Systems Design Engineering Graduate Symposium

Spring 2022

Hello and Welcome!

The Department of Systems Design Engineering is delighted to announce that we will be holding our annual Graduate Symposium again in 2022! The symposium will take place on Thursday, June 23, 2022 in Faculty Hall (E7 7th floor room 7363).

Schedule

The Symposium has been broken into four sessions, with two industry guests speaking during the lunch hour about their experiences taking their degree into an industry position.

1 Image & Signal Analysis

Time: 9:30 AM - 11:30 AM
Chair: Alex Wong
Speakers: Matthew Bradley, Yuan Fang, Gauri Sharma, Amir Nazemi, Natarajan Vaidyanathan, and Ali Asghar.

2 Biomedical Engineering

Time: 11:15 AM - 12:30 PM
Chair: Nima Maftoon
Speakers: Elahe Cheraghi, Alkris Warren, Ali Nasr, Hajar Abedifirouzjaei, and Nargess Heydari Beni

3 Human Factors

Time: 1:30 PM - 3:00 PM
Chair: Tais Sigaeva
Speakers: Marco A Moran Ledesma, Wendy Ding, Ebru Emir, Hyun Su Seong, Fatemeh Karimi, and Siti Nandiroh

4 Systems Modeling and Simulations

Time: 3:20 PM - 4:20 PM
Chair: Shi Cao
Speakers: Muna Alateibi, Mariam Lahlou, Keaton Inkol, and Arash Ebrahimian

Session 1: Image and Signal Analysis

Towards Viewpoint-Free Visual Place Recognition

Matthew Bradley

Visual Place Recognition is a class of computer vision techniques that detect when a camera returns to a previously visited location. It is critical to a variety of other navigation tasks, for example to Simultaneous Localization and Mapping through loop closures that reduce accumulated error. The basic principle is to describe the current surroundings of the camera and compare this against past descriptions at various points in time. VPR is most commonly treated as an image-to-image description-matching problem.

In real-world settings, changes in illumination throughout the day affect the appearance of a scene, which adversely impacts methods reliant on small image regions. CNN-driven methods which holistically consider an image can fare better, but this creates a compromise with viewpoint sensitivity. Changes in camera position between revisits will alter feature locations in an image, invalidating descriptions which use 2D feature location.

Our key observation is that there is a lack of appreciation in existing methods that these features exist in a 3D world, and that describing this would allow for recognition from theoretically any viewpoint. This 3D information is available to many navigational tasks through a sequence of images reflecting the camera's trajectory. Only some VPR methods make use of image sequences however, and fewer still incorporate 3D feature information into descriptions. Methods de-emphasizing individual image matching by encoding an image sequence technically encode 3D information, but do so at the image level and not the feature level. This means that the spatial arrangement of viewpoints (the path followed) must be repeated, rather than merely the features themselves.

In initial publication, we sought to produce a Neural Radiance Fields representation so that images from past visits could be used to produce new images better matching the viewpoint of new visits. This would allow viewpoint variation to be ignored in 2D descriptors. We found that while rudimentary views could be produced from the images of a linear traversal, the models available at the time were slow to train on even a few images.

This was followed by investigation of simpler view synthesis based on depth estimation and the more direct reprojection of existing images. Of particular interest was the impact of occluded and out-of-view regions that become areas of missing information. We found that these can noticeably impact the VPR performance of some common image description techniques.

Instead of attempting to correct for viewpoint change, for use of existing 2D descriptors, the alternate approach is to describe 3D feature positions themselves. This area is underexplored despite promising past work and the related field of LIDAR place recognition. Existing structure from motion incorporated into the SLAM systems which benefit from VPR can provide this local 3D information. This is to be combined with the powerful deep features that visual sensing can provide, resulting in a combined representation that is both robust to the appearance of a scene and potentially viewpoint-free.

Deep Image Prior for Disentangling Mixed Pixels

Yuan Fang

A mixed pixel in remotely sensed (RS) images contains multiple types of objects/targets (e.g., tree, grass and building) rather than just one type. Mixed pixels exist commonly in spaceborne hyper-/multi-spectral images due to sensor design limitations, causing the signature ambiguity problem and greatly impeding high-resolution remote sensing mapping. Despite its importance, disentangling mixed pixels into the underlying constituting components is a challenging ill-posed inverse problem, which requires efficient modeling of spatial prior information and other different prior knowledge concerning the mixed pixel generation process.

This thesis aims to improve mixed pixel disentangling in three key applications, i.e., spectral unmixing (SU), subpixel mapping (SPM) and soil moisture product downscaling (SMD) by integrating the recent deep image prior (DIP) approach and other prior information into a Bayesian framework to allow comprehensive usage of different prior knowledge for enhanced data inversion. This thesis has the following main contributions. (1) To improve the decomposition of mixed pixels into pure material spectra (i.e., endmembers) and their constituting fractions (i.e., abundances) in SU, a designed deep fully convolutional neural network (DCNN) and a new spectral mixture model (SMM) with heterogeneous noise are integrated into a Bayesian framework that is efficiently solved by a new iterative optimization algorithm. (2) To improve the decomposition of mixed pixels into class labels of subpixels in SPM, a dedicated DCNN architecture and a new discrete spectral mixture model are integrated into the Bayesian framework to allow the use of both spatial prior and the forward model. (3) To improve the decomposition of mixed pixels into soil moisture concentrations of subpixels in SMD, a new DIP architecture and a forward degradation model are integrated into the Bayesian framework that is solved by the stochastic gradient descent approach. The above new Bayesian approaches not only improve the state-of-the-arts in their respective applications (i.e., SU, SPM and SMD), but also provide new solutions to other ill-posed inverse problems where simultaneous modeling of the spatial prior and other prior knowledge is needed.

