamard) Decoding
- Coherent compound

### Power Doppler image

- Myofiber orientation

### Wall motion during

- Kinematics (motion, strain, twist)
- High-quality ultrafast ultrasound imaging
- Mechanical properties (stiffness, anisotropy, nonlinearity)
- Acoustic radiation force
- Hemodynamics (blood flow)

### Ultrasonic High Frame Rate Imaging of the Artery

**Guided wave generation by acoustic radiation force and wave dispersion analysis for the artery**

**Arterial wall deformation varies with blood pressure over the entire cardiac cycle**

### Summary of Our Ultrasound Imaging Platform

- Strain and stiffness analysis
- Adaptive speckle tracking (motion estimation)
- Real-time feedback
- Personalized computational modeling for other applications

### Acknowledgements

- Hong Kong Research Grants Council (RGC) 2013/14 (ECS 739413E)
- National Natural Science Foundation of China (NSFC)/Research Grants Council (RGC) Joint Research Scheme (N_HKU713_15)
- Midstream Research Programme for Universities under Innovation and Technology Commission (MRP/1772/17X)
- The University Development Fund
- Dr. Kai Hang Yiu and Professor Hung Fat Tse from the Department of Cardiology at HKU
- Professor Jianwen Luo, Department of Biomedical Engineering, Tsinghua University, Beijing
The current overarching challenge in neuroscience is to establish an integrated understanding of the brain circuits, particularly the spatiotemporal patterns of neural activities that give rise to functions and behaviour. Brains form highly complex circuits where circuit elements communicate using electrical and/or chemical signals. However, our present understanding of complex spatiotemporal patterns of long-range and large-scale neural activities within such an architecture remains elusive. This is primarily due to the lack of suitable neurotechnologies to monitor and characterize these spatially segregated and functionally integrated activities in intact brains.

Objectives

Here, our collaborative research team develops a novel neuroimaging approach - the combined use of optogenetic neuromodulation with functional MRI (fMRI) – that will enable us to characterize the dynamic properties of the long-range networks. With such whole brain imaging capability, we will investigate two categories of fundamental, long-standing questions regarding long-range brain circuits:

1. What are the dynamic response properties that govern the activity propagations and interactions within networks?
2. What is the functional relevance of long-range low frequency neural activities?

Research Methods (Synergize Neuromodulation Techniques with Brain-wide Functional Imaging)


Brain-wide Functional MRI Mapping of Optogenetic Activations

1. Thalamo-cortical Network

2. Hippocampal-cortical Network

3. Central Vestibular Pathways

Publications

Team and Acknowledgements

Prof Ed X Wu and Dr. Alex Leong, Laboratory of Biomedical Imaging and Signal Processing (http://www4.hku.hk/bisplab/)

1. Hong Kong Research Grant Council
2. Lam Woo Foundation.
3. Shenzhen Municipal Brain Science Platform Technology Project
4. Guangdong Provincial Key Brain Science and Research Project.
5. Stanford University (Dr. K. Deisseroth) for the Optogenetic Viral Construct.
Novel optical generation (Fiber Lasers)

- Tunable laser @ 1.7 μm
- Optical parametric oscillator

Ultrafast optical signal processing and imaging

- Soliton collision
- Soliton explosion
- Multi-pulse mode-locking

Raman Spectroscopy

- Mouse kidney slides
- Mouse brain slides
- Butter
- Bone marrow slide

Optical coherence tomography

- 3D fish eye
- Density application

Photonics Systems Research Laboratory

- Broadband swept laser source
- Fiber laser

Acknowledgement

- Research Grants Council (RGC) of HKSAR
- University of California, Los Angeles (UCLA), for the micro-resonator
- Sumitomo Electric Industries (SEI), Japan, for the HNLF
- University of Bielefeld, Germany, for the CARS/SRS
- University of Lille 1, France, for the PCF
Introduction

Human brain MRI image segmentation by performing pixel-analysis with deep learning approaches.

- **Automated** segmentation into anatomical structures allows quantitative measurements.
- **Deep learning** can be used to carry out pixel-level analysis for determining its class in the brain **anatomical structure**, which can enhance visual intelligence.

The Issues

- **Segmentation** is the process of labeling pixels in 2D (voxels in 3D), which is a critical component of quantitative analysis (manual work by a radiologist).
- **Localization of abnormal tissue** and surrounding healthy structures are crucial for diagnosis, surgical planning, and chemo/radiotherapy treatment.
- The 2012 MICCAI dataset has 35 sets of MRI images with their corresponding labelled atlases consisting of **134 brain structures**.
- The model achieves segmentation by **pixel-by-pixel classification of voxels**.

Research accomplishments

- This work has used the latest deep learning techniques like **dropout, batch normalization** and data preprocessing to accurately segment images.
- The segmented result into 134 classes/regions are then visualized in **colored images**.
- The model uses a **multi-patch data extraction algorithm** which helps to classify the center voxel of the extracted patches.
- The result obtained reaches a mean dice coefficient of **76.2%**, which has outperformed the best previous result of a mean dice coefficient of 72.5%.

Convolutional Neural Network Architecture

- **Layer 1**:
  - Conv2D: 32 3x3 filters
  - Max Pooling: 2x2
  - Batch Normalization
  - ReLU activation
  - ... to give 32 1x1x14

- **Layer 2**:
  - Conv2D: 32 3x3 filters
  - Max Pooling: 2x2
  - Batch Normalization
  - ReLU activation
  - ... to give 32 1x14x14

- **Layer 3**:
  - Conv2D: 64 3x3 filters
  - Max Pooling: 2x2
  - Batch Normalization
  - ReLU activation
  - ... to give 64 1x14x14

- **Layer 4**: (similar to Layer 3)

- **Dropout**: 0.5
- **Batch Normalization (BN)**
- **Softmax**: probability distribution
- **3000 x 3000**: output image
- **1310**: output size

Figure: Visualization of MRI datasets for anatomical brain segmentation.
Our research focuses on the application of ergonomics, data analytics, and machine learning to develop and implement smart health information technology, medical devices, and healthcare work processes, and examine their efficacy on patient safety and health outcomes, aiming to enhance the performance, safety, and health of patients, care providers, and healthcare systems.

**Medical Device and Technology**

Optimizing Healthcare Processes through Smart Technologies

- Provide evaluation and procurement advice on medical device
- Improve drug selection process through smart pharmacy shelf
- Promote use of electronic health records (EHR)
- Develop electronic prescribing and clinical decision support system (CDSS)
- Apply root cause analysis to investigate adverse events in healthcare
**Translational Medical Engineering**

Chair Professor W. John Kao, PhD FBSE

Department of Industrial and Manufacturing Systems Engineering

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### Challenges

**“VALLEY OF DEATH”**

takes +14 years, +2 billion USD with a success rate of 1 out of 10,000 to get a new drug onto the market

- Discovery (traditional role of univ)
  - 2 – 5 yrs
- Pre-clinical Development
  - 0.5 – 2 yrs
- Development (traditional role of private sector)
  - 1 – 2 yrs
  - 1.5 – 3.5 yrs
  - 2.5 – 4 yrs
- Submission & Approval
  - 0.5 – 2 yrs
- Commercial Drug Product Support
  - 10-20 yrs

