DESIGN ENGINEERING RESEARCH BOOKLET

Poster Symposium 2024

IMPERIAL

Dyson School of
Design Engineering

PREFACE

The vision of the Dyson School of Design Engineering is to empower innovators and decision-makers to harness the power of a rigorous and creative discipline towards constructing better social and technical systems using new technologies as building blocks. By fusing the technical to the human, we're helping to create a world that's just, sustainable, and teeming with possibilities.

This research booklet showcases some of the work produced by the Design Engineering research community. It includes 64 posters produced by PhD students and postdoctoral researchers within our School, which were presented at our Research Symposiums in July and October 2024. These activities align with our six key research themes: regenerative ecosystems, augmented living, smart futures, adaptive horizons, peer-to-peer society, and equality in evolution. Each theme is dedicated to shaping a future that is sustainable, healthy, intelli- gent, resilient, collaborative, and equitable. Our approach is inherently trans- disciplinary, integrating perspectives and expertise from various fields and stakeholders. From exploring digital mental health interventions to investigat- ing fairness in consumer electricity markets, and beyond, these outputs demonstrate the diversity of impactful research being done at the School.

As this is the first of many research showcases, and quite aptly aligned with the 10 year anniversary of our School, it is useful to have some introspection about achievements to date and guiding thoughts moving forward. One provocation comes from English economist and philosopher John Manyard Keynes who states "The difficulty lies not so much in developing new ideas as in escaping from old ones". The sentiment expressed here is crucial in our research approach because if we don't ask the right questions, we'll never find the right answers. This innate thinking process is core to our identity here in the Dyson School and is important as we look to emerging research challenges with a holistic and interdisciplinary lens.

We hope that you will enjoy reading this booklet, and that it will provide an illustration of the breadth of ongoing research work within our school. Moreover, we also hope that it acts as a catalyst for discussions and collaboration with us in the future. We love to collaborate, and we love to work on problems that matter!

Prof Bob Shorten, Head of School
Dr Billy Wu, Director of Research
Dr Mazdak Ghajari, Director of Postgraduate Studies

CONTENT July 2024

CONTENT October 2024

AutoTriage: predicting traumatic brain injury (TBI) in road traffic collisions using vehicle sensors

Existing, widespread **vehicle sensor dynamics** measurements can be used to **predict** specific, time-critical traumatic **brain injuries**, with the potential to **automatically triage** injury.

Dr Claire E Baker, c.baker17@imperial.ac.uk
Dr Mazdak Ghajari, Dr Phil Martin, Prof David Sharp, Prof Mark Wilson

Abstract

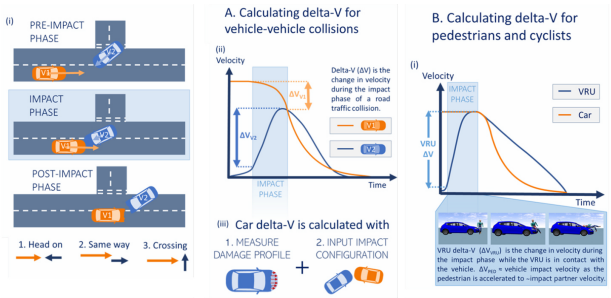
Road traffic collisions (RTCs) are a major cause of traumatic brain injury (TBI) [1-2]. We demonstrate a relationship between collision dynamics that can be recorded by in-vehicle sensors and traumatic brain injury severity and type in historic collision data. The relationship between sensor-recorded parameters and injury could automatically inform the emergency services to time-critical TBI, aiming to reduce mortality and improve patient outcomes.

Introduction

There are an estimated 34 million TBIs in RTCs each year [2]. However, the relationship between road traffic collision dynamics and traumatic brain injury risk for different road users is unknown. Direct transfer to neurosurgical provision reduces mortality and improve outcomes [3]. Relating collision dynamics to TBI outcome could inform how routinely fitted automatic collision notification systems alert the emergency services to time-critical TBIs [4]. Automatically and rapidly identifying those that require neurosurgical care and ensuring they are transported directly to a centre with neuro-specialist provisions could improve patient outcomes.

Methods

We investigated TBI prevalence in 2,065 collisions from Great Britain's Road Accident In-depth Studies (RAIDS) database involving 5,374 subjects (2013–20). We developed a novel free-text search tool to classify TBI in free-text using the Mayo classification system [5]. We report prevalence of key TBI types. We extended our results nationally using 1 million police-reported RTC casualties. RAIDS detail facilitates vehicle collision dynamics understanding and change in velocity ('delta-V') estimation for a subset of in-depth collision data. We modelled the relationship between delta-V (magnitude and direction) on TBI (severity and type) with multivariate logistic regression and stratified k-fold cross-validation.



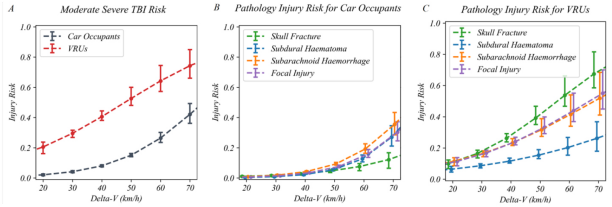
Results

Five hundred and ninety-five subjects sustained a traumatic brain injury (20.2% of 2940 casualties), including 315 moderate–severe and 133 mild–probable injuries. Key pathologies included skull fracture (179, 31.9%), subarachnoid haemorrhage (171, 30.5%), focal brain injury (168, 29.9%) and subdural haematoma (96, 17.1%) [6]. Extrapolating from the in-depth data we estimate that there are 20,000 traumatic brain injury casualties (5,000 moderate–severe) annually on Great Britain's roads.

	TOTAL	PEDESTRIANS	CYCLISTS	MOTOR-CYCLISTS	CAR OCCUPANTS	VAN OCCUPANTS	HGV OCCUPANTS	BUS OCCUPANTS
ALL SUBJECTS	5374	144	112	267	3992	369	262	196
INJURED SUBJECTS	2940 54.7%	138 95.8%	108 96.4%	251 94.0%	2096 52.5%	188 50.9%	78 29.8%	75 38.3%
ALL TBI	595 11.1%	69 47.9%	43 38.4%	67 25.1%	365 9.1%	31 8.4%	15 5.7%	5 2.6%
MODERATE TO SEVERE TBI	315 5.9%	52 36.1%	29 25.9%	46 17.2%	166 4.2%	15 4.1%	7 2.7%	0 0.0%
FATAL TBI	133 2.5%	10 6.9%	9 8.0%	17 6.4%	84 2.1%	7 1.9%	4 1.5%	2 1.0%

	TOTAL	PEDESTRIANS	CYCLISTS	MOTOR-CYCLISTS	CAR OCCUPANTS	VAN OCCUPANTS	HGV OCCUPANTS	BUS OCCUPANTS
ALL SUBJECTS	5374	144	112	267	3992	369	262	196
SKULL FRACTURE	179 3.3%	34 23.6%	16 14.3%	23 8.6%	92 2.3%	11 3.0%	3 1.1%	0 0.0%
SUBDURAL HAEMATOMA	96 1.8%	17 11.8%	8 7.1%	10 3.7%	53 1.3%	5 1.4%	3 1.1%	0 0.0%
SUBARACHNOID HAEMORRHAGE	171 3.2%	25 17.4%	26 23.2%	27 10.1%	92 2.3%	8 2.2%	3 1.1%	0 0.0%
FOCAL INJURY	168 3.1%	32 22.2%	13 11.6%	25 9.4%	80 2.0%	13 3.5%	5 1.9%	0 0.0%

Higher delta-V increased the risk of moderate–severe brain injury for all road users. The four key pathologies were not observed below 8 km/h delta-V for pedestrians/cyclists and 19 km/h delta-V for car occupants (higher delta-V threshold for focal injury in both groups). Accounting for delta-V, pedestrians/cyclists had a 6-times higher likelihood of moderate–severe brain injury than car occupants. Car occupants exposed to a higher lateral delta-V component had a greater prevalence of moderate–severe brain injury, particularly subarachnoid haemorrhage. Multivariate logistic regression models created using total delta-V value and whether lateral delta-V was dominant had the best prediction capabilities (area under the receiver operator curve as high as 0.95).



Discussion

We address a key knowledge gap in the understanding of how collision dynamics relate to specific types of TBI pathology in varying types of road users. We described TBI prevalence and model the relationship of injuries to collision dynamics (delta-V). Moderate–severe TBI risk increased with delta-V and was significantly higher in VRUs for a given delta-V. The results have the potential to influence trauma care directly by informing the development of advanced automatic collision notification systems that are increasingly being fitted in new vehicles. Vehicle sensors can record delta-V, opening the door to real-time distinct injury risk alerts in post-crash care.

Conclusion

The new relationships presented connect widely available collision dynamics and distinct brain injury types and severities. The ability to identify time-critical injury in real-time using widely available sensors can support existing post-crash care. Early notification of high-risk scenarios can enable quicker activation of the highest level of emergency service response.

Bio

Dr Claire E Baker is an EPSRC Doctoral Prize Research Fellow (Research Associate) in HEAD Lab. She completed her interdisciplinary PhD in Design Engineering under the CDT Neurotechnology umbrella, funded jointly by EPSRC and industry partner TRL. She collaborates closely with Imperial Medicine and the NHS.

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Randomised transport plans via Hierarchical Fully Probabilistic Design

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Supervisors: Anthony Quinn, Robert Shorten

> " A new methodology for the design of randomised policies and diversity elicitation in transport, resource allocation and fairness-aware data repair problems"

Abstract

In this research, we propose to recast the classical Entropy-regularised optimal transport problem (EOT) into a Hierarchical Fully Probabilistic Design question. We call this new framework for OT: HFPD-OT. In doing so, we furnish the classical OT setting with crucially important mechanisms that allow the modeller to measure and reason about uncertainty in the transport problem in a principled way. Importantly, HFPD-OT enables a randomised and diversified choice of transport policies in the face of uncertainty, randomisation being a key mechanism for fairness elicitation.

Introduction

Optimal Transport (OT) and its Entropy-regularised version (EOT), are well-established mathematical frameworks for designing optimal transport plans and matching policies (images and video processing, matching workers and firms, etc.) However, the current paradigm hinges on the (unrealistic) assumption of fully-characterised observations (marginals) and is framed as a purely deterministic optimization problem. HFPD-OT, our new paradigm for OT, addresses these shortcomings by modelling the transport plan as a random process, endowed with its own probability density, the optimal hyperprior. Having access to this hyperprior enables the sampling of random transport plans (Figure 1), which can then be used in downstream tasks, where randomised, robust and diverse transport policies are needed. Critically, randomisation furnishes the transport problem with the mathematical tools to measure and reason about uncertainty, by constructing distributions of measures of interest, instead of a single point estimate.

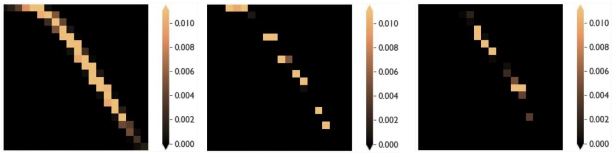

Figure 1: The classical EOT plan between two Gaussian distributions (left). Two random realisations sampled from the optimal hyperprior learned using HFPD-OT (middle and right).

Methods

The key object of interest in HFPD-OT is the optimal Bayesian hyperprior. Learning the hyperprior mainly consists in projecting the Lagrange multipliers (the parameters controlling for the degree of uncertainty in the transport problem) into the knowledge constraints set (Figure 2-a). This is done primarily using a mix of stochastic optimization and MCMC techniques. Once the hyperprior available, random realisations of transport plans can be drawn (Figure 2-b), by leveraging a MCMC sampler. Using these samples, we can construct, for instance, an estimate of the expected transport plan, which can then be used in downstream transport problems, in lieu of the optimal transport plan.