Automatic Assembly Machine Part Spatiotemporal Segmentation Using External Observers

Gauri Sharma

An automated assembly system is an integral part of various manufacturing industries as it reduces production cycle-time resulting in lower costs and a higher rate of production. The modular system design integrates main assembly workstations and parts-feeding machines to build a fully assembled product or sub-assembly of a larger product. Machine operation failure within the subsystems and errors in parts loading lead to slower production and gradual accumulation of parts. Repeated human intervention is required to manually clear jams at varying locations of the subsystems. To ensure increased operator safety and reduction in cycle-time, visual surveillance plays a critical role in providing real-time alerts of spatiotemporal parts irregularities.

In this study, surveillance videos are obtained using external observers to conduct spatiotemporal segmentation within the ATS Automation: Symphoni digital assembly, SuperTrak conveyance, and vibratory bowl parts-feeder machine. As the datasets have different anomaly specifications and visual characteristics, we follow a bottom-up architecture for motion-based and appearance- based segmentation using computer vision techniques and deep-learning models.

To perform motion-based segmentation, we evaluate deep learning-based and classical techniques to compute optical flow for real-time moving-object detection. As local and global methods assume brightness constancy and flow smoothness, results showed fewer detections in presence of illumination variance and occlusion. Therefore, we utilize RAFT for optical flow and apply its iteratively updated flow field to create a pixel-based object tracker. The tracker differentiates previous and current moving parts in different colored segments and simultaneously visualizes the flow field to illustrate movement direction and magnitude. We compare the segmentation performance of the optical flow-based tracker with a space-time graph neural network (ST-GNN), and it shows increased accuracy in boundary mask IoU alignment than the pixel-based tracker. As the ST-GNN addresses the limited dataset challenge in our application by learning visual correspondence as a contrastive random walk in palindrome sequences, we proceed with ST-GNN to perform motion-based segmentation.

As ST-GNN requires a first-frame annotation mask for initialization, we explore appearance-based segmentation methods to enable automatic ST-GNN initialization. We evaluate pixel-based, interactive-based, and supervised segmentation techniques. Results illustrate that K-means applied with watershed segmentation and gaussian blur reduces superpixel oversegmentation and generates segmentation aligned with parts boundary. We find that GLCM segmentation performs better in segmenting dense parts regions than MeanShift, Graph-based and Edge-based segmentation. Although manual annotation decreases efficiency, we see that the GrabCut annotation tool generates segmentation masks with increased accuracy than the pre-trained interactive tool. To ensure segmentation of all parts within the bowl-feeder, we train Detectron2 with data augmentation. We see that supervised segmentation outperforms pixel-based and interactive-based segmentation.

To address illumination variance within datasets, we apply color-based segmentation by image datasets conversion to HSV color space. We utilize the images, converted within the value channel of HSV representation, for background subtraction techniques to detect moving bowl-feeder parts in real-time. To resolve image registration errors due to lower image resolution, we create Flex- Sim synthetic dataset with various anomaly instances consisting of multiple camera viewpoints. We apply preprocessing methods and affine-based transformation with RANSAC for robust image registration. We compare color and texture-based handcrafted features of registered images to ensure complete image alignment. We evaluate the PatchCore Anomaly detection method, pre- trained on MVTec industrial dataset, to the Flex-Sim dataset. We find that generated segmentation maps detect various anomaly instances within the Flex-Sim dataset.

An online continual learning model for video object segmentation

Amir Nazemi

Recent state-of-the-art One-shot Video Object Segmentation (O-VOS) methods have shown significant improvements in target object segmentation accuracy when information from preceding frames is used in undertaking segmentation on the current frame. In particular, such a history-based approach can help a model handle appearance changes or occlusions more effectively. Ideally, to reach maximum performance, all or most of the preceding frames (or their extracted information) would be stored in memory, however this is infeasible; in practice the available memory is necessarily limited in real-world applications. Inspired by the success of continual learning methods in preserving previously-learned knowledge given limited memory, a new regularization technique is proposed to reduce the memory requirement of the O-VOS method while maintaining the modeling accuracy.

Here, it is hypothesized that taking advantage of continual learning techniques can improve the effectiveness of the online VOS methods in modeling the target appearance. To this end, we proposed a new loss function which can be integrated with any online video object segmentation algorithms to preserve the modeling accuracy with limited memory requirements.