**n ~ 10,000**

**Market**

```
<table>
<thead>
<tr>
<th>Phase</th>
<th>Duration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 – 5 yrs</td>
<td>Discovery</td>
</tr>
<tr>
<td>2</td>
<td>0.5 – 2 yrs</td>
<td>Pre-clinical Development</td>
</tr>
<tr>
<td>3</td>
<td>1 – 2 yrs</td>
<td>Development (traditional role of private sector)</td>
</tr>
<tr>
<td>4</td>
<td>1.5 – 3.5 yrs</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.5 – 4 yrs</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.5 – 2 yrs</td>
<td>Submission &amp; Approval</td>
</tr>
<tr>
<td>7</td>
<td>10-20 yrs</td>
<td>Commercial Drug Product Support</td>
</tr>
</tbody>
</table>
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### Objectives: Role of IMSE

**Unique Role of IMSE**

To provide a path to safely and efficiently integrate new medical technologies and discoveries into the market place.

**“TRANSLATIONAL MEDICAL ENGINEERING”**

The process of getting basic research to improve the condition of patients and a larger community. Also a conduit of identifying urgent public needs to direct research

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### Designing and Executing Quality Systems for Development and Clinical Feasibility

**“Product Development Roadmap”**

5 Phases:
- Feasibility
- Planning
- Design
- Implementation
- Commercialization

IMSE is well positioned to bring together and coordinate all critical stakeholders: basic scientists, clinicians, practitioners, CRO/CMO, regulatory agencies, industry, capital, etc.

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### Outcomes

**HK is poised to develop a biomedical innovation ecosystem.**

Academia-private-public partnerships are critical in bridging the “valley of death” in translating promising life-science technologies to benefit the public

Transdisciplinary teamwork is a MUST. IMSE brings skill sets to work at the systems level.
OR provides a scientific foundation (e.g., analytical modeling and mathematical optimization) for illuminating management issues and improving decisions. The subject of OR was first formally introduced in World War II for military planning and has been successfully applied in various areas such as manufacturing, transportation and logistics, energy management, and environmental engineering.

What is Healthcare Systems Engineering?
Healthcare Systems Engineering is a discipline which applies advanced engineering tools and mathematical techniques to analyze, design, and optimize complex systems in healthcare settings. We will provide several examples of our research projects to showcase the applications of OR for healthcare systems engineering.

Emergency Department Operations Management
Emergency Department (ED) overcrowding is a long-standing and serious issue confronting many countries and cities. ED overcrowding can lead to numerous grievous consequences, including prolonged pain and suffering, patients’ dissatisfaction, and, most importantly, delay in the delivery of appropriate medical care to emergency patients. In this project, we apply OR techniques (analytical modeling and systems simulation) and data analytics for analyzing and improving ED operations in Hong Kong.

Medical Appointment Scheduling
Medical appointment scheduling is a challenging problem for hospitals and clinics due to the multi-dimensional stochasticity in practice, such as patient no-shows, patient unpunctuality, and non-deterministic service times. An inefficient appointment schedule can lead to wastes of valuable resources (e.g., physician times) and long patient waiting times. In this project, we developed a stochastic mixed-integer linear programming model to optimize medical appointment schedules.

Acknowledgment
The research projects are supported by Research Grants Council (RGC) of Hong Kong and Health and Medical Research Fund (HMRF), Food and Health Bureau of Hong Kong.

Contact
You are welcome to visit us for the relevant publications and more information about our research.
E-mail: yhkuo@hku.hk
Webpage: https://www.imse.hku.hk/people/y-h-kuo
**Virtual Reality System for Strategic Operation Training**

*Principal Investigator: Dr. Henry Y.K. Lau*

**Department of Industrial and Manufacturing Systems Engineering**

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### Ramp Operation Training

**Ramp Operation in Virtual Environment (TROVE)**

- Operator training and skills assessments for air cargo handling with imseCAVE VR system.
- Operation planning and evaluation using simulated situations with virtual scenarios.

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### Innovation

- State-of-the-art virtual reality empowered training.
- Human skill profiling with artificial intelligence (AI) techniques.

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### Advantages

- Cost and time saving
- Full body immersion
- Scalable and versatile
- High performance

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### R&D Development Road Map of the imseCAVE

- **1998**
  - Pioneering R&D in VR at HKU
- **2002**
  - First prototype of imseCAVE VR system
- **2003**
  - First generation imseCAVE for crane simulation
- **2005**
  - imseCAVE installed at TsingHua University State Key Lab of Modern Logistics
- **2009**
  - New generation of imseCAVE with real-time tracking system
- **2011**
  - Invention of the Magic Pad and Magic Pen
- **2015**
  - imseCAVE won ICT Best Digital Entertainment Silver Awards
- **2018**
  - Deployed over 20 imseCAVE solutions including HKPolice, CSD, Fire Services, Cathay Pacific, TW Hospital, etc
- **2019**
  - Introduction of low cost high-performance imseCAVE systems

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### Aim

- Fully immersive and interactive VR systems and intelligent training management systems.
- Management and professional to make strategic decisions in critical operations.
- Virtual reality technology to create dynamic scenarios, real-time motion capture with artificial intelligence-based algorithm to evaluate performance and build trainee’s profiles.
ImseCAVE VR
Dr. Henry Lau and Dr. Leith Chan
Department of Industrial and Manufacturing Systems Engineering

Immersive and Interactive Virtual Environment

Innovative VR Technology
- Embodied interaction with seamless boundary between real and virtual worlds
- Fully body immersion based on interactive real-time motion tracking
- Smart stereoscopic 3D visualization engine with dynamic control of virtual sceneries
- Intelligent user behavior profiling for enhanced interactivity

Use Cases
Cross-border e-commerce has recently enjoyed rapid development worldwide and record breaking “Double Singles Day” trading has topped the Greater China region. It is easy to place online orders through keyboards but it is extremely challenging to fulfil the orders with a vast number of fast-moving goods of incredibly wide variety of SKUs. Three types of synchronization and coordination determines the cost-effectiveness and efficiency throughout the ecommerce order fulfillment process. They include S1 - from goods manufacturers to logistics parks, S2 - order consolidation within distribution centers (DCs), and S3 - order delivery from DCs to customers.

HKU’s iPark initiative is funded by an ITF project. It serves the purpose of innovating core technologies for building a smart physical internet as a platform to elevate Hong Kong logistics businesses towards Logistics 4.0 and gain competitiveness and market share from rapidly growing ecommerce. The platform can be deployed as a consortium (open) cloud for a group of third-party businesses or as a private cloud for an ecommerce corporation with a group of subsidiaries. Solutions and provided to interact / interface with manufacturers, warehouses, distributors and retailers involved in a typical ecommerce value chain.
IoT-enabled Real-time Advanced Planning and Scheduling
Dr. Ray Y. Zhong
Department of Industrial and Manufacturing Systems Engineering

**IoT-enabled Manufacturing**

IoT-enabled manufacturing is an advanced principle where typical production resources are converted into smart objects which are able to sense, interconnect, and interact with each other to automatically carry out the manufacturing activities. As the wide usage of IoT digital devices which are able to generate huge number of data, manufacturing companies are facing challenges for making full use of these collected data:

1. As the deployment of enormous IoT-enabled devices which may be different in functionalities, vast heterogeneous data will be captured and collected;
2. The collected data are with large volume whose relations of each individual data are so complicated;
3. The complex and bulky datasets are difficult to use in various applications, thus, innovative data presentation and interpretation approach are needed.

**System Architecture**

<table>
<thead>
<tr>
<th>Utility Service</th>
<th>Planning</th>
<th>Scheduling</th>
<th>Execution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuring Planning Parameter</td>
<td>Configuring Scheduling Parameter</td>
<td>Configuring Data Source</td>
<td></td>
</tr>
<tr>
<td>Processing Customer Order</td>
<td>Evaluating Capacity</td>
<td>Converting CO to Production Order</td>
<td></td>
</tr>
<tr>
<td>Sequencing Jobs</td>
<td>Assigning Jobs</td>
<td>Executing Production Schedules</td>
<td></td>
</tr>
<tr>
<td>Controlling Production Schedules</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Re-engineered Production Processes**

- IoT devices like RFID readers are used for creating smart production environment, where real-time data are captured.
- Real-time RFID information plays important roles in coordinating decisions and operations across different parties.
- Adaptive optimization models, solution algorithms and rules are developed and deployed as web services.
- Standard HPP decision-making process integrated with real-time RFID information enables more precise production plans.

**Innovations**

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- Standard HPP decision-making process integrated with real-time RFID information enables more precise production plans.

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Liability Concentration and Systemic Losses in Financial Networks

Dr. Peng-Chu Chen

Department of IMSE

Introduction

- **Main Contributions:** (1) Identify balancing and unbalancing systems to bring out the implications of liability concentration on the system’s loss profile. (2) Identify perfectly and imperfectly tiered networks identified by empirical research. (3) Validate our framework using data from the European banking network. (4) Support regulatory policies of the Basel Committee limiting the size of gross exposures to individual counterparties.

- **Systemic Losses:** The clearing payment vector $\mathbf{p}^*$ is a solution to the fixed point equation (Eisenberg and Noe (2001)):

$$\mathbf{p}^* = \mathbf{\nu} + \lambda (\mathbf{p}^* \odot \mathbf{K}$$

where $\lambda$ is a positive factor, $\mathbf{K}$ is a network topology matrix, and $\mathbf{n}$ is the vector of total liabilities. $\mathbf{\nu}$ is the relative liability matrix, and $\mathbf{c}$ is the vector of outside assets. Loss vector under the network topology $(\mathbf{N}, \mathbf{\nu})$:

$$\mathbf{s} = \mathbf{n} - \mathbf{p}^* (\mathbf{N}, \mathbf{\nu})$$

Objective of the Study

- **Common Feature:** The node with the smallest equity value generates the largest loss in the system. The network with the smallest net exposure to this node is always the most preferred in terms of losses.

- **Distinguishing Feature:** In the top panels, the undesired system is the network whose liabilities are less concentrated.

In the bottom panels, the undesired system is the network with higher concentration of liabilities.

- **Our goal:** Capture this behavior quantitatively through the concepts of balancing and unbalancing systems.

The Framework

- **A Key Insight:** A 3-tuple $(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1)$, $\alpha \in [0,1]$, is called the $\alpha$-relaxed equivalent version of a financial system $(\mathbf{N}, \mathbf{\nu})$, if $\mathbf{N}_1 = (1 - \alpha) \mathbf{N} + \alpha \mathbf{1}$ and $\mathbf{c}_1 = (1 - \alpha) \mathbf{c} + \alpha \mathbf{1}$.

- **Loss Preferences:** Let $x := s(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1)$ and $y := s(\mathbf{N}_2, \mathbf{\nu}_2, \mathbf{c}_2)$ be the loss vectors associated with two financial networks differing in the liability distribution. $x$ is preferred to $y$ if $x <_L y$, i.e., $x_1 <_L x_2$, ..., $x_{\ell} <_L x_{\ell}$, where $\sum_{j=1}^{\ell} x_j \leq \sum_{j=1}^{\ell} y_j$ for $k = 1, \ldots, n$ (sum of $k$ largest losses).

- **Concentration of Liabilities:** Let $X$ and $Y$ be two matrices. $X$ is majorized by $Y$, $X <_M Y$, if there exists a doubly stochastic matrix $S$ such that $X = SY$.

Definition

Given two financial systems $(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1)$ and $(\mathbf{N}_2, \mathbf{\nu}_2, \mathbf{c}_2)$, we say that $b$ has higher liability concentration than $a$ if there exists $\alpha \in [0,1]$ such that $\mathbf{N}_1 < \mathbf{N}_2$.

- **Network Setup:** Nodes are labeled so that $\ell_1 \leq \ell_2 \leq \ldots \leq \ell_\ell$. Assume that the outside asset vector $\mathbf{c}$ is similarly ordered to the liability vector $\mathbf{\nu}$ (empirically verified).

**Definition**

1. $(\mathbf{N}, \mathbf{\nu}, \mathbf{c})$ is balancing if, for $j = 1, \ldots, n - 1$,

$$\sum_{i=1}^{n} (x_i + \mathbf{c}_i) = \sum_{i=1}^{n} (\mathbf{c}_i + x_\ell)$$

2. $(\mathbf{N}, \mathbf{\nu}, \mathbf{c})$ is unbalancing if, for $j = 1, \ldots, n - 1$,

$$\sum_{i=1}^{n} (x_i + \mathbf{c}_i) > \sum_{i=1}^{n} (\mathbf{c}_i + x_\ell)$$

Framework Cont.

- **Main Results**

Let $\mathcal{P} := \{ p | p \text{ is a probability vector} \}$.

- **Proposition (Caponi et al. 2015)**

Suppose $\mathcal{P}_1$ is order preserving w.r.t. $\mathcal{P}$ for some $\alpha \in [0,1]$. Then, (i) $\mathbf{p}^*$ is similarly ordered to $\mathbf{c}$, $0 \leq p \leq \ell$.

(ii) If $(\mathbf{N}, \mathbf{\nu}, \mathbf{c})$ is balancing, then $s(\mathbf{N}, \mathbf{\nu}, \mathbf{c}) = s(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1)$. If $(\mathbf{N}, \mathbf{\nu}, \mathbf{c})$ is unbalancing, then $s(\mathbf{N}, \mathbf{\nu}, \mathbf{c}) > s(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1)$.

(iii) If $\mathbf{N}_1$, $\mathbf{N}_2$, and $\mathbf{c}$ are weak supermajorizing preserving w.r.t. $\mathcal{P}$, $(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1)$, and $(\mathbf{N}_2, \mathbf{\nu}_2, \mathbf{c}_2)$, then $s(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1) > s(\mathbf{N}_2, \mathbf{\nu}_2, \mathbf{c}_2)$.

**Theorem (Caponi et al. 2015)**

Let $(\mathbf{N}, \mathbf{\nu}, \mathbf{c})$ and $(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1)$ be balancing. Suppose $\exists \alpha \in [0,1]$ such that both $\mathbf{N}_1$, $\mathbf{N}_2$, and $\mathbf{c}$ are order preserving w.r.t. $\mathcal{P}$ and

(i) $\mathbf{N}_1$, $\mathbf{N}_2$, and $\mathbf{c}$ are weak supermajorizing preserving w.r.t. $\mathcal{P}$

(ii) $\mathbf{N}_1 < \mathbf{N}_2$, $\mathbf{\nu}_1 < \mathbf{\nu}_2$, $\mathbf{c}_1 < \mathbf{c}_2$.

Then, $s(\mathbf{N}_1, \mathbf{\nu}_1, \mathbf{c}_1) > s(\mathbf{N}_2, \mathbf{\nu}_2, \mathbf{c}_2)$.

**Empirical Analysis and Policy Implications**

- **Real-world networks are most likely to be in an unbalancing state.**

- **Higher concentration of liabilities induces larger systemic losses in unbalancing systems.**

- **Support regulatory policies of the Basel Committee aiming to reducing gross exposures to individual counterparties.**
City climate and environment
Professor Li Yuguo, Mr Wang Qun, Ms Wang Zixuan, Mr Zhang Cheng

Department of Mechanical Engineering

Unique world laboratory
The Hong Kong air temperature rose by 0.37°C per decade since 1989, but wind speed decreased by 0.6 m/s per decade. This worrying trend continues.
Hong Kong has the highest population density and the built volumetric ratio. Hong Kong is with the most energy efficient city. Hong Kong has the typical but complex urban climate problem.

Challenges
Asian cities differ. The significant horizontal and vertical spatial variability, making data collection and prediction challenging.
Current analysis tools cannot be used for city scale micro-environment.
Complex turbulence phenomenon in the high-rise urban canopies, interacting with regional scale winds and micro-scale flows.

Similar to Hong Kong?

Similar to US sparse cities?

Monitored data (2012-2014), Stone Forest, Yunan, China

Our Objectives
We use both new urban physics-based design approach and new data analyses to the challenges of urban heat islands and air pollution in cities in Asia considers an entire city to be like a building:

What we have learned
1. Co-existence of urban heat islands at night and urban cool islands during the day.
2. City shape affects circulation in the urban heat island (heat dome) and developed the polygon city hypothesis.
3. The daily cycle of air temperature is different between urban and rural stations, while the annual cycle is similar.
5. Continuous densification and elevation of buildings is found to be responsible for the continuous wind weakening phenomenon that has affected Kowloon since the 1960s.

Outlooks
Innovative engineering and architectural control/mitigation methods for urban heat island and air pollution.
New urban and building design strategies, and evidence-based design/planning policies.

In collaboration with HKO, PlanD, CUHK/HKU architecture, HKU Geography, HKU Computer Science, Professor Lord Julian Hunt, supported by grants from RGC GRF and CRF, RGC/EU Horizon 2020 and NSFC.
Emerging infection – an major challenge in Asian mega cities

1. Relative importance of different transmission routes unknown
2. Mechanisms of fomite and close contact routes unknown
3. Effective control methods for short-range airborne route unknown

Our concept of surface touch network

A new contact aerosol transfer model

Our 48 seats air cabin mock-up

Our objectives

1. Understand the generation, evaporation and transport of expiratory droplets as within and beyond respiratory systems.
2. Understand the impact of environment intervention on exposure to respiratory droplets in critical building environment.
3. Develop samplers, and better environmental control systems.

We have found so far

1. Probable evidences of airborne transmission in SARS outbreaks and some influenza outbreaks.
2. New ventilation and environment systems for infection control.
3. New WHO guidelines on natural ventilation for infection control.
4. New transmission mechanisms

Outlooks

Common cold is still all too common, and influenza still spreads in seasonal epidemics. Engineering can help not only in engineering control, but also the mechanisms of transmission.

In collaboration with HKU and CUHK Faculty of Medicine, QMH, Hospital Authority, etc

Financially supported by RGC GRF, CRF, RFCID, NSFC, WHO, Boeing and Hospital Authority

Distribution of the infected in Hong Kong

New HKU system

Surface touch transitivity

Degree ($) Surface network is scale-free

WHO meeting in Geneva
Introduction

- **Shape sensing**
  - Measurement of 3D object shape
  - Target applications include wearable devices and rehabilitation

- **Fiber Bragg Gratings (FBGs)**
  - Light-weight strain sensors with excellent electromagnetic immunity, and long-term stability

- **Finite element analysis (FEA)**
  - Sensor parameters analysis
  - Simulation of mapping from local strains to global 3D deformation

Methodology

**Working principle of FBG**

Design of the shape sensor [1]

- A single-core fiber with a series of FBGs to measure the local strains.

FEA of the soft sensor

- Validate the unique mapping from sparse strains to continuum shape of the sensor.

<table>
<thead>
<tr>
<th>Deformation pattern</th>
<th>Simplified fiber model</th>
<th>Strain responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending</td>
<td><img src="#" alt="Bending Diagram" /></td>
<td><img src="#" alt="Strain Graph" /></td>
</tr>
<tr>
<td>Twisting</td>
<td><img src="#" alt="Twisting Diagram" /></td>
<td><img src="#" alt="Strain Graph" /></td>
</tr>
<tr>
<td>Combined deformation</td>
<td><img src="#" alt="Combined Diagram" /></td>
<td><img src="#" alt="Strain Graph" /></td>
</tr>
</tbody>
</table>


**Real-time shape reconstruction**

- High accuracy, low hysteresis
- Stable, reliable sensing performance validated by 1,000 deformation cycles done on 45×45mm sensor

**A4 size (210×297 mm) shape sensing**

- Thin (1 mm) and flexible
- Target application: Wearable device for human shoulder

**Shape sensing for tube-shaped structure**

- Optical fiber helically-wound along a soft continuum
- Closed-loop control for soft and flexible robots

Reference:


Acknowledgments:
The Croucher Foundation and the Research Grants Council (RGC) of Hong Kong (Ref. no.: 17202317, 17227616, 27209515).

Conclusions

- Real-time shape sensing for high-performance soft robot modelling and control.
- FEA-based optimization scheme to investigate optimal layouts of optical fibers and sensor parameters for complex deformations or customized shape structures.
On-demand Droplet Collection for Single-Target Analysis
Nan Lang, Anderson H. C. Shum

Faculty of Engineering

Significance of on-demand droplet collection

Droplet microfluidics appears as a powerful tool to isolate and manipulate single targets in separate compartments, but inefficient collection hampers further analysis of desired samples off-chip, representing a gap between droplet microfluidics technologies and quantitative biological studies. To address this, through precise control over droplet number, the processed encapsulants can thus be quantitatively isolated, enabling further analysis at single-target level.

How to realize on-demand collection

Through alternate and independent operations in separate branch channels, the positive droplets can be continuously collected at single-droplet resolution. This system enables precise control over droplet number to realize continuous single-cell capture with a high throughput (20 events/ min), single-cell encapsulation ratio (98.5%), and recovery rate (99%).

Collection of single-cell encapsulation droplets

Microscope images of collected droplets encapsulating green and red cancer cells with the droplet number of 1, 5, 10 and 20. Scale bars: 100 μm.

Single-cell imaging analysis

To investigate the effect of virus infection on cell development at single-cell level, the normal cells and virus-infected cells are respectively collected and cultured. The detailed recording of cell development indicates the system does not impose adverse effects on cells and be capable of analyzing and monitoring individual-cell responses under physiological conditions.

Advantages and future opportunities

Compared with most other techniques to manipulate samples in continuous flow, the droplet-based method allows for encapsulation of tinier targets, such as viruses and bacteria, and processing of them in confined compartments with a high purity. Hence, through incorporation of multiple manipulation modules between target encapsulation and droplet collection, such as pico-injection and Polymerase Chain Reaction (PCR), this technique has great potential to realize integrated processing and analysis of single targets.
WHAT ARE FLUOROGENIC RNA APTAMERS?

Green fluorescent protein (GFP) has transformed the use and analysis of proteins for diverse applications. Fluorogenic RNA aptamers are those RNA structures able to bind fluorophores resembling the fluorophore in GFP. *(J.S.Paige et al, Science, 2011)*

![Fluorogenic RNA aptamers diagram](image)

METHODOLOGY

Workflow of droplet-based RNA aptamer screening. Experimental procedures involving both *on-chip* (black title) and *off-chip* (blue title) steps.

**DNA recovery**

**Droplet based RNA aptamer screening**

**Fluorescence activated droplet sorting (FADS)**

**Collection & Incubation**

**Reinjection**

**Picoinjection**

**Droplet Generation**

\[ f \approx 2700 \text{ s}^{-1} \]

**Droplet sorting**

\[ f \approx 300 \text{ s}^{-1} \]

**Collected droplets for thermal cycling**

\[ \approx 3 \text{ million droplets} \]

Sketch of the optical setup of Fluorescence activated droplet sorting (FADS). Matthew Y. H. Tang and Ho Cheung Shum. Lab Chip, 2016, 16, 4359

APPLICATIONS & IMPACTS

**Live-cell imaging**

Autour et al, Nat. Commun, 2018

Visualization of RNA genome in live cells.

Luo et al, JACS, 2019

**Molecular sensors**

Autour et al, Methods, 2019

Light-up RNA aptamers constitute an appealing class of biosensors.

RNA IMAGING TOOLBOX

Pichon et al, Molecular Cell, 2018

PRELIMINARY RESULTS

Bright field (a) and fluorescence microscope (b) images of the droplets. Droplets containing the fluorogenic aptamers are well distinguished from those without any aptamers. The scale bar is 100 um. (c) Gel electrophoresis results of selected droplets (performed by Dr. Andrew Kinghorn in Prof. Julian Tanner’s lab).