Results

To illustrate the HFPD-OT setting, we use data repair for algorithmic fairness as an exemplar. OT and the induced Wasserstein barycenter have gained major traction recently for designing data repair algorithms, the Wasserstein barycenter being used as a target distribution for debiasing data. However, these OT/EOT-based mechanisms assume perfectly observed data and produce crisp, deterministic measures of fairness. Conversely, HFPD-OT treats the barycenter as a random process. Thus, following a sequence of sampling and repair operations, we can construct full distributions of fairness proxies (Figure 3).

Discussion

Figure 3 shows the distribution of a fairness measure (the distance between the two repaired distributions). Using 100 Monte Carlo experiments, transport plans are sampled from the optimal hyperprior, and used in a sequence of repair rounds. This yields a full distribution, allowing for an in-depth analysis of uncertainty in the repair problem. In contrast, the classical OT produces a single, possibly biased, point estimate.

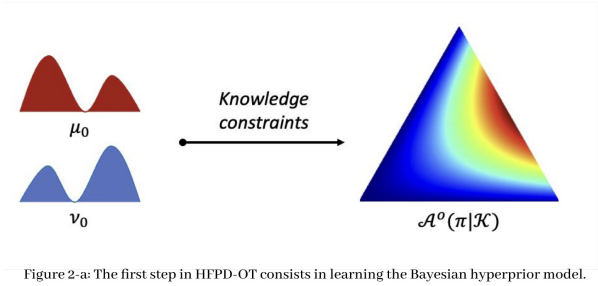

Figure 2-a: The first step in HFPD-OT consists in learning the Bayesian hyperprior model.

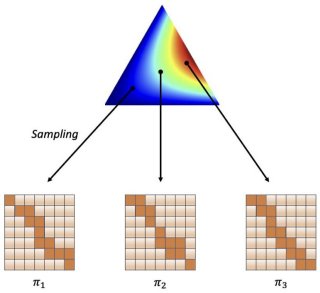

Figure 2-b: With the optimal hyperprior, random realisations of transport plans can be sampled and used in downstream tasks, such as data repair.

Conclusion

HFPD-OT is a new paradigm for solving transport and matching problems, that departs from the purely deterministic setting of OT and its various approximations. By recasting the transport problem as an inference question and treating the transport plan as a random process, the designer has access to critical tools for measuring uncertainty when designing transport policies. Moreover, randomisation and diversification of transport plans can elicit fairer distribution of outcomes, in contrast with a single and immutable OT plan.

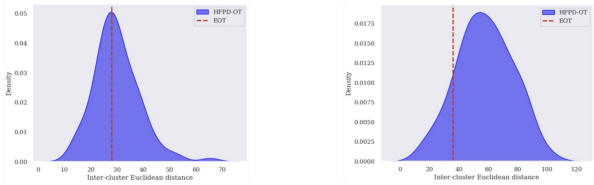

Figure 3: Distribution of fairness measure enabled by random transport plans versus the single point estimate constructed with EOT, obtained in two independent repair experiments.

Biography

Sarah B.Y is a scientist at the GenAI Lab at Amazon. Her research lies at the intersection of optimal transport, Bayesian modelling and machine learning, with a focus on unsupervised and generative models, robust learning and hallucination detection in LLMs.

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QR Code

Virtual Reality Delivered Exposure for Subclinical OCD: A Single-Session Study

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> "[VR] is a step forward to [confronting your fear] in a real-life situation... I feel this is a big step forward...because it is **available to everyone**."

Background

- A large treatment gap exists for individuals with anxiety [1]. This gap is larger for those with subclinical symptoms, since they do not meet diagnostic criteria and are often excluded from formal treatment.
- Exposure-based therapy, a way of repeatedly confronting a fear-provoking stimulus, is a gold-standard treatment for anxiety-related disorders.
- Virtual reality (VR) is increasingly used to deliver exposure-based therapy (Virtual Reality Exposure-Based Therapy; VRET) to help address this treatment gap and shows promise as an effective intervention [2]. Advantages include scalability, personalizability, reproducibility, decreasing cost, and ability to design and control the VR environment.
- Use of VR in contamination Obsessive Compulsive-Disorder (OCD) has remained heavily understudied.

Screenshot of VR environment created by XRHealth.

Aims

1. Test impact of single-session VRET on momentary anxiety and contamination OCD symptoms.
2. Investigate participant perception of presence & plausibility of VR environment and influence on effectiveness of intervention.
3. Examine acceptability of intervention.

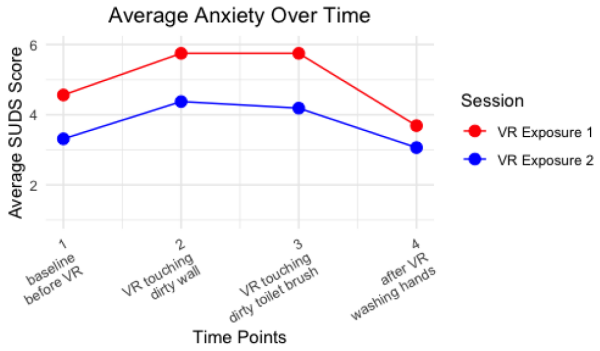
Methods

Procedure:
- Single session which includes 2 identical self-paced VR exposures and 1 month follow-up online survey.

Participants:
- 16 participants (6 female, 9 male, 1 prefer not to say) recruited via Instagram advertisements.
- Identified as avoiding/unable to use a dirty public toilet or having elevated scores on contamination subscale of the OCI-R and no OCD diagnosis.
- Age range: 18 - 32 years old (*M* = 21.75)
- 4 participants have used VR before.

Measures:
- OCD symptoms — Obsessive Compulsive Inventory-Revised (OCI-R)
- Anxiety — Subjective Units of Distress (SUDs), Positive and Negative Affect (PANAS)
- Acceptability – System Usability Scale (SUS), Simulator Sickness Questionnaire (SSQ)

Results



1. No change in contamination symptoms after 1 month: p = 0.09, g = 0.90
   - Negative affect ↓ & Positive affect ↑ after 1 month: p < 0.001, g = > 1 for both
   - Momentary anxiety ↓: p < 0.001 between exposures and within each exposure
2. Both VR Presence questions were not found to be correlated with change in anxiety (r = 0.05, 0.07), but sensation of being in the public toilet was moderately correlated with negative affect (r = 0.41), positive affect (r = 0.33), and change in contamination symptoms (r = 0.38)
3. Only 1 participant reported cybersickness
   - Overall, participants found the VR intervention to be acceptable (range = 30.0 – 87.5, *M* = 69.6)

Discussion

- The VR intervention seemed to improve affect and evoke anxiety enough to enable exposure-based therapy.
- Contamination symptoms did not change significantly, which could be due to the current intervention being limited to a single session.
- Low report of cybersickness and high acceptability suggests VRET is well-tolerated and accepted.
- Future directions include testing larger sample size, larger number & longer length of exposures, and against a control group to further investigate the efficacy of VRET.

Bio

Anna Caltabiano is a PhD student at the Dyson School of Design Engineering funded by the LISS DTP CASE studentship. Her research interests lie in VR and broader technology-driven interventions for mental health.

References

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LISS DTP XRHealth

Real-time Brain Injury Prediction Based on Machine Learning and Sports Wearables

> “ This novel model enables **pitch-side** surveillance systems to immediately assess **brain deformation** in sports collisions. ”

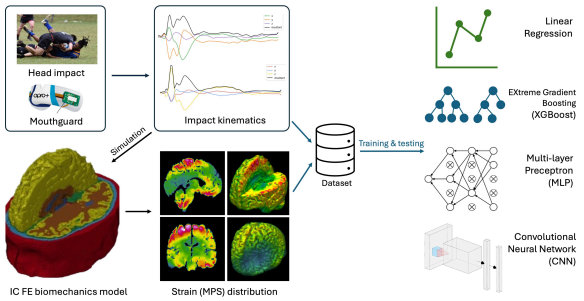
Emily Yik Kwan Chan (emily.chan21@imperial.ac.uk)
Xiancheng Yu, Qin Chen, Mazdak Ghajari

Background

Head impacts in sports can cause traumatic brain injury (TBI). Instrumented mouthguards (iMGs) worn by athletes capture head kinematics data in both linear and rotational. Finite element (FE) brain models use this data to simulate impacts and quantify brain deformation by mechanical strain, but each simulation takes 5-6 hours on a high-performance computer.

Research Aim

To reduce the computational time, previous studies introduced two deep learning models, a convolutional neural network (CNN) and a multi-layer perceptron (MLP), for real-time brain strain prediction. However, these models require the entire kinematics signal, i.e. over 600 data points per impact, which cannot be reliably transmitted from iMGs in real-time.
Therefore, models requiring fewer data points are needed for on-field real-time brain deformation prediction.



Methods

Impact kinematics Protecht iMG collected 1701 rugby impacts. Features were extracted from rotational velocity and acceleration.
Strain estimation Imperial College FE model simulated the impacts and calculate brain strain and strain rate distribution. FE-calculated strain were extracted: the max in the whole brain and regions of interest (ROIs).
ML models developed:

- A linear regression (LR) model to predict max strain in whole brain.
- An extreme gradient boosting (XGB) model to predict strain in ROIs.
- A CNN and an MLP model was developed to predict strain distribution.

We evaluated models' performances for both accuracy and efficiency.

Results

We trained and tested LR, XGB, CNN, and MLP models on the same dataset to predict brain strain.

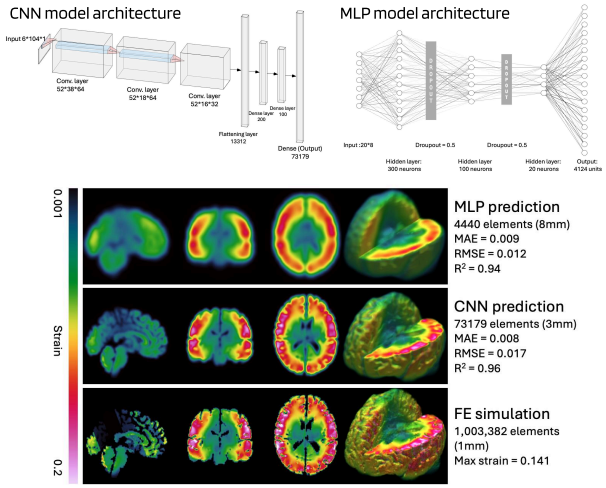
- Prediction accuracy (R^2) were 0.73, 0.92, 0.83 and 0.90, respectively.
- Inference time were 0.08, 0.1, 0.5 and 0.6 seconds, respectively.

ML models predict strain of multiple impacts in **fraction of a second**, which significantly improve the computational time.

	LR	XGBoost	MLP	CNN
Prediction task	Strain in ROIs	Strain in ROIs	Strain distribution	Strain distribution
Input size per impact	1	4 (2 features * 2 channels)	160 (20 features * 8 channels)	624 (104ms * 6 channels)
Output size per impact	1	18	4440	73179
Accuracy (R^2)	0.731	0.924	0.837	0.90 5
Inference time (s)	0.08	0.1	0.5	0.6

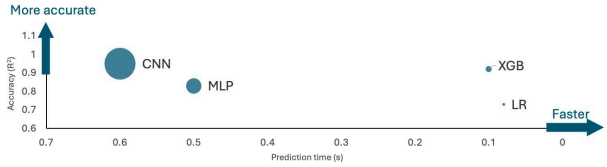
Discussion

- All four ML models quickly and accurately predicted strain at different resolutions: max in whole brain, in ROIs and high resolution distributions.
- With simple input requirements, LR and XGB models can integrate with iMG-based injury surveillance systems for near real-time predictions.
- With high resolution of the predicted distribution, the CNN and MLP models can be used for more detailed post-impact analysis.



Conclusion

The proposed XGB model can allow integration with iMG-based injury surveillance systems for near real-time estimation of brain deformation, which can guide pitch-side decision making in both professional and grassroot sports. Different ML models can be used at various stages of TBI analysis.



Bio

Emily is a PhD student whose current project is focusing on traumatic brain injury (TBI) caused by sports impacts, which is funded by Sports and Wellbeing Analytics (SWA)/Cellbond/Royal Academy of Engineering Senior Research Fellowship.
Emily received her master's degree in the Department of Computing, Imperial College in 2022. She studied electronic engineering and computer science for her undergraduate in Queen Mary University of London.

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Robot Learning with Foundation Models

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Nicolas Rojas, Petar kormushev

"Foundation model shapes the future of robot research"

Abstract

The integration of foundation models, such as GPT and BERT, SAM and YOLO into robotics promises to revolutionize robot learning and performance. These pre-trained models enhance robots' abilities in natural language understanding, visual perception, decision-making, and multimodal learning. Key applications include improved human-robot communication, advanced vision and perception capabilities, and more effective reinforcement learning. While the potential is vast, challenges like computational demands, real-time processing, and ethical considerations must be addressed. This integration marks a significant advancement, offering the potential for more intelligent, adaptable, and autonomous robotic systems that can transform various industries and improve human-robot interactions.

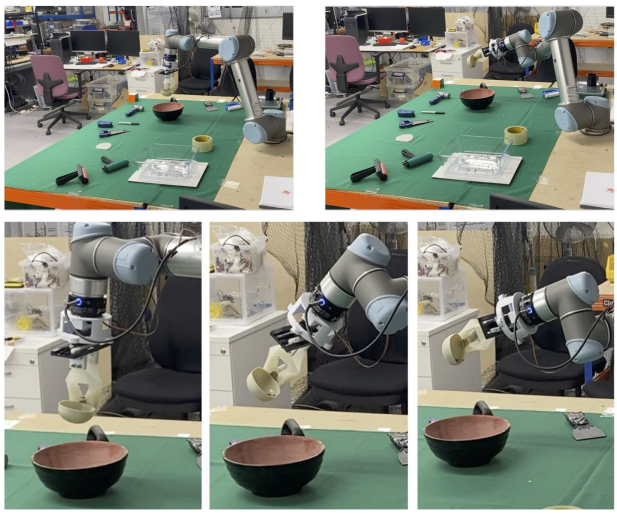
Introduction

In recent years, the field of robotics has witnessed significant advancements, driven by the integration of cutting-edge technologies from artificial intelligence (AI) and machine learning (ML). One of the most transformative developments is the emergence of foundation models—large-scale, pre-trained models that serve as a basis for a wide range of downstream tasks. These models have shown remarkable capabilities in understanding and generating human-like text, recognizing images, and even performing complex reasoning tasks. The potential of foundation models extends far beyond traditional applications, offering new opportunities in the realm of robot learning.

Foundation models, such as OpenAI's GPT (Generative Pre-trained Transformer) series and Google's BERT (Bidirectional Encoder Representations from Transformers), have revolutionized natural language processing (NLP) and computer vision. These models are trained on vast amounts of data, enabling them to learn intricate patterns and representations. Their versatility and generalization capabilities make them ideal candidates for addressing the diverse and dynamic challenges faced in robotics.

Methods

- Natural Language Interaction: Foundation models enable robots to understand and generate human language, facilitating more intuitive and effective communication with users.
- Vision and Perception: By integrating vision transformers and other advanced architectures, robots can achieve superior image and video recognition, object detection, and scene understanding.
- Reinforcement Learning: Foundation models can be combined with reinforcement learning techniques to allow robots to learn from their experiences and improve their performance over time.
- Multimodal Learning: The ability to process and integrate information from multiple modalities (e.g., text, images, audio) is a significant advantage of foundation models.



Conclusion

Despite the promising potential of foundation models in robotics, several challenges remain. These include the need for vast computational resources, the complexity of real-time processing, and the ethical considerations related to AI and robotics. Future research should focus on addressing these challenges, optimizing model architectures for efficiency, and ensuring the responsible deployment of AI-powered robots

Bio

I am Xiaoshuai Chen, a 2nd-year Ph.D. student at the Robot Intelligence Lab. My research focuses on leveraging the most advanced techniques in AI to enhance robotic capabilities. My goal is to contribute to the development of Artificial General Intelligence (AGI) in robotics, thereby advancing the field and improving the integration of intelligent robots into society.

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IMPERIAL Dyson School of Design Engineering

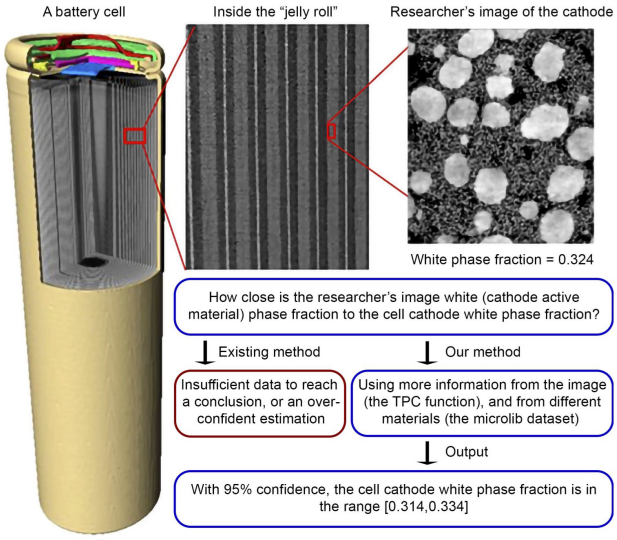
Predicting microstructural representativity from a single image

Amir Dahari (a.dahari@imperial.ac.uk),
Steve Kench, Samuel J. Cooper

> **Single image** representativity estimation gives researchers and practitioners their **first tool** for measuring the proximity of their image properties to the material properties together with an associated confidence level

Background and existing method

Precise control over phase-fractions is essential for optimizing materials for specific applications, ensuring optimal performance and reliability. However, usually only a very small image sample of the material is available, which is used to deduce the bulk material properties, such as the material phase fraction. Therefore, knowing how much the image is representative of the material is crucial.
To determine image representativity, the existing traditional method require many large image samples, which are expensive, time consuming and sometimes only feasible for simulated data to obtain. Moreover, we find that when the dataset is not large enough, the existing method suffer from biased over-confident representativity predictions.



Our representativity method

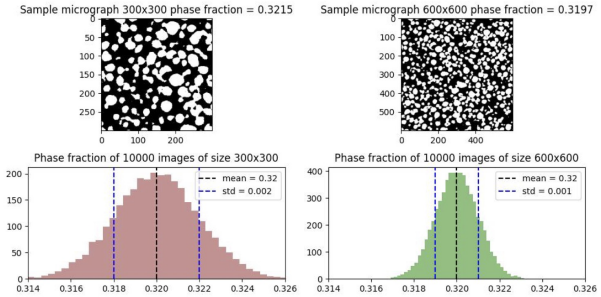
In this study, we present a novel method for predicting the phase fraction of a material (the fraction of a specific phase in a material), from a single image sample, with associated confidence levels.
Our method leverages the Two-Point Correlation function (TPC) to directly estimate the variance of phase fraction from a single image of the material, while validating the variability of our prediction using the heterogenous microlib (microstructure library) dataset. Importantly, we prove that our prediction is unbiased and is the right prediction in expectation.

User confidence level flexibility

By allowing users to input their desired confidence level, this method not only estimate the material phase fraction but also gives researchers the flexibility to choose their preferred level of confidence of the estimation.

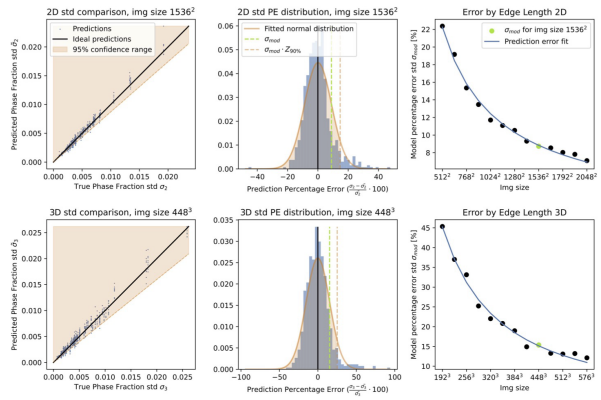
Measuring representativity

From a certain image size, the distribution of the phase fraction of a random image reaches a normal distribution centered around the phase fraction of the bulk material, which the images are sampled from.
If the standard deviation of this distribution is known, we would know, with a certain amount of confidence, the closeness of the phase fraction of the image to the phase fraction of the bulk material. So predicting how much an image is representative equals predicting the standard deviation of the distribution of phase fractions of images of the same size.



Results

The method was tested for all 77 2-phase materials in microlib, predicting the phase fraction standard deviation for the different materials and image sizes. For each image size, 10 predictions were made for each material (hence the horizontal scatters) vs. the ground truth standard deviation obtained by observing the standard deviation of thousands of images.
The prediction percentage errors around 0% (perfect prediction) form a normal distribution and is used in the final prediction as the model error.



Further validation

To further validate the method, we test the method with 27 different materials generated with PoresPy, and further 3 real open-source battery materials. Observing how the method outputs accurate predictions, which are for example having the true phase fraction within the bounds 95% of the time if 95% is the user confidence level.

Bio

Amir is a 2nd-year PhD student, supervised by Dr. Sam Cooper, whose current project is understanding materials image representativity, for adding confidence to image-based results. Prior to that Amir worked on 2D and 3D image data fusion using machine learning. Before joining Imperial College Amir studied Mathematics and Computer Science at the Hebrew University of Jerusalem.

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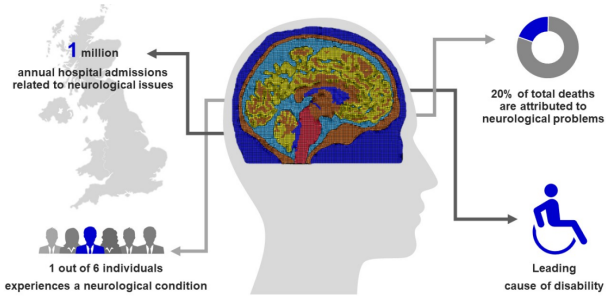
Computational Models of Brain: Toward a Better Understanding of Neurological Conditions

Vahid Darvishi (v.darvishi23@imperial.ac.uk)
Mazdak Ghajari, David Sharp

> “Virtual models have the potential to assist in **designing** more **optimized interventions** for **neurological conditions**.”

Introduction

Neurological disorders and injuries encompass a wide range of conditions, including stroke, traumatic brain injury, Alzheimer’s disease, and Normal Pressure Hydrocephalus (NPH). While some of them can result in immediate death, others lead to a gradual decline in the function of the brain. In the UK, near 140,000 deaths per year are attributed to them.



Biomechanics-based computational models serve as powerful tools for enhancing our understanding of neurological conditions. In disorders like NPH, where ventricular expansion occurs (leading to mechanical loads playing a significant role), these models can provide valuable insights into how biomechanical forces contribute to brain-related abnormal conditions.