**OBJECTIVES**

Current RNA aptamer screening methods include SELEX and FACS, with limitations such as no real-time fluorescence detection and lack of compartmentalization. The selected aptamers from these methods are usually not optimal. Droplet-based microfluidic technologies have shown great advantages in the field of high-throughput screening. In this project, we developed a droplet-based microfluidic platform for high-throughput fluorogenic RNA aptamer screening, aiming to find new RNA aptamer variants with excellent properties e.g. enhanced thermal stabilities and higher sensitivities than reported ones.

**Reported fluorogenic RNA aptamers**

- **Spinach**
  - Science, 2011
- **Spinach 2**
  - Nat. Methods, 2014
- **Broccoli**
  - JACS, 2013
- **iSpanich**
  - Nucleic Acids Res, 2014

**APPLICATIONS & IMPACTS**

- **Live-cell imaging**
  - Visualization of RNA genome in live cells.
  - Luo et al, JACS, 2019

- **Molecular sensors**
  - Autour et al, Methods, 2019

Light-up RNA aptamers constitute an appealing class of biosensors.

**RNA IMAGING TOOLBOX**

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All-aqueous systems, also known as aqueous two-phase systems (ATPSs), are formed by phase separation of an aqueous mixture containing two incompatible additives, such as two incompatible polymers or one polymer and other salts above certain critical concentrations.

**WHAT ARE ALL-AQUEOUS SYSTEMS?**

All-aqueous systems, also known as aqueous two-phase systems (ATPSs), are formed by phase separation of an aqueous mixture containing two incompatible additives, such as two incompatible polymers or one polymer and other salts above certain critical concentrations.

**FACTORATION OF ALL-AQUEOUS DROPLETS**

*All-aqueous simple emulsion droplets*

*All-aqueous complex emulsion droplets*

**STABILIZATION OF ALL-AQUEOUS DROPLETS**

**ALL-AQUEOUS-DROPLET-BASED APPLICATIONS**

**FUTURE POTENTIAL OF ALL-AQUEOUS SYSTEMS**

Novel strategies to stabilize all-aqueous emulsion droplets:

- Oil-free food industry and cosmetics
- Designed new all-aqueous systems: Cell-mimicking and formation of membraneless organelles in synthetic biology
- All-aqueous-based materials: 3D bioprinting and liquid device
**Healthy and Comfort Environment**

**Bio-aerosol deposition and resuspension and disease transmission**

Wind

Particle removal rate: 87.2%

**Escherichia coli (E.coli, ATCC 11303)**

**Personalized ventilation for thermal comfort and infection control by dynamic airflow**

**Personal ultrafine particle sensor development by acoustic technology**

**Artificial Intelligence Optimization**

- Energy Efficient Built Environment
- Bio-aerosol deposition, dispersion and resuspension
- Personal ventilation systems
- Urban aerosol filtration
- Ultrafine particles sorting by acoustic technique

---

**Advanced Thermal Engineering**

- Advanced thermal Engineering
- Heat transfer enhancement: Nanofluid, graphene coating, etc.
- Bio-inspired heat sink technology
- Biomimetic radiative coolers

---

**Introduction**

- Healthy and Comfort Environment
- Sustainability and Green Energy

---

**Advanced Thermal Engineering**

- Hybrid nanofluids as a next generation working fluid

- Enhanced heat transfer by graphene coating

- Biomimetic Polymer-based Radiative Coolers

- Bio-inspired heat sink technology by fluttering

- Actual 3D mapping of chiller OFC

---

**AI optimization**

- Layout of artificial neural network

<table>
<thead>
<tr>
<th>Average heat flux at channel walls (mW/cm²)</th>
<th>Calculated ANN model</th>
<th>Predicted ANN model</th>
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<tr>
<td>427.63</td>
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<td>785.27</td>
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<table>
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<th>% of optimized heat flux contributed by the ANN model</th>
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<th>Enhanced heat transfer caused by graphene-coated nickel foam</th>
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<thead>
<tr>
<th>Better prediction on cooling load demand and chiller plant COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better efficiency of the chiller plant and energy saving</td>
</tr>
</tbody>
</table>

---

**Errors in prediction**

- Cooling Load Demand: 5.6% vs 20.0%
- COP: 4.5% vs 7.2%

---

**Acknowledgment of funding support:** GRF 17205419, 1620918, 16207817, 16203015; C8082-16G, C1025-16G; D4420-1206419C
Advanced Thermal and Environmental Technologies for Green Buildings

Prof. Christopher YH Chao
Dr SC Fu, Dr Oscar Chan
Department of Mechanical Engineering

Healthy and Comfort Environment

- Bio-aerosol deposition and resuspension and disease transmission
- Personal ultrafine particle sensor development by acoustic technology

Personal ventilation for thermal comfort and infection control by dynamic airflow

- Personalized ventilation for thermal comfort and infection control by dynamic airflow

AI optimization

- Hybrid nanofluids as a next generation working fluid
- Enhanced heat transfer by graphene coating
- Biomimetic Polymer-based Radiative Coolers
- Bio-inspired heat sink technology byfluttering

Errors in prediction

- Better prediction of cooling load demand and chiller plant COP
- Better efficiency of the chiller plant and energy saving

Acknowledgment of funding support: GRF 172054/19, 162069/18, 162078/17, 162003/18; CRF C6022-16G, C7025-16G; EMSD 1296EM19C
Bijels and Biomedical Applications
Prof. Min Wang
PhD Students: Haoran Sun, Junzhi Li
Department of Mechanical Engineering

What Are Bijels?
Bicontinuous interfacially jammed emulsion gels ("bijels") are a new class of soft materials which were predicated by computational simulation in 2005 and experimentally realized in 2007. Bijels have bicontinuous interlocking structures of two phase-separated immiscible liquids which are stabilized by a jammed monolayer of interfacial colloids at the fluid-fluid interface. The unique bicontinuous phase morphologies and other properties of bijels present bijels themselves and also bijels-derived structures for many potential applications.

New Methods for Synthesizing Bijels and Bijels-Derived Structures
A major obstacle for the wide application of bijels and bijels-derived structures is the difficulties in bijels fabrication. Bijels can be fabricated using a few approaches. The first method used for bijels creation by Clegg et al. utilizes phase separation via spinodal decomposition. Bijels can also be made via solvent-transfer induced phase separation (STRIPS). But these techniques have respective drawbacks. New methods that can produce large 3D bijels must be developed.

Bijels-Derived Structures in Biomedical Applications
Generally, when oil and water (two immiscible liquids) are mixed together, oil-in-water or water-in-oil emulsion will form (pathway 2a or 2b). A critical quench can introduce phase separation via spinodal decomposition (pathway 1).

Phase-inversion Bijels-Derived Structures in Biomedical Applications
Bijels-derived scaffolds: (a) porous structure, (b) NIH 3T3 cells cultured on a scaffold

Cell release, proliferation and migration of mesenchymal stem cells using alginate hydrogel membranes as a cell delivery vehicle for tissue engineering

Other Applications of Bijels-Derived Structures
Electrospinning and Biomedical Applications

Prof. Min Wang

Members: H.W. Tong, C. Wang, Q. Zhao, C. Liu, Y. Zhou, L. Guo, H. Li

Department of Mechanical Engineering

**What Is Electrospinning?**

Electrospinning is a simple and versatile technique for producing fine fibers. It uses electric force to draw charged threads of a polymer solution or polymer melt to form fibers with diameters in the range of tens of nanometers to hundreds of micrometers.

**Advanced Techniques**

- **Emulsion electrospinning for encapsulating a growth factor (GF)**
- **Coaxial electrospinning for encapsulating a growth factor (GF)**
- **Coaxial electrospray for encapsulating live cells**
- **Multi-source multi-power electrospinning (MSMP-ES)**

**Biomedical Applications**

- **Evolution of core-shell structure in emulsion electrospun fibers**
- **Nanofibers and microspheres**
- **Controlled release of drugs and growth factors from fibrous delivery vehicles**
- **Multicomponent and multifunctional scaffolds for tissue engineering**
- **For GI tract regeneration: (a) a bi-layer scaffold, (b) two types of cells labeled in different layers.**