Methods

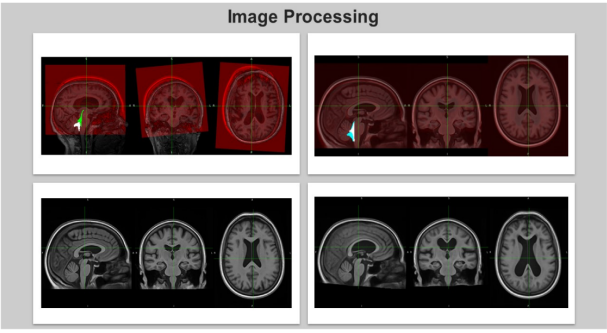
MRI Image Processing and Analysis MRI images were acquired from 16 patients with Normal Pressure Hydrocephalus (NPH) (11 male, 5 female) and 30 healthy individuals (15 male, 15 female). These images were processed and analyzed to extract the necessary information for developing a computational model.

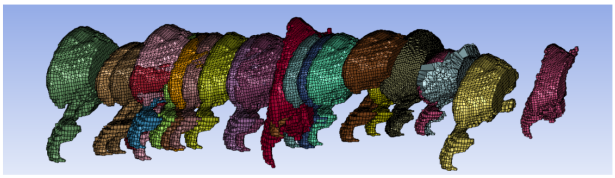
Mesh Generation At the HEAD Lab of Imperial College, image-based head models were created. These models serve as representations of the human head for further analysis.

Finite Element Analysis (FEA) Computational and numerical methods were used to simulate NPH disorder. Variables such as strain were investigated as indicators of damage.

Results

More than 30 distinct ventricular models were generated using a combination of rigid, linear, and non-linear registration methods. These techniques significantly improved the geometrical accuracy of the models (up to 80 % respect to ventricles’ volume). Subsequently, the strain distribution was calculated during ventricular expansion to identify regions at high risk of damage.



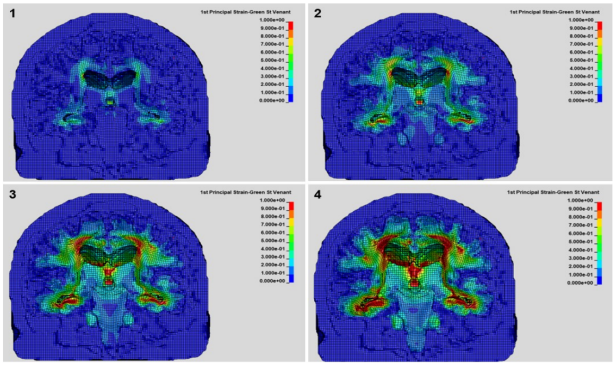


FE model of Ventricular System - Control

FE Model of Ventricular System - NPH

Discussion

The strain distribution illustrates that brain tissue near the ventricular boundary is at the highest risk of damage. Although further efforts are needed to improve geometrical accuracy to over 80%, the current outputs show the potentials of this computational model for the **determination of a threshold for brain damage.**



Conclusion

Computational models can aid medical scientists and surgeons in gaining a **deeper understanding of neurological conditions** and potentially **designing more effective surgical procedures**. These models show the potential to significantly impact the lives of people who suffer from brain-related issues, ultimately contributing to a better quality of life for everyone.

Bio

Vahid is a PhD student currently working on brain injuries and disorders, with funding from the Dyson School of Design and Engineering. Prior to joining Imperial, he collaborated with cancer institutes and hospitals on cancer detection and treatment since 2015. His passion lies in biomechanical engineering and its transformative applications for addressing complex medical challenges.

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A new one-shot forming technology for ultra-high strength steel-based fibre metal laminates

> “ Ultra-high performance FMLs with ~70% less manufacturing cost. ”

Zerong Ding, Hongyan Wang, Chunyi Gao
Nan Li* (nan.li@imperial.ac.uk)

Abstract

Current production of ultra-high strength steel (UHSS)-based fibre metal laminate (FML) relies on a multi-step process, resulting in high equipment and tooling investment, long cycle times and recyclability challenges due to adhesive usage. This work presents a novel one-shot, adhesive-free forming process to address these challenges. Forming trials were conducted. The as-formed demonstrator components show good bonding quality, as revealed by computed tomography (CT) scan, and ultra-high performance, as indicated by the UHSS hardness. The successful development of this cost-effective, energy-efficient one-shot forming technology can enable a wider application of UHSS-based FMLs, contributing to a more sustainable automotive industry.

Introduction

Fibre metal laminates (FMLs), composed of interlaced metal alloy and fibre-reinforced polymer (FRP) sheet layers, offer substantial improvements in vehicular structural efficiency due to their high strength-to-weight ratio and other advantages. Following their success in the aviation industry [1], interest in designing FML component for automobile Body-in-White (BiW) has grown considerably [2]. In particular, ultra-high strength steel (UHSS)-based FMLs, such as the B-pillars on the BMW 7-series [3], exhibit exceptional structural performance.

However, manufacturability challenges hinder a wider application of UHSS-based FMLs. For optimal formability and post-form performance, UHSS is often hot stamped at a temperature around 800 ºC, which is significantly higher than the preferred forming temperatures, as well as the decomposition temperatures of all known FRPs. Due to this fundamental forming temperature mismatch, current UHSS-based FMLs are formed in a multi-step process. In this process, the CFRP layers are adhesive-bonded onto separately hot-stamped UHSS subcomponents. This multi-step process requires multiple equipments and forming tools, and has prolonged cycle time, translating to high investment and manufacturing cost. Moreover, using adhesives poses recyclability challenges.

To address these challenges, a novel forming technology has been proposed to form UHSS-based FML components in one-shot and without requiring extra adhesives. Forming trials have been conducted, followed by examining the bonding quality and hardness of the as-formed components, demonstrating the feasibility of this newly-developed technology.

Methods

The proposed one-shot forming technology involves an innovative pre-heat treatments strategy, tailored for hot stamping UHSS and forming high-performance unidirectional (UD) FRPs for their optimal formability, as well as the post-form performance. Moreover, the bonding between the UHSS and FRP layers is achieved by the thermoplastic matrix, eliminating the usage of adhesives.

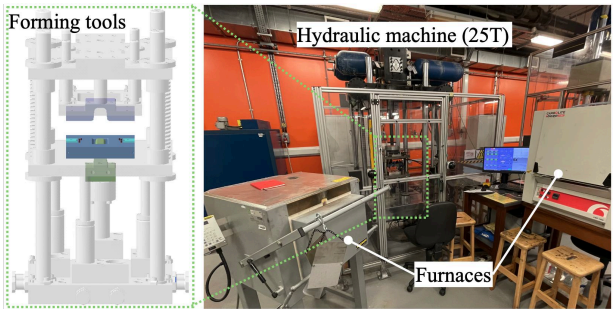

Figure 1 The experimental setup for the forming trials.

The UHSS used in this work is boron steel 22MnB5, provided by Shougang Group. The FRP is cross-plied carbon fibre-reinforced PEEK (CF/PEEK), consolidated using UD prepregs provided by Teijin, with a layup of $[\pm 45]_{4s}$. Forming trials were conducted using the experimental setup as shown in Figure 1.

Results and discussion

Figure 2a) showcases a U-bending demonstrator component formed using the newly developed one-shot forming technology. Figure 2b) shows a cross-sectional CT scan of the components, revealing a good bonding quality between the 22MnB5 and CF/PEEK layers. In addition, the 22MnB5 in the as-formed components exhibit an average hardness of 453HV10, indicating a martensite microstructure and ultimate tensile strength of approximately 1400 MPa [4]. These results demonstrate the feasibility of producing ultra-high performance UHSS-based FMLs components through this innovative one-shot process.

This one-shot forming technology offers significant advantages compared to existing multi-step manufacturing process. It can reduce the equipment and tooling investment by at least 50%, as only one set of tools is required. The manufacturing cost is estimated to be reduced by 70%, attributing to the significantly shorter cycle time of 30 seconds and anticipated energy consumption reduction. Moreover, utilising the thermoplastic matrix within the FRP to bond the two materials eliminates the need for adhesives, resulting in an enhanced recyclability.

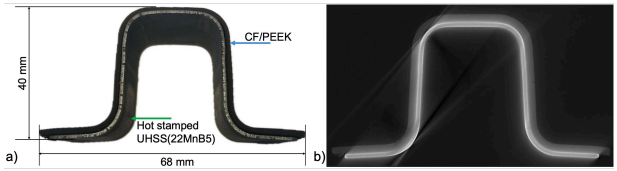

Figure 2 a) The as-formed component and b) its cross-sectional CT scan.

Conclusion

This work has developed an innovative one-shot forming technology for producing UHSS-based FML components. Through forming trials, demonstrator components have been formed with a good bonding quality between the boron steel and CF/PEEK layers. The successful formation of a martensite microstructure within the boron steel indicates that the as-formed components attain ultra-high performance.

Compared to the existing multi-step process, this one-shot forming technology offers significant advantages, including reduced equipment and tooling investment, energy consumption, and manufacturing costs. In addition, by eliminating the need for adhesive, components produced using this technology have an enhanced recyclability.

Bio

Zerong Ding’s research focuses on advanced manufacturing technologies for composite and hybrid materials. His expertise spans mechanical engineering design, fundamental material characterisation, material modelling, and process simulations.

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IMPERIAL Dyson School of Design Engineering

Experimental characterization of the shear beheviors of woven fiber reinforced thermoplastics under new thermoforming conditions

Author: Chunyi GAO
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Supervisors: Dr. Nan Li, Professor Bamber Blackman

“Enhanced Comprehension of Intra-Ply Shear Behavior in Woven Fiber-Reinforced Thermoplastic Composites”

Abstract

This study characterizes the intra-ply shear properties of carbon fiber-reinforced PA6 2/2 twill composites under varying temperatures using experimental methods. The findings contribute to understanding the thermomechanical behavior near the melting point, aiming to enhance material performance in advanced manufacturing applications.

Introduction

PA6-based 2/2 twill woven fiber-reinforced thermoplastics (WFRTPs) are crucial across various industries due to their high specific strength, stiffness, and formability [1]. However, data on their thermomechanical behavior near the melting point under bias-extension is still lacking. This study aims to systematically investigate the intra-ply shear properties of carbon fiber-reinforced PA6 2/2 twill composite under forming conditions.

Materials & Methods

Tepex® dynalite, a 2/2 twill carbon fiber-reinforced PA6 prepreg, was used to produce laminates with a layup of $[+/-45]_{10}$ and a thickness of 2 mm. The laminates were then cut into specimens of 106 x 24 mm using waterjet cutting, with a gauge length of 68 mm.

Bias-extension tests (ASTM D3518) [2] were conducted to characterize the in-plane shear response at different temperatures (190°C-220°C). A constant crosshead speed of 50 mm/min was used. For PA6-based composites, the strain rate has been shown to have a negligible impact on the material's intra-ply deformation properties [3]. The composite specimens were loaded using an Instron 5584 universal testing machine with a load cell of 10 kN (Figure 1).

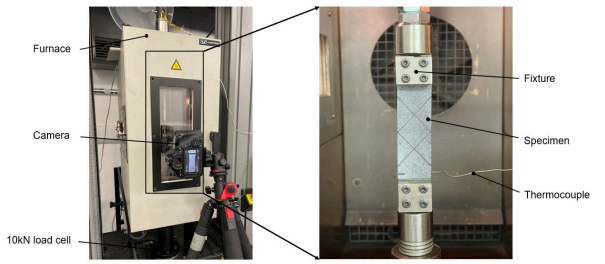

Figure 1. Experimental setup.

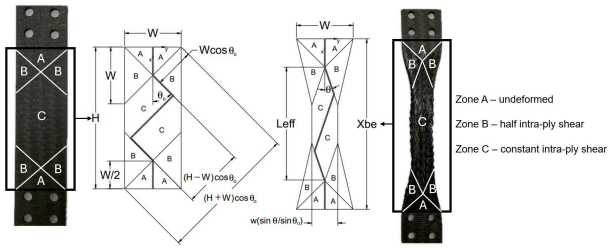

Figure 2. Schematics showing the undeformed (left) and deformed (right) shapes of the specimen in the bias-extension test.

Figure 2 illustrates the schematics of the undeformed and deformed shapes of the specimen in the bias-extension test. The shear angle in region C is assumed to be twice that in region B, while region A remains undeformed. Consequently, measurements were taken in region C of the specimen, representing a pure intra-ply shear state.

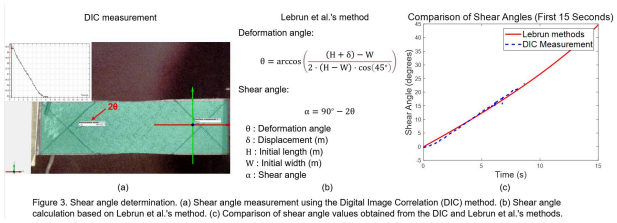

Figure 3. Shear angle determination. (a) Shear angle measurement using the Digital Image Correlation (DIC) method. (b) Shear angle calculation based on Lebrun et al.'s method. (c) Comparison of shear angle values obtained from the DIC and Lebrun et al.'s methods.

As shown in Figure 3, the shear angle was initially measured using Digital Image Correlation (DIC). However, at high shear deformations, coating detachment reduced its effectiveness. Therefore, the method by Lebrun et al. [4], which calculates the shear angle from displacement, was adopted, assuming the yarns are inextensible and no slippage occurs in the sample.

Progress to date

Experiments were conducted in two states: solid-state (190°C, 200°C, 210°C) and melt-state (220°C). Data on load and displacement were collected. Stress was calculated using the formula from the ASTM D3518 standard [2], and strain from DIC was used to calculate the engineering strain in the bias-extension test.

Results (Figure 4):
Temperature has significant effects on the intra-ply shear behavior of the tested material:

- Solid State: The material shows high stiffness and strength. Additionally, strain-softening effects are evident, suggesting a notable resistance to deformation.
- Melt State: The material exhibits minimal load and shear stress, indicating low resistance to deformation.

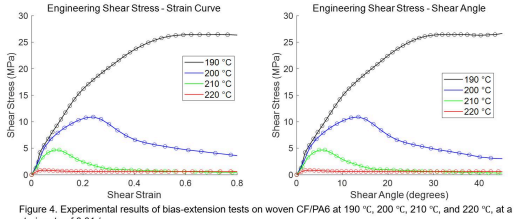

Figure 4. Experimental results of bias-extension tests on woven CF/PA6 at 190 °C, 200 °C, 210 °C, and 220 °C, at a strain rate of 0.01 /s

Future work

A constitutive model of the material will be developed based on these data to predict its thermomechanical properties under forming conditions. This model will be integrated into finite element process simulations, aiding in determining the forming temperature window and identifying the optimal thermoforming conditions for the new forming process.

Bio

Mr. Gao is a Ph.D. student at Imperial College London, specializing in composite/metal materials and advanced manufacturing. Focused on Fiber Metal Laminate (FML) structures, Mr. Gao researches forming methods and parameters to improve material performance and efficiency, aiming for sustainable and cost-effective engineering solutions.

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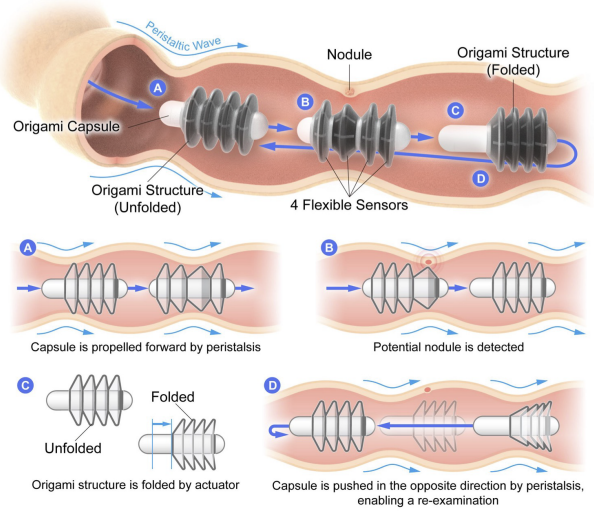
An Origami-Inspired Endoscopic Capsule with Tactile Perception for Early Tissue Anomaly Detection

Yukun Ge (yukun.ge20@imperial.ac.uk),
Rui Zong, Xiaoshuai Zhang,
Thrishantha Nanayakkara* (t.nanayakkara@imperial.ac.uk)

> " The origami capsule can detect early-stage nodules as small as 3 mm through **tactile perception** and estimate the size of the nodules. "

Abstract

We designed a camera-free origami capsule endoscope for detecting intestinal nodules. The origami structure can control the capsule to move to specific areas under **intestinal peristalsis** and then detect potential nodules through **tactile perception**.

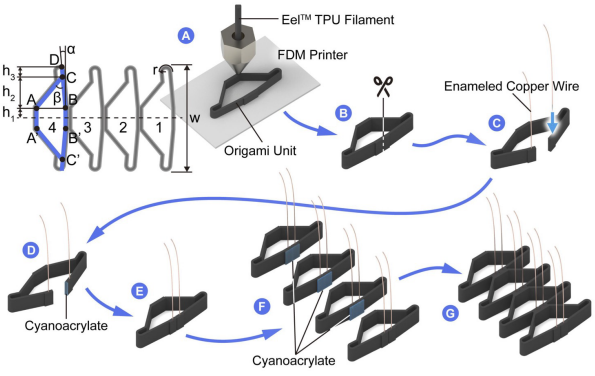


Introduction

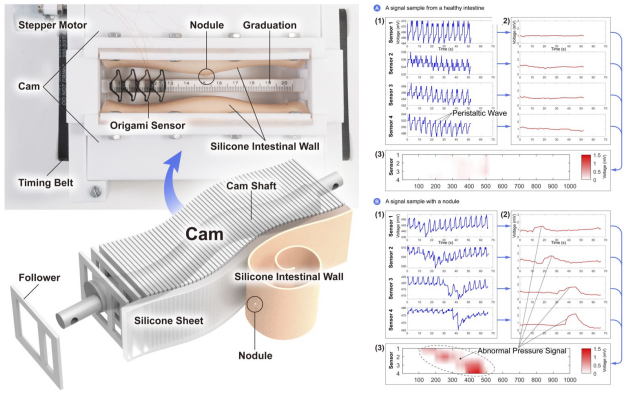
Video Capsule Endoscopy is currently one of the most effective methods for detecting intestinal diseases. However, it is challenging to detect early-stage nodules with this method because they **lack obvious color or shape features**. Since nodules are **harder** than normal tissue, tactile perception has an advantage over visual perception.

Methods

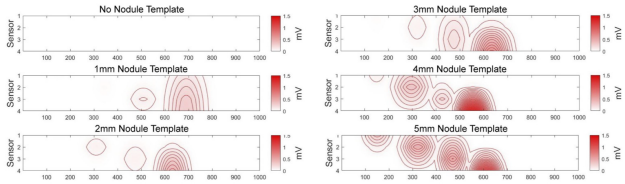
The two-dimensional origami structure (tactile sensor) is made from **flexible piezoresistive material** using an FDM printer. The two-dimensional intestinal phantom is made of silicone. Two cams are used to simulate intestinal peristalsis. Nodules are represented by small rubber balls of different diameters.



In the experiment, intestinal peristalsis propels the origami structure forward to pass through the region with a nodule. Four soft tactile sensors feed four channels of phase-shifted data that are processed using **a particle filter**.

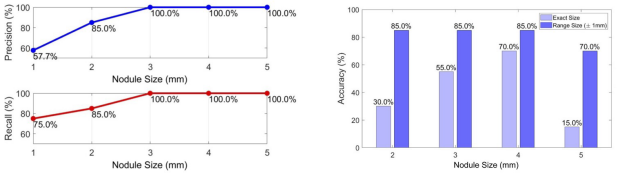


The particle filter uses an importance assignment template designed using experimental data from five known sizes of nodules.



Results

Experimental results show that the proposed capsule can **detect nodules of more than 3 mm diameter with 100% accuracy**. The results indicate that while the sensor struggles to provide precise estimates of nodule sizes, it can provide an approximate range for the nodules, with a tolerance of ±1 mm.



Discussion & Conclusion

We proposed a novel 2D origami capsule designed using flexible piezoresistive material to detect early-stage small intestinal nodules. A particle filter was designed to estimate the size of nodules in the intestine phantom. The proposed method demonstrates reliable detection for nodules of 2 mm and above, while also assessing the size range of the nodules.

Bio

Yukun Ge is a PhD student in soft robotics and is currently studying at **Morph Lab** at Dyson School of Design and Engineering. His main research areas are reconfigurable origami structures and flexible sensors. He has won the 2023 Amazon PhD Prizes for Outstanding Achievement in Robotics, the 2022 James Dyson Award, and the 2022 Award for Outstanding Achievement in the MSc IDE Prize.

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IMPERIAL Dyson School of Design Engineering

Systematic Analysis of the Stress-relaxation Behaviours for Optimising Heat Stamping of Ti-6Al-4V Panel Components

Author: Ziang Guo
Supervisor: Dr. Nan Li

> “To optimise the resulting springback of components in heat stamping process of Ti-6Al-4V”

Abstract

This research provides significant insights into the thermal behaviour and mechanical properties of Ti-6Al-4V under various conditions, through a series of deformation and stress relaxation tests. Several crucial factors affecting the material's stress-strain reaction and residual stress relief, including the impact of soaking and deformation temperature variations, initial strain level, and strain rate which are the key parameters associated with Heat Stamping [1], were analysed. Notably, a high strain rate during deformation process exhibited the fastest rate of stress relaxation, indicating its potential effectiveness in mitigating springback.

Introduction

Titanium alloys are extensively utilised in the aerospace sector because of their exceptional characteristics, including a high strength-to-weight ratio and resistance to high temperatures. Manufacturers in the aerospace sector have prioritised the use of titanium alloys for the production of lightweight and high-performance structural components, to meet the aircraft's demands of lightweight and energy efficiency by the aircraft. Ti-6Al-4V titanium alloy, a two-phase alloy, which makes up 60% of the overall titanium output and has been widely applied in the manufacturing of aircraft components [1].

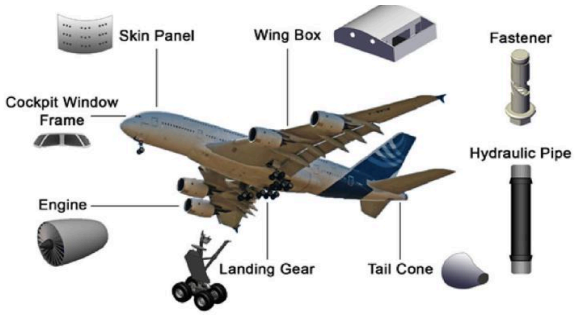


Figure 1. Example of the applications of titanium alloy used for an aircraft. [1]

Methods

As existing studies only explore stress relaxation behaviours of Ti-6Al-4V alloys at relatively low strain rate ($0.0001s^{-1}$-$0.001s^{-1}$) [2], in order to obtain results which are much closer to the practical Heat Stamping process and for experimental validation for the simulation, this research conducted comprehensive stress relaxation tests at relatively higher strain rates of $0.1s^{-1}$ – $5s^{-1}$, with initial strains of 0.5%-10%, temperatures of 850 °C-950 °C, that have not been previously investigated.
The Gleeble 3800 thermo-mechanical testing machine was utilised to conduct high temperature uniaxial tensile tests. The specimens' temperatures were measured and regulated using a pair of K-type thermocouples that were spot welded in the centre of the specimen parallel section.