Biological Tissue vs. Abiotic Tools: Challenges

**Mismatches:**
- Biological Tissue: Soft, Self-Organized, Dynamic
- Abiotic Tools: Rigid, Lithographically Patterned or Machined, Static

Organ-Integrated Soft Electronics

An elastic, multifunctional membrane device integrated on a Langendorff-perfused rabbit heart

Biomechanical compatibility:

<table>
<thead>
<tr>
<th>Volume</th>
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<tr>
<td>120%</td>
<td>164</td>
</tr>
<tr>
<td>145%</td>
<td>296</td>
</tr>
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</table>

Physiological sensing and stimulation:

- L. Xu et al., Nat. Commun. 5, 3329 (2014)

Bridging the Gap with Biomimetic Soft Systems

**Applications:** Biomedical Implants, Wearable Electronics, Tissue Engineering Construct, etc.

Aramid-Nanofiber-Based “Artificial Cartilage”

A combination of high stiffness, toughness and water content/porosity

Kirigami-Inspired Reconfigurable Devices

L. Xu et al. ACS Nano 10, 6156 (2016)
L. Xu et al. ACS Nano 11, 7587 (2017)
Green and sustainable manufacturing of flexible electronics

Flexible light emitting devices

Stretchable and foldable light emitting film

Wearable personal therapy devices

Wearable thin-film heater for medical therapy

Flexible optical sensors

Flexible optical metasurface for highly-sensitive biosensing

Flexible remote sensing by nanostructured optical fiber

Flexible transparent ammonia gas sensor

Wireless sensing platform based on near-field communication

References

Large-Area Lithographic Nanopatterning

Pl: Dr. Wen-Di Li
Members: Jingxuan Cai, Siyi Min, Liyang Chen, Zhuofei Gan, Chuying Sun, Zhouyang Zhu, Tuo Qu, Chuwei Liang

Nanostructures in emerging applications

**Solar cells**

Bromersma et al., Nat. Mater., 2014

**Magnetic storage devices**


**Enhanced light extraction**

Li et al., Opt. Express, 2011

**Step-and-repeat nanopatterning**

Different nanopatterns fabricated on a single wafer by step-and-repeat FOIL

Fiber-optics interference lithography (FOIL)

- Physical principle of FOIL
- Sub-50 nm resolution and high-aspect-ratio nanostructures
- Large-area uniform nanopatterning

Large-area uniform nanopatterning

3-inch fused silica wafer with 440-nm period gratings

SEM images on 4 different locations across a 3-inch wafer with 240-nm-pitch gratings

Large-area nanopatterning capability

Nanoimprint lithography (NIL)

Nanoimprinted perovskite for enhanced light emitting

Enhancement in photoluminescence of nanoimprinted inorganic perovskite thin film

Nanopatterning on arbitrary surfaces

Water-assisted nanotransfer patterning on arbitrary surfaces

References

Molecular Monolayer Crystals: Fabrication Methods, Device Physics, and Applications in Flexible Electronics

Boyut Peng and Paddy K. L. Chan
Department of Mechanical Engineering

A. Background and Motivations

- Conventional organic semiconductor films
  - Polycrystalline (grain size ~ 1 μm)
  - Rough surface (R_a > 1 nm)
  - Multiple crystal polymorphs
  - Thick film (t: 30-50 nm)
  - Low mobility (μ < 5 cm²V⁻¹s⁻¹)

- Molecular monolayer crystal (MMC)
  - Single crystalline (size > 1 mm)
  - Smooth surface (R_a < 0.3 nm)
  - One crystal lattice
  - Ultra-thin film (t < 5 nm)
  - High mobility (μ > 10 cm²V⁻¹s⁻¹)

B. Fabrication method of MMC

Solution-shearing equipment

- Dual-shearing method for MMC deposition
  - Blade
  - Substrate
  - Heater
  - Cortections (Cs) in solution
  - Crystallization
  - Homogeneous islands

C. Ultra-flexible OFET array

- Conventional multilayer semiconductor
  - Current in
  - Current out
  - R_D

- Molecular monolayer crystal
  - Minimized contact resistance (R_C)
  - Current in
  - Current out

D. Ohmic contact at metal/semiconductor interfaces

- Transfer length method for R_D evaluation

E. Velocity saturation and self-heating effects

- Ultra-sensitive NH₃ sensor

F. Conclusion

The molecular monolayer crystals can be deposited by solution-processing into large areas. They possess unique advantages including outstanding mobility, sensing capabilities, mechanical flexibility, low contact resistance, etc. They are believed to be the optimum candidates as the active layers in the next-generation flexible electronics.

Sponsors: General Research Fund (HKU 17264016, HKU 17204517); Collaborative Research Fund (C704514E)
Understanding the Growth Mechanism of Organic Semiconductors in Meniscus-Guided Coating Method

Ming Chen and Paddy K. L. Chan*
Department of Mechanical Engineering

Objective

- Investigate crystal growth mechanism of organic semiconductors under meniscus-coating method
- Develop uniform, crystallized thin film with high mobility ($\mu$) for organic transistor applications.

I. Mass Conservation

$$\bar{m} = \rho \omega v t_{eq} = c \frac{dv}{dt}$$

Thickness Definition:
$$t_{eq} = t_{app} \frac{\sigma_2}{\sigma_1 + \sigma_2}$$

Mass conservation is used to analyse the influence of shearing speed ($v$) and solute concentration ($c$) on crystal growth. $v$ acts as thickness modulation factor while $c$ is direct proportional to crystal growth rate.

II. Temperature Effect

Heptane and chlorobenzene

- An thickness increasing trend is observed with deposition temperature ($T$) elevation.

III. Electrical Performance

Thin films of different types are characterized in terms of microscopic morphology and electrical performance. Highest $\mu$ ($7.18 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$) could be achieved in Type II.

C$_8$-BTBT thin films appear three distinct types of morphology influenced by four key parameters. Type II exhibits uniform morphology with highest $\mu$ of 7.18 cm$^2$ V$^{-1}$ s$^{-1}$. During coating process, shearing speed ($v$) serves as thickness regulation factor while solute concentration ($c$) is linearly proportional to grow rate. Furthermore, an deposition temperature ($T$) dependent increase relationship is observed in crystal growth process.

Sponsors
GRF (HKU 17204517 and 17264016)
CRF (C704514E)
Mimicking Associative Learning Using Synapse-Like Non-Volatile Organic Electrochemical Transistor

Xudong Ji and Paddy K. L. Chan

Department of Mechanical Engineering

A. Background and Objectives

- Can we use OECT as artificial synapse and mimic the function of synaptic circuit?

B. Fabrication and Characterization

- Active layer deposition
- OECT schematic view
- Memory behavior of OECT Vs PTHF ratio

C. Synaptic Behaviors of non-Volatile OECT

- Short-term synaptic plasticity (STP)
- Long-term synaptic plasticity (LTP)

D. Artificial Perception Using non-Volatile OECT

- Tactile perception
- Visual perception

E. Neuromorphic Circuit for Associative Learning

- Associative learning model of pavlov’s dog and schematic diagram
- Photograph of associative learning dock and circuit diagram

F. Conclusion

- Non-volatile OECT with memory effect has been successfully fabricated
- STP and LTP behaviors have been successfully simulated by non-volatile OECT
- Tactile and visual information have been associated with memory of OECT
- Neuromorphic circuit has been developed with associative learning property

Sponsors:
- RGC of HKSAR: General Research Fund (HKU 17264016, HKU 17204517)
- Collaborative Research Fund (C704514E)
Thermo-electrochemical Cell
for Harvesting Low-Grade Heat
Xun Wang, Yu-Ting Huang, Chang Liu, Kaiyu Mu, Ka Ho Li, Sijia Wang, Shien-Ping Feng

Introduction
Energy conversion from primary energy carriers to the final energy of use is subject to considerable losses equivalent to ~72% of the global primary energy consumption. The major loss is identified as waste heat, and specifically 63% of which occurs as low-grade heat below 100°C. Efficient recovery of low-grade heat is vital to abate greenhouse-gas emissions and also promises potential economic and environmental benefits. Current technologies such as solid-state thermoelectric devices (TEs) are capable of converting heat into electricity, but their conversion efficiency ($\eta$) is either too low or system is too complex for economical deployment. Thermo-electrochemical cell (TEC) is promising for low-grade heat harvesting for its high temperature coefficient, the ability to engineer entropy changes, thermal and electrical transport. However, current TECs to fulfill the efficient and practical heat-to-electricity are still far from optimum. Here we invent direct thermal charging cell (DTCC), which is direct charged by heating without the need of external electricity and then electrically discharged at a high temperature ($T_H$). This system exhibits a markedly high $\alpha$ of 5.0 mV/K and attains $\eta$ of 5.84% the highest ever achieved at 70°C (44.5% of $\eta_{Carnot}$). DTCC opens a promising new technology for efficiently harvesting low-grade heat.