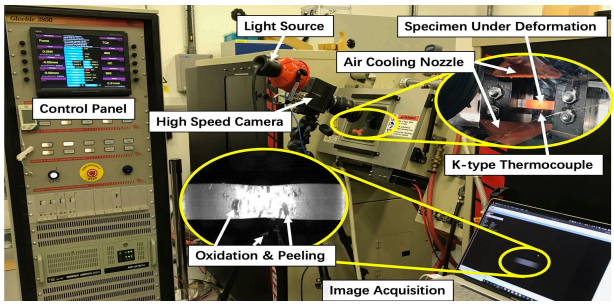
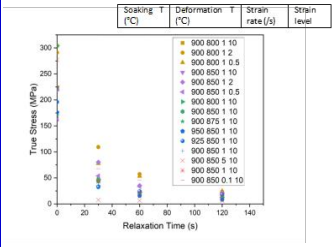


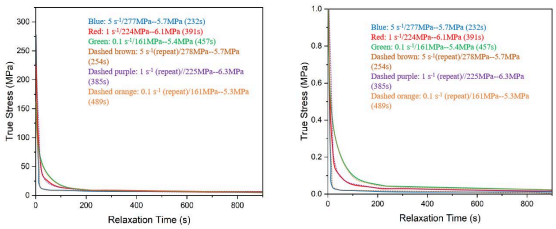
Figure 2. The setup of uniaxial tensile tests using Gleeble 3800 with a high-speed image acquisition system.

Results



According to Figure 3, the strain rate of $5\ s^{-1}$ was the most effective among all experimental conditions in increasing the rate of stress relaxation. The optimal condition for achieving the fastest relaxation was step quenching from 900 °C to 850 °C with an initial strain of 10% at a strain rate of $5\ s^{-1}$.

Figure 3. Stress values at 0s, 30s, 60s, 120s during the stress relaxation. For all testing parameters. The four numbers in each legend indicates heating temperature, deformation temperature, strain rate, and initial strain.



Further comparing the stress vs relaxation time curves at fixed temperature of 900 °C-850 °C and starting strain of 10%, it can be more clearly to observe that a higher strain rate significantly accelerates the process of relaxation of stress. This can be more clearly seen from the data after normalisation. Although the actual threshold times of reaching the complete stress-relaxation did not vary significantly, a higher strain rate took the least time it takes to reach the threshold time.

Discussion

Based on the observation of the results, it can be inferred that the strain rate has the greatest impact on the stress relaxation rate compared to the initial strain, soaking temperature, and deforming temperature. Potential mechanisms can be summarized as follow: [3] [4] [5]

- Dynamic phase transformation
- Dynamic globularisation of α lath
- Grain Size

Conclusion

Through the comprehensive analysis of stress-relaxation behaviours in this study, it was demonstrated that strain rate has a greatest impact on the rate of stress-relaxation of Ti-6Al-4V. The results also indicated that precise control over processing parameters is vital for optimising the formability and minimising the springback of Ti-6Al-4V. Future work will focus on microstructural investigations to confirm the mechanisms underlying the experimental findings of the stress-relaxation tests.

Bio

Ziang Guo, PhD in Dyson design engineering apartment, Imperial College London.
Direction: Development of a Novel Stamping process for Titanium Alloy Panel Components

Reference

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QR Code

AI-Enhanced Live-Streamed Environment for Second Language Learning

***Nan Jiang**, nj120@ic.ac.uk*
Peter Childs

> “Our study pioneers **AI-driven pronunciation feedback and dynamic roles in live-streamed lessons**, significantly enhancing learner confidence and engagement.”

Abstract

Our study explores improving live-streamed English lessons for Chinese learners through an AI-integrated platform. Focus group findings highlight concerns about pronunciation accuracy and contextual practice. We propose AI-driven pronunciation feedback and AI-led conversational practice to enhance engagement and effectiveness

Introduction

In China, a novel trend has emerged at the crossroads of education and live-streaming platforms, redefining how knowledge is shared. Platforms such as Douyin (TikTok), originally crafted for amusement, are now being employed by an expanding number of learners for educational purposes. These platforms typically operate on a large scale, hosting thousands of learners in a single live-streaming session[1]. **Our research aims to enhance live-streamed English lessons to promote better learning.**

Methods

This study uses the following research methods
Phase 1: Pre-study Focus Group. The process starts with conducting focus group discussions to gather firsthand accounts of learner experiences in live-streamed English classes.
Phase 2: Development of Educational Interventions. Using insights gained from the focus group, this phase involves designing and developing educational interventions.
Phase 3: Initial Testing of Interventions. Once the interventions are ready, they are initially tested in a controlled setting. This stage evaluates the effectiveness of the new approaches in a live-streamed environment, focusing on learner engagement and educational outcomes.
Phase 4: Full-scale Experimental Deployment. After refining the interventions based on pilot results, a full-scale experiment is conducted.

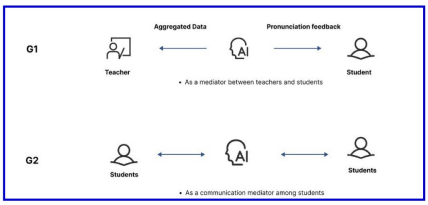
Results

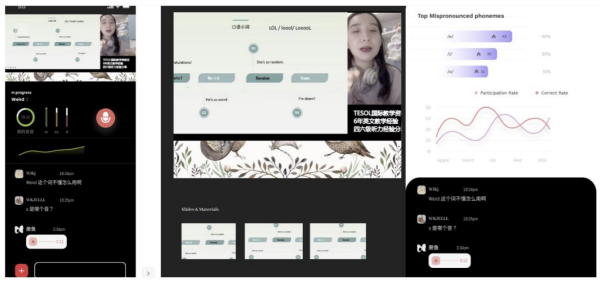
Challenges Identified:
Uncertainty about Pronunciation Accuracy: Many participants expressed frustration over not knowing whether they were pronouncing words correctly during live-streamed sessions.
Limited PracticeOpportunities: Participants also highlighted a lack of sufficient opportunities to practice spoken English in real-life contexts.

Proposed Solutions:

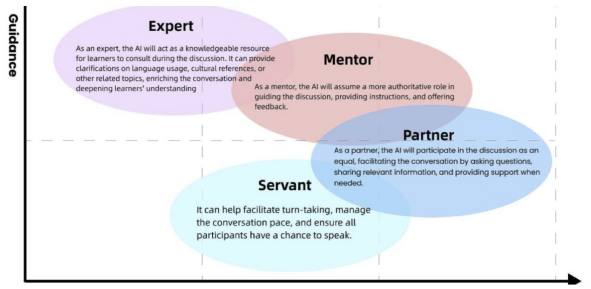
G1 Real-Time Pronunciation feedback;

G2 AI-led conversational practice in BreakOut Rooms

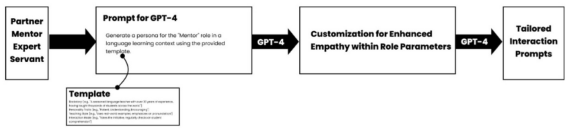




The pronunciation feedback module is an integral part of the platform, aiming to address learners' uncertainty about their pronunciation accuracy. The system should be capable of recognizing and evaluating individual phonemes and prosodic features such as stress, intonation, and rhythm[2].



We identify two primary dimensions to better understand the roles of AI in conversational practice: Closeness and Guidance.These dimensions borrow insights from the social actor theory[3].



In the development of our experimental environment, we chose to create a ChatGPT Telegram bot, specifically designed to facilitate interactions within Telegram groups.

User Study

In our study, we assessed a pronunciation feedback module and various AI roles in live-streamed English lessons. Immediate, multimodal feedback was effective, with 85% showing pronunciation improvement and 70% gaining confidence. The AI Mentor and Partner roles were preferred, boosting engagement.

Bio

Nan is a third-year PhD student at the Dyson School of Design Engineering, holding a Master's degree in Information & Design from Tsinghua University. Her research interests include interactive media design, artificial intelligence in education, and creativity in design. She also promotes innovative K-12 learning methods and family education strategies through online media and social platforms, helping students and families from lower socio-economic backgrounds in China to access higher quality educational resources.

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SELECTIVE GENE EXPRESSION IN HYDROGEL SUSPENDED *ESCHERICHIA COLI* THROUGH OPTOGENETICS WITH SPATIOTEMPORALLY CONTROLLED LIGHT FOR THE PURPOSES OF ADDITIVE MANUFACTURING

"Bacteria **are** the 3D printer"

Borut Lampret[1], Andreas Hadjimitsis[1], Guy-Bart Stan[1], Connor Myant[1]
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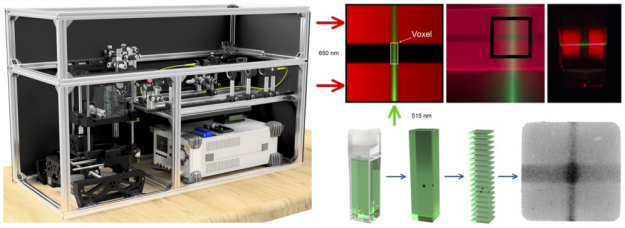
Abstract

Natural and engineered biology offer diverse biological materials with varied properties, with most not suitable for conventional additive manufacturing (AM). Advances in gene editing allow for programable cell factories to be exploited in artificial creation of complex structures with biological materials through AM. A novel method using *e.coli* in hydrogel and optogenetics allows for selective bioloical material deposition in three dimentions.

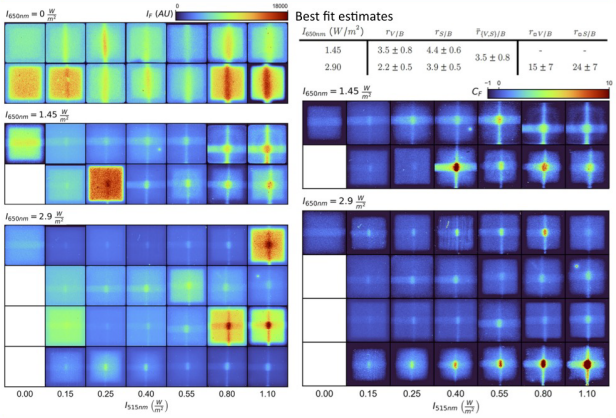
Methods

A custom-built 3D printer was used to illuminate a cuvette filled with *e.coli* populated agarose hydrogel. Green light activates the cells and red light deactivates them. Localized gene expression in 3D can be achieved through the overlap of red and green light.
Gene expression was visualized via fluorescent imaging of the produced tdFast2 protein bound to fluorogenic ligand TFLime ("fluorescent dye").