Direct Thermal Charging Cell

- Asymmetric electrodes cell: graphene oxide/platinum nanoparticles (GO/PtNPs) cathode, polyaniline (PANI) anode, aqueous Fe$^{2+}$/Fe$^{3+}$-based redox electrolyte.
- Working principle:

  ![Diagram of DTCC](image)

  - Initial stage Built-in voltage
  - Stage 1 Thermal charging
  - Stage 2 Electrical discharging
  - Stage 3 Self-regeneration

  A built-in open circuit voltage ($V_{OC}$) is observed due to the differential of electrochemical potentials ($\Delta V_3$) between GO/PtNPs and PANI electrodes at room temperature ($T_R$).

  - Stage 1 Thermal charging
    When DTCC is heated from $T_R$ to $T_H$, in open circuit condition, a thermal-induced voltage is built up by two parts inclusive of the temperature-induced pseudocapacitive effect of GO and the thermogalvanic effect of Fe$^{2+}$/Fe$^{3+}$ while PANI has little contribution to the increase voltage.

  - Stage 2 Electrical discharging
    When an external load is connected, the DTCC is discharged continuously at $T_H$, where the discharge capacity is mainly attributed to the oxidation of PANI anode and the simultaneous reduction of Fe$^{3+}$ on catalytic GO/PtNPs cathode. The cell $V_{OC}$ drives the oxidation of PANI anode to produce electrons through the external circuit; the majority of electrons are then carried by the reduction reaction of Fe$^{3+}$ to Fe$^{2+}$ in cathode side, which protects the functional groups of GO from being reduced and significantly enhances the discharge capacity of DTCCs.

  - Stage 3 Self-regeneration
    The oxidized PANI would react with Fe$^{3+}$ in an acidic electrolyte at $T_R$ to chemically regenerate PANI and Fe$^{2+}$; this synergistic self-regeneration mechanism allows the cyclability of DTCCs.

Results
- Temperature-induced pseudocapacitive effect: High temperature induces a fast and reversible faradic process arising from the chemisorption of proton on the oxygen containing functional groups of GO. The temperature coefficient ($\alpha$) of cell consists of GO/PtNPs cathode, PANI anode and KCl electrolyte could reach 3.1 mV/K.

- Cooperative thermogalvanic effect: Fe$^{2+}$/Fe$^{3+}$ redox couple has an intrinsic positive $\alpha$ so that heating could facilitate the reduction reaction; the electrons transfer from the GO/PtNPs to the lowest unoccupied molecular orbital (LUMO) of Fe$^{2+}$ during heating conduces to an enlarged $V_{OC}$. Thus, DTCC reaches a markedly high $\alpha$ of 5.0 mV/K in thermal charging stage.

Performance & Demonstration
- Maximum Volumetric power density: 856 W/m$^3$ at 70°C and 3345 W/m$^3$ at 90°C.
- Efficiency: 5.84% at 70°C (44.3% of $\eta_{Carnot}$) and 6.65% at 90°C (37.2% of $\eta_{Carnot}$), which are much higher than that of current TEC technologies.

Outlooks
A new electrochemical cell for efficiently converting low-grade heat to electricity is invented, which depends on a thermal-induced potential gradient and chemical cycle and thus allow the isothermal heating operation during the entire charging and discharging processes instead of using temperature gradient in geometric configuration or thermal cycle. The great applicability and fast thermal response of DTCCs have been demonstrated in some practical scenarios. With further research and development, DTCC may find many applications, such as low power sensing and communication for smart cities and body heat-powered technologies.
Lattice dynamics describe the vibration of atoms and their effects on physical properties, such as lattice stability [1], melting behavior [2], and thermal transport [3]. Based on harmonic approximation, only the lattice dynamics at low temperatures, when phonon coupling is weak, can be studied. At elevated temperatures, phonon lifetime is reduced due to enhanced phonon coupling, accompanying with frequency shift compared with the harmonic frequency. In our research, anharmonic lattice dynamics at finite temperatures of several materials have been investigated from first-principles based on perturbation theory or self-consistent ab-initio lattice dynamics calculation. Additionally, the effects of compressive and tensile strains on anharmonic phonon coupling are also studied. In-depth understanding of the lattice dynamics paves the path for further studies of related physical properties.

Methodology

Harmonic phonon dispersions are calculated using the finite displacement approach [4]. The phonon spectra at elevated temperature are calculated using the frequency dependent phonon self-energy (\(\Sigma_\lambda(\omega)=\Delta_\lambda(\omega)-i\gamma_\lambda(\omega)\)) based on the lowest-order perturbation theory. The real part of the phonon self-energy describes the frequency shift, while the imaginary part is the reciprocal of phonon lifetime. Beyond perturbation theory, the temperature dependent phonon frequency can also be calculated using a self-consistent ab initio lattice dynamics approach [5].

Results

- **Strain effects on the phonon coupling of graphene**

- **Phonon coupling of sodium under high pressures**

  - The TO mode at K point softens significantly at high temperatures when graphene is under equibiaxial strains, indicating an accelerated phonon mediated mechanical failure when temperature is increased.

- **Negative thermal expansion in sodium above 90 GPa**

- **Counter-intuitive strain dependent lattice thermal conductivity of Te**

  - As the uniaxial strain along c increases from -7% to 7%, the lattice thermal conductivity along this direction initially increases and then decreases, whereas the lattice thermal conductivity along a and b directions decreases even though the corresponding lattice constants are actually reduced.

  - The counter-intuitive strain dependent lattice thermal conductivity is related to the variations of 1NN and 2NN bond lengths.

Conclusions

By studying the strain effects on phonon coupling of graphene, its accelerated mechanical failure at elevated temperatures is rationalized. From the phonon spectra of bcc sodium, the pressure-induced softening and temperature-induced stiffening of the TA modes along Γ-N are found to be related to its anomalous melting behavior. Furthermore, negative thermal expansion is predicted in fcc and c16 sodium above 90 GPa, which originates from the phonon modes with negative gruneisen parameters. Lastly, counter-intuitive strain dependent lattice thermal conductivity is found in thermoelectric Te crystal.

References

Quad-copters are the premier platform for data collection tasks, yet their ability to fly in narrow spaces is severely compromised due to their huge size when carrying heavy sensors. Our proposal, known as Gemini, is comprised of a novel bi-copter configuration that allows for similar levels of versatility whilst also improves compactness and efficiency. This special arrangement allows for the preservation of propeller size, meaning that we can effectively reduce the horizontal width of the UAV whilst maintaining its payload carrying capability. Furthermore, pitch, roll and yaw control can also be achieved through mechanically simple means as well, increasing reliability and precision. We also found that the Gemini platform is the most power-efficient yet practical solution for indoor application among all the twelve common UAV configurations.

Aerodynamics Analysis

The hovering power of aircraft is derived from the momentum theory:

\[ P = T \sqrt{\frac{V}{2A \rho}} \]

This implies that the hover efficiency is inversely proportional to the square root of disk loading: a lower disk loading leads to a higher efficiency.

we analyzed the power consumption of the Gemini bi-copter and other multi-rotor configurations with the same takeoff weight and effective size, including helicopter (one-propeller), tri-copter, hexa-copter, and octo-copter, each with a single propeller and two co-axial propellers along each axis.

<table>
<thead>
<tr>
<th>Configuration</th>
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<tr>
<td>G297/4</td>
<td>0</td>
<td>0</td>
<td>7.571</td>