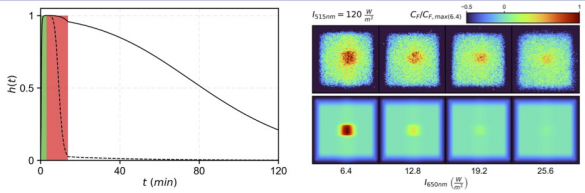


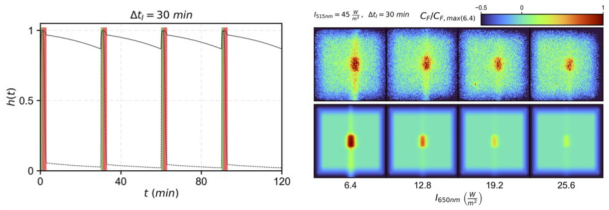
Results

Steady-State Illumination
Ratio between maximum and background gene expression rate (a/b)

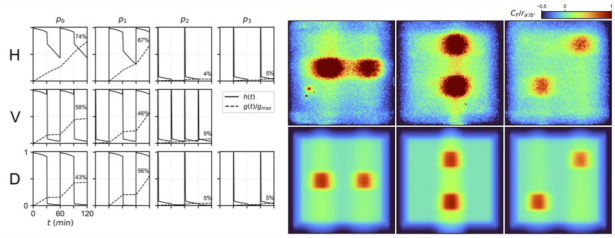


Discontinuous Illumination
The ability to induce gene expression at different points and times is a necessity when 3D printing objects using individual voxels.
Persistence of the active state can be favourably exploited for gene expression in the absence of direct illumination.

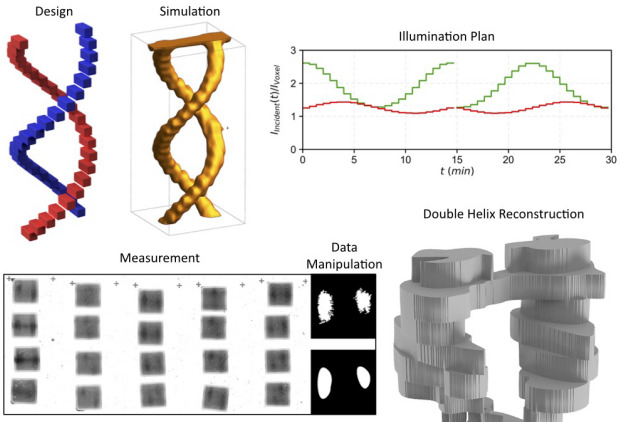




Gene Expression in Multiple Voxels
Producing a 3D object requires gene expression in multiple voxels per plane. A verified valid illumination strategy is individual illumination of voxels regardless of spatial distribution of other voxels in the plane.



Gene Expression in 3D Geometry
Knowledge from previous experiments and measurements was used to generate the illumination procedure that would result in gene expression in the shape of a double helix.
The double helix consists of two sets of 22 voxels. Each helix was allocated 15 min and illumination of both was repeated four times.



Conclusion

Selective gene expression can be achieved in 3D with proper spatiotemporal light distribution. Limitations of the method are mainly dictated by light absorption and scattering, signal to noise ratio, and by the lifecycle of cells.

Performace can be increased by improving the dynamic range of gene expression though enviromental and genetic factors. Additionally, different combinations of bacteria, light response systems, and produced proteins could yield better results.

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Fairness for Unseen Data: A Novel Distributional Approach to Data Repair

Abigail Langbridge (al4518@ic.ac.uk),
Anthony Quinn & Robert Shorten

> “This approach allows us to repair **unseen data**, which is critical for **data-streaming applications**.”

Abstract

With the advent of **the AI Act**, there is now an urgent need for algorithms that **repair unfairness in data** for machine learning applications. In this work, we **define fairness** in terms of **conditional independence** between **protected attributes** (S) and features (X), given **unprotected attributes** (U) and design a **scalable data-repair algorithm** to achieve this. We address data streaming applications, where **torrents of unfair data** need to be repaired using an operation designed on a **small training dataset**.

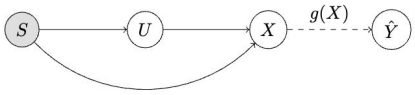
Introduction

The notion of fairness is important across many applications, where **some protected attribute should not impact some decision outcome**. With **decisions increasingly made by automated systems** across a broad range of industries, from creditworthiness to automotive hazard detection, **ensuring the fairness of these systems is crucial**. These automated systems generally learn their behaviour from **historic human decisions** or from **rules designed by domain experts**. However, this can lead to systems **encoding historical biases**, or introducing bias through the learning process [1, 2, 3].

Many **existing methods** for data repair [1, 4, 5], however, rely on the notion that **data are available in a finite batch** such that a repair operation can be designed and conducted once, and the problem of fairness is solved. Instead, we propose a **repair operation inspired by approaches in domain adaptation** [6] which can be learned on a small training set, and then applied to **repair unseen data**.

Methods

We model the set of random variables Z = {X, U, S}, where S is a binary **protected characteristic** (like race, sex or sexual orientation), U is some **unprotected, but influential, characteristic** (like education level or whether an individual has dependents) and X is a **vector of features** that we want to use for some **downstream predictive task** g(X).



We distinguish between **AI unfairness**, which we define as cases where **X are not conditionally independent of S** (and therefore the protected attribute S influences X even conditional on U), and **societal unfairness**, which occurs where **U and S are not independent** (such as when education is more accessible to certain groups, for example).

We consider two datasets: a **research dataset**, which we consider as the ‘training set’ for designing our repair, and an **unseen dataset** on which we evaluate our method’s performance.

A successful repair makes the data **S-invariant** in some way which is **minimally damaging** (such that predictive information in the data is substantially retained). To achieve this, we utilise the **Wasserstein barycentre** ν [1,4] between our S=0 and S=1 data. A **key difference from other approaches** here is that we consider the **underlying distributions,** μ_0 and μ_1, rather than the data themselves.

The Wasserstein barycentres fall on the geodesic between marginals μ_0 and μ_1, for $t \in [0, 1]$:

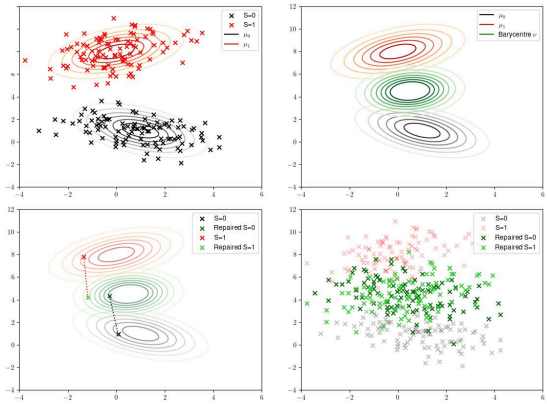
$$\min_{\nu_t} \{(1-t)\mathcal{W}(\mu_0, \nu_t) + t\mathcal{W}(\mu_1, \nu_t)\} \quad (2)$$

The $t = 0.5$ barycentre, ν, is—by construction—s-invariant, and lies at the centre of the geodesic such that

$$\mathcal{W}(\mu_0, \nu) = \mathcal{W}(\mu_1, \nu).$$

Results

We demonstrate the operation of our method on two-dimensional simulated data X = [x_0, x_1]. First, the **underlying s-conditional distributions are approximated** from the research data (top left), which can then be used to **calculate the barycentre** (top right). **Previously unseen points** can then be repaired by **relating them to the barycentric distribution** (bottom left). Any unseen points with the **same underlying distribution** as the research data can be repaired in this way (bottom right).



Discussion

As shown in the Figures above, this **distributional approach** is able to achieve S-invariance, such that the S-classes of the repaired points are **indistinguishable**. Crucially, we are also able to **repair unseen data** since we can relate these points to our distributional representations. Another key benefit of this method is its **scalability**, since the data is represented as a Gaussian mixture model (GMM) on a **compact support set**.

We have benchmarked this method on a number of **simulated and real data**, including the Adult Income dataset where we demonstrate that this method can **effectively remove the dependence on an individual’s sex**, conditional on their education level, **when predicting their income**.

Conclusion

We have presented a **novel method for data repair** on distributions, where unseen data can be repaired. This is a key step towards **generalisability of fairness tools** for machine learning applications.

Bio

Abigail Langbridge is a second-year PhD student in the I3 Lab at Imperial College London, working on developing novel approaches to algorithmic fairness in partnership with IBM Research Ireland. She received her master’s degree in Design Engineering from Imperial College London in 2022.

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Rapid prediction of crashworthiness performance of vehicle panel components

Haoran Li, Nan Li

> "The model rapidly and accurately predicts both **manufacturability** and **crashworthiness** performance."

Abstract

This poster presents a convolutional neural network (CNN)-based surrogate model for predictions of crashworthiness performance of vehicle components considering manufacturability. The model was evaluated with FE results of hot stamped B-pillars. The components were analysed with side crash tests to study the deformation under impact. The model can achieve rapid prediction with high accuracy.

Introduction

Hot stamped ultra-high strength steels (UHSS) are widely used in vehicle safety-critical components like the B-pillar. To ensure the performance of the designed components, crashworthiness analysis assesses how efficiently the components can absorb energy during vehicle collisions. Moreover, manufacturing constraints such as post-stamped thinning must also be considered. Finite Element (FE) simulations can be time consuming for iterative design optimisation tasks. This poster presents a CNN-based surrogate model for predicting crashworthiness performance of vehicle components considering manufacturability.

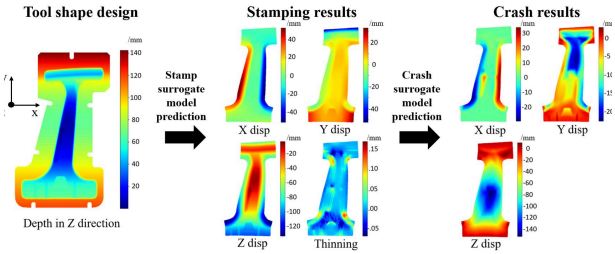
Methods - Overall framework

The proposed integrated framework consists of two CNN-based surrogate models operating on images, a hot stamping surrogate model (stamp model) and a crash simulation surrogate model (crash model).

Stamp model:
- Input images: 2D projections of the tool shape
- Output images: Blank post-stamp displacement fields, thinning fields

Crash model:
- Input images: Blank post-stamp displacement fields, thinning fields
- Output images: Blank post-crash displacement fields

The prediction output from the stamp model are fed into the crash model as input images, forming a complete prediction chain.



Methods - Model architecture

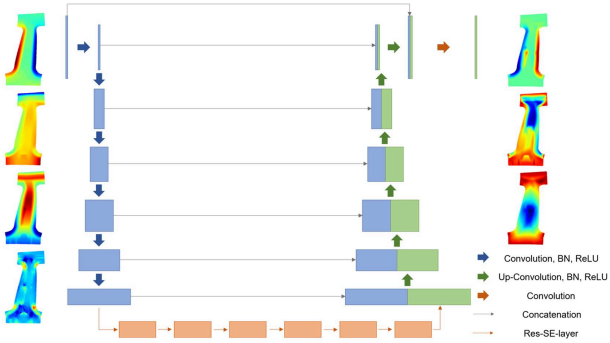
This section focuses on the architecture of the crash model, which consists of a Res-SE-U-Net architecture.

Downsampling layers:
- 6 convolutional (conv) layers each followed by a batch normalisation (BN) layer and rectified linear unit (ReLU) activation function

Processing layers:
- 6 Res-SE blocks each consisting of 2 conv layers with BN and ReLU followed by a squeeze-excitation (SE) block with residual connections

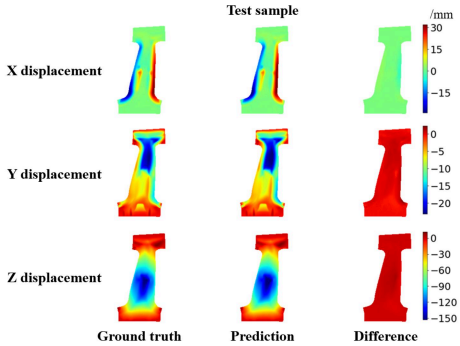
Upsampling layers:
- 6 up-conv layers with BN and ReLU, followed by an output layer

Similar architecture was used for the stamp model, more details can be found in [2, 3].



Results

The models were trained with a train, validation, and test set of 400, 50, and 20 samples in total. The trained models can accurately predict the post-stamp component shape and thickness, and the deformations after crash test, when providing the designed tool shape. The maximum intrusion during crash test can be predicted with error below 1.89%.



Conclusion

The integrated CNN-based surrogate model connects manufacturability and crashworthiness considerations for vehicle component dynamics prediction. The trained model is able to accurately predict the impact behaviours of previously unseen hot-stamped B-pillar components under side crash test. In addition to the displacement fields, the model shows potential in predicting any field data such as stress and strain fields. This integrated framework can be used in multi-objective optimisation tasks for structural design of any vehicle components.

Bio

Haoran Li is a PhD student who is working on deep-learning based design optimisation frameworks for vehicle panel components. He studied Mechanical Engineering for both Master's and Bachelor's degrees at Imperial College London and UCL respectively.

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Acoustic measurement contributes to the longevity of battery lifespan by precisely deciphering lithium metal degradation

Author: Genlin Liu g.liu23@imperial.ac.uk
Supervisor: Billy Wu

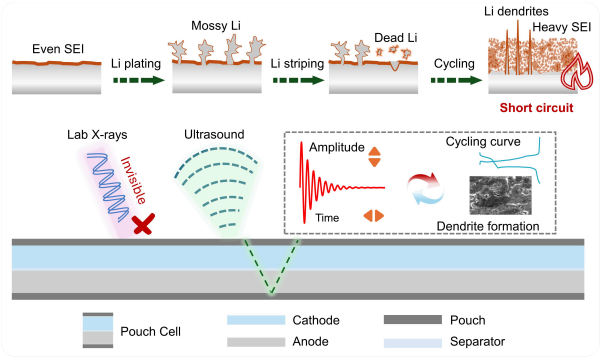
> “ Operando detection of lithium metal by ultrasound fills the knowledge gap of lithium-metal battery failure. ”

Abstract

Lithium-metal batteries (LMBs) are one of the most promising energy storage systems. However, the growth of lithium dendrites on the lithium-metal side significantly jeopardizes battery lifespan. Traditional operando morphological detection is limited by lab-based X-rays. In this project, ultrasound is applied to diagnose dendrite growth in practical pouch cells. We aim to decipher the practical growth mechanisms in pouch cells and decouple the related factors. Ultimately, we will propose lithium anode protection strategies based on our findings to extend the lifetime of LMBs, promoting their commercialization and enhancing sustainability through more efficient energy storage.

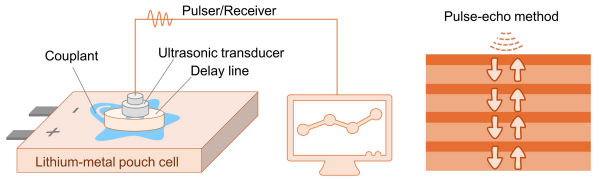
Background

Lithium metal provides LMBs with superb capacity, yet its highly active nature causes uneven deposition and dendrite formation, leading to deteriorating stability [1]. Nevertheless, operando detection of morphological change toward lithium anode is rarely achieved because of the limitation of X-rays [2]. Therefore, ultrasound serves as an economical and time-saving technique for operando detection of the lithium anode.



Method

The setting is based on the use of transducer. Specifically, a PC controls and collects data from a transducer. Under the transducer, a delay line is applied to separate the signal between batteries inside and surface in time scale. Pulse-echo method is used, with one transducer serves both as pulser and receiver [3, 4].



The ultrasound speed in batteries varies with the bulk Young's modulus and density.

$$c = \sqrt{\frac{E}{\rho}} \quad (1)$$

Acoustic resistance z between surfaces decides reflection ratio R.

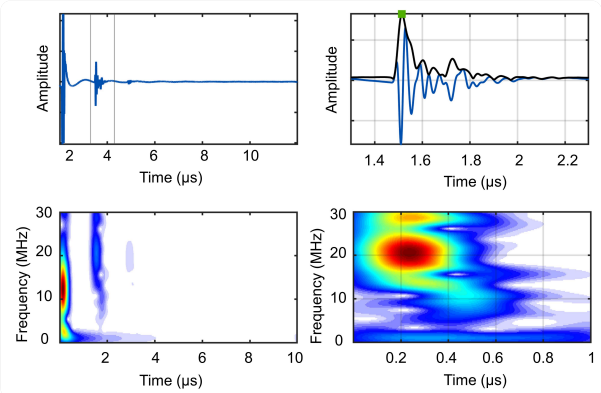
$$z = \rho \cdot c \quad (2)$$

$$R = \frac{z_2 - z_1}{z_2 + z_1} \quad (3)$$

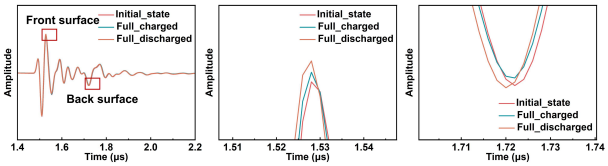
When a battery is cycling, its physical properties change regularly, resulting in regular ultrasonic patterns. Abnormal phenomena (such as dendrite formation, gas production, etc.) show distinct patterns due to different acoustic speeds and reflection ratios.

Results

An ultrasound pulse was introduced into a single-layer pouch cell. Due to the delay line, an obvious reflection wave can be observed around 1.6 μs. The frequency of the input signal is 10 MHz, yet the received signal shows a maximum frequency of 20 MHz because of the overlap of the signals from the front and back surfaces of the battery. The highest peak around 1.5 μs represents the front surface, while the peak around 1.7 μs indicates the back surface.



Signals at different states of charge (SOC) (0%, 20%, 100%) are compared. The time of flight (TOF) of the front surface remains constant across different SOCs due to the unchanged thickness of the delay line. According to the enlarged figure, the TOF of the fully charged sample is larger than that of the fully discharged one, which aligns with the fact that the lithium anode thickness increases during charging and decreases during discharging. However, the TOF at open-circuit voltage (OCV) is abnormal, and there are not enough data points to accurately locate the peaks.



Perspective

1. Signal from the back surface of a battery was observed.
2. The sampling settings and other parameters need to be optimized.
3. Further analysis is required to examine the relationship between ultrasound features and SOC.
4. Higher current densities can be further applied to initiate lithium dendrites.
5. Other in-situ techniques can be applied, such as X-rays CT, neutron diffraction.

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Advancing Sensing Resolution of Impedance Gesture Recognition Devices

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> “Electrical impedance gesture recognition utilising ***motion*** and ***force*** information, with optimised frequency and drive pattern.”

The bigger picture

Muscle activity information from the hand has great potentials in domains such as human robot collaboration. **However, current hand gesture recognition solutions such as cameras and strain sensors primarily focus on correlating hand gestures with motion information and force information is seldom addressed.** Here we proposed a electrical impedance (EI) based hand gesture recognition wearable that can recognize hand gesture utilising both motion and force information. With the motion and force information, the device can be integrated in applications such as remote robotic arm control, tangible virtual reality and so on.

Methods

When flexing fingers, muscle contractions lead to inner impedance distribution changes and outer hand boundary shape changes. These changes can be reflected in the changes of impedance signal. This study aims to identify the parameters (frequency and drive pattern) for impedance base hand gesture recognition.

- **Frequency:** The impedance response is strongly correlated with the frequency of injecting current. We optimized the frequency used in electrical impedance measurement by selecting one that has highest signal to noise ratio and highest mean impedance change between two gestures.
- **Drive pattern:** Choosing different electrodes pairs to inject current and measure voltage reveals different aspects of hand gesture impedance features. We proposed a new opposite inject-measurement drive pattern that demonstrates higher separability criterion than the conventional adjacent drive pattern.
- **Machine learning:** We customized a 1-dimensional convolutional neural network (1D-CNN) model to perform hand gesture recognition.

Results and discussion

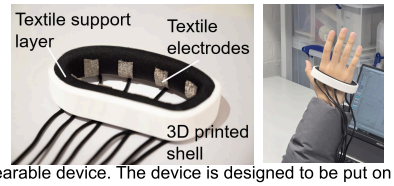

Fig. 1. Wearable device. The device is designed to be put on hand and is composed of 8 dry textile electrodes.

Gesture dataset collection

We collected gesture samples from 6 participants using both medical electrodes and our device. The dataset consists of 49,920 samples.

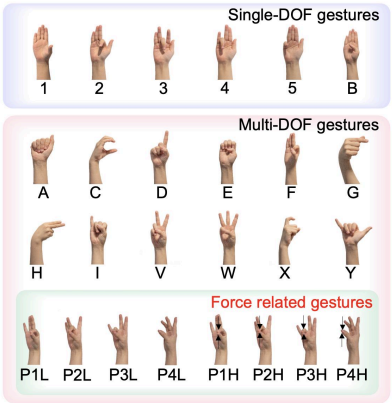

Fig. 2. Gesture Dataset. Most previous work on gesture recognition focus on recognize motion related gestures [1][2][3]. Here we included gestures with different force level (pinch with low force (e.g. P1L) and high force (e.g. P1H)).

Hand gesture impedance dataset analysis

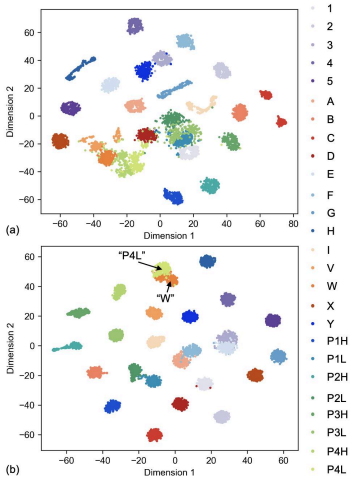

Fig. 3. t-Distributed Stochastic Neighbor Embedding (t-SNE) results of the hand gesture dataset with (a) adjacent drive pattern and (b) proposed opposite drive pattern. The proposed opposite drive pattern demonstrates better clustering results. However, gesture groups such as “P4L” and “W” are still similar so further classification with 1D-CNN is performed.

Machine learning

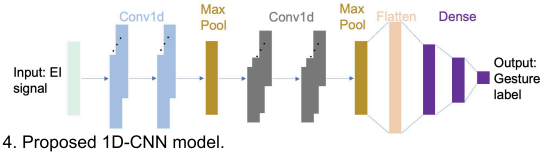

Fig. 4. Proposed 1D-CNN model.

Gesture classification results and comparison with other works

Mechanism	Method	Gestures	Force Related	1 DOF Gestures	Accuracy	Ref
Piezo-resistive	Amplitude	26	No	Yes	NA	[3]
PPG	SVM	12	Yes	No	77.5%	[4]
EIT	SVM	3	No	No	95%	[1]
EIT	CNN	10	No	No	95.94%	[2]
EI	CNN	26	Yes	Yes	>98%	This work

With optimized frequency and drive pattern, our device demonstrates high gesture recognition accuracy (>98%) in the dataset consists of 49,920 samples.

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Bio

Zhiyuan Lou is a second year Ph.D. student sponsored by Chinese Government Scholarship.