</tr>
</tbody>
</table>

Gemini flying through gap

Fig. 2. Efficiency comparison among multi-rotors UAVs. (Gemini has the lower power consumption among the single propeller configurations, and it is also the most practical and mechanically simplest one among all configurations. Note all the power are normalized by the single propeller helicopter configuration.)

Control

The whole control structure of Gemini is shown in Fig. 3. The navigation module produces the target position \( \mathbf{p}_d \) and yaw angle \( \psi_d \) for position controller to track. The position controller will generate the desired attitude \( \mathbf{R}_d \) and body-Z axis force \( T_d \). The attitude controller will calculate the desired moment \( \tau_d \) based on the desired attitude. And finally, the mixer will calculate the motor thrust commands and servo angle commands based on the \( \tau_d \) and \( T_d \).

<table>
<thead>
<tr>
<th>Specification</th>
<th>Width</th>
<th>Power</th>
<th>Takeoff Weight</th>
<th>Flight Time</th>
<th>Payload</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4 cm</td>
<td>297 W</td>
<td>1.8 kg</td>
<td>13 minutes</td>
<td>0.5 kg</td>
<td>5000 mAh</td>
<td></td>
</tr>
</tbody>
</table>

Experiment Validation

To validate the performance of the Gemini, a hovering flight with a disturbance test and a flying through 400 mm gap test were conducted. Fig. 4 shows that the actual power consumption is around 335 W, which is 12.8% higher than our prediction of 297 W. The error is due to the downwash purling induced by the UAV body. Fig. 5 demonstrate the preciseness of the position control. Even after poking disturbances, the Gemini recovered within half a second, proving the robustness of the control system.

Fig. 3. Control structure

Fig. 4. Disturbance test

Fig. 5. Top, side and back view of the Gemini flying through gap

Fig. 6. Crossing gap test
Hong Hu - An aerobatic yet efficient quadrotor tail-sitter UAV

Wei Xu, Haowei Gu, Fu Zhang
Mechatronics and Robotic Systems (MaRS) Laboratory
Department of Mechanical Engineer,
University of Hong Kong

Introduction

This work introduces the design, implementation and control of an efficient and versatile tail-sitter VTOL UAV platform - Hong Hu. A multidisciplinary design and optimization framework is used to optimize the aircraft’s aerodynamic configuration and propulsion system. Then the carbon fiber structured aircraft is manufactured based on the optimal design. The resulting Hong Hu UAV platform could be used for various outdoor applications. In this abstract, we demonstrate its application in large-scale surveying and mapping.

Design Optimization Framework

We form the design as an optimization problem:

$$\min_{x \in \mathcal{X}, z} \min_{\mathcal{L}} \{ L(x) = W, I_1(x) \leq 0 \}$$

The objective function $I_0(x, z)$ is a mixed flight time, where 10% of the time the UAV is hovering to account for takeoff and landing and the rest of the time the UAV is at level flight to execute actual missions. For a given aircraft, aerodynamic configuration $x$ denoting the vector of wingspan, angle of attack, flight speed, etc. and propulsion system $z$ indicating the specific combination of propeller, motor, and battery, $I_0$ can be computed based on the aerodynamic and propulsion model that are identified from pre-known empirical aerodynamic models and propulsion database.

The optimization problem also has two constraints: one is the lift must be equal to the aircraft weight, and the other one may refer to constraints on UAV size and other aerodynamic configurations. Since the number of propulsions systems available in the database is finite (i.e. the set $\mathcal{S}$ in the optimization problem is a finite set), the resulting optimization problem involves both continuous variables in $x$ and discrete variable $z$. To decouple the two optimization variables, we employ a coordinate descent optimization method as shown in Fig.1. The optimization procedure is shown in Fig.2. Notice that the initial values are randomly chosen, so they may not satisfy the constraints $L(x, z) = W$ and the corresponding objective function are not valid although they may be higher than the following iterations.

Implementation

Hong Hu is implemented based on the optimal aerodynamic configuration and propulsion system returned by the above optimization. The entire system, including all on-board electronics, sensors, propellers, engines, electronic speed controller (ESC), is shown as following. The total weight is 1.6kg, leaving 400g for payloads such as cameras.

Application In Surveying and Mapping

To demonstrate the capability of Hong Hu, we conduct a 3D mapping task in an outdoor construction site which is 500m $\times$ 600m. The actual experiment shows that the UAV can execute the task autonomously with high stability and accuracy\(^1\). The resulting map is shown in the following Fig.3 with the full 3D model available on Altizure\(^2\).

Fig. 1. Multidisciplinary design optimization via coordinate descent.

Fig. 2. Objective function versus optimization iterations for different initial values.

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1https://youtu.be/STO8Ty7WMhw
2https://www.altizure.cn/project-model?pid=5cff56902c2de6eb8d7598

The Ambition of Hong Hu

— The Records of the Grand Historian, Sima Qian, 94 BC.

Hong Hu means Swan in Chinese.
Loam_livox: An open source, robust, high-precision LiDAR odometry and mapping package for LiDARs of small FoV
https://github.com/hku-mars/loam_livox
Jiarong Lin and Fu Zhang
Department of Mechanical Engineering

Introduction

With the capacity of estimating the 6 degrees of freedom (DOF) state, and meanwhile building a high precision map of environments, SLAM methods using LiDAR sensors have been regarded as an accurate and reliable way for robotic perception. Recently, we open source a project named Loam_livox, which is a robust, low drift, and real time odometry and mapping package for Livox LiDAR, an extremely low-cost yet high performance LiDAR sensor. Our package address many key issues like feature extraction and selection in a very limited FOV, robust outliers rejection, moving objects filtering, and motion distortion compensation. In addition, we also integrate other features like parallelization, point cloud management, loop closure, and utilities for maps saving and reload, etc.

Methodology

The above image shows the framework of our package, where each new frame is matched directly with the global map to provide the odometry output. The matching result is in turn used to register the frame to the global map, leading to the same rate (i.e., 20 Hz) of odometry output and map update.

Let $P_k$ be a point of the current frame (k-th frame) in LiDAR frame, $R_k$ and $T_k$ are of the pose of current LiDAR relative to world frame. $P_w$ is transformed to the world frame $P_w = R_kP_k + T_k$. Then, the LiDAR pose is solved by minimizing the distance of an edge point to the closest edge and a plane point to the closest plane in the last frame.

The distance of point to edge (see subfigure (a)) is:

$$r_{e2e} = \frac{|(P_w - P_5) \times (P_w - P_1)|}{|P_5 - P_1|}$$

The residual of point to plane (see subfigure (b)) is:

$$r_{p2p} = \frac{(P_w - P_1)^T ((P_3 - P_5) \times (P_3 - P_1))}{|(P_3 - P_5) \times (P_3 - P_1)|}$$

Results

The above image is the 3D mapping results of the Chong Yuet Ming Cultural Center in the University of Hong Kong (HKU), overlaid with the estimated trajectory in white. The level of details of the stair and railing show that our algorithm is of high precision.

We evaluate the localization of our algorithm by comparing with the measurement of GPS, shown in above figure. We compute the distance of two positions of the odometry output and compare it with the measurement of GPS. The accumulated error is as low as 0.65%, which implies that the localization is of high accuracy.

To further improve the precision, correct the long-term drift of large-scale mapping. We also develop a fast, complete, point cloud based loop closure for our algorithm, and one of our results are show as follow:

Fig. a: the RGB image of the map area. Fig. b: the red and withe points are off the map before and after loop closure, respectively. Fig. c: the red dashed line indicates the detected loop, the green, and blue solid lines are the trajectories before and after loop closure, respectively.