The reported results showed that the proposed regularized loss function can improve the modeling accuracy of the baseline VOS in different scenarios. Moreover, the proposed model is more accurate on DAVIS16, DAVIS17 and YouTube-VOS datasets and more robust against the forgetting of preceding learning on a limited-size memory. Additionally, a new forgetting test scenario justified the superiority of the proposed method on the DAVIS16 and DAVIS17 datasets and illustrated that the online VOS algorithms are suffering from forgetting the target appearance in preceding frames.

The robustness of the model against different number of update epochs also is improved when the proposed regularized loss function is used. In addition to the proposed loss function, a new memory selection thechnique is proposed based on the LASSO method. The method provides a faster solution with comparable results on DAVIS16, DAVIS17 and YouTube-VOS datasets.

Neural Adaptive Filter - A biologically plausible estimation mechanism to control nonlinear systems with delay

Natarajan Vaidyanathan

Designing a controller to accurately estimate system states and control a system to a desired trajectory is a common problem in many engineering fields. This problem, in a realistic environment, becomes particularly complex as we introduce nonlinearities, uncertainties or feedback delays. While there are several techniques that address these issues individually, such as Extended Kalman filters, Particle filters, Nonlinear autoregressive models, and blackbox function approximators, they come with limitations and do not address each of these issues at the same time.

In contrast, biological control systems have evolved to perform efficiently in an environment characterized by high uncertainty, continuously changing nonlinearities, sensory and motor delays and unexpected disturbances, while relying on noisy sensors and unreliable actuators. Furthermore, biology tackles this control problem with extreme computational and power efficiency that far surpasses many of today's modern control systems.

In an effort to bridge this gap between the demands of modern control problems and the effective mechanisms observed in nature, I here propose a biologically inspired estimation technique. The Neural Adaptive Filter is a prediction mechanism that utilizes the given delayed sensory data and learns to predict the system states for the control while being represented in a biologically realistic neural framework. It is also interesting to note that the model learns to map a function between the optimally represented time window of system states and the input and simultaneously uses this online estimation for control as well.

This mechanism provides a systematic approach to the design of strategies that achieve excellent performance in estimating and controlling a nonlinear system with feedback delay. The appeal of this work, while relevant from a control engineering perspective, can also be used to explore other fields, in particular disciplines focussed on studying the brain.

Fusion of Estimated Depth and RGB Features for Improved GraspType Selection of Novel Objects

Ali Asghar

Prostheses can alleviate some of the challenges faced by upper limb amputees in performing activities of daily living. However, electric powered prosthetic hands have not seen much improvement over the past decade. Most notably, unintuitive interfaces for selecting grasp types have resulted in low user satisfaction and high abandonment rates. Recently, efforts have been made to automate the grasp type selection process by collecting visual data, such as Red, Green Blue (RGB) or depth data, of the object to be grasped and classifying the object into the desired grasp type. This effort has been greatly aided by the advent of Deep Convolutional Neural Networks (DCNNs), which have been trained on examples of objects and their desired grasp types. However, the biggest challenge is to improve the generalization capabilities of DCNN models, so that they can efficiently classify novel objects, i.e., objects the model was not trained on. Combining RGB and Depth data has been shown to improve model generalization, however, acquiring depth data requires bulky hardware, that cannot be installed on a prosthetic hand for practical applications. Therefore, this thesis proposes the use of estimated depth maps acquired through pre-trained models, instead of dedicated hardware. An object detector based DCNN architecture was used to detect grasp types of objects along with their bounding boxes in cluttered scenes. To combine the RGB data with Depth data, this thesis proposes a novel method to fuse RGB feature maps and Depth feature maps.

In order to train the DCNN, a dataset was created with images of objects in a cluttered scene from the point of view of a camera mounted on a prosthesis. Every graspable object in each image was annotated with a bounding box and assigned one of two grasp types: neutral wrist palmar and pronated wrist precision. While only tested on two grasp types, the proposed method can be extended to an arbitrary number of grasp types. In total, the dataset consists of 6,729 images with over 18,000 bounding boxes.

Different methods of encoding single channel depth maps as three channel depth data were evaluated, including duplication, surface normal encoding, jet colormap encoding and HHA encoding. Moreover, different strategies to fuse RGB feature maps with depth feature maps were also evaluated. The result is up to a 12.7% boost in key metrics for measuring the model's generalization capabilities as well as a model that is capable of operating in real-world scenarios, such as in cluttered scenes with multiple graspable objects.

To the best of the author's knowledge, this is the first work that provides empirical evidence for the improvement in the performance of a DCNN model on the task of detecting grasp types of novel objects, through the fusion of RGB and estimated depth map features. More significantly, the improvement in performance exceeds even those methods that require dedicated hardware to acquire depth data. Therefore, the proposed model can be incorporated in the control schemes of upper limb prosthesis, without the need for dedicated hardware.

Session 2:
Biomedical Engineering

Lightweight and Flexible Bismuth Oxide Composite with Enhanced X-Ray Shielding Efficiency

Elahe Cheraghi

Lead-based shielding materials are commonly used to protect clinical personnel and patients from high energy x-ray radiations. However, the toxicity and high weight of lead can result in serious health concerns and limit its applications. During the recent decades, polymer composites containing high atomic number fillers are characterized by good X-ray absorption and promising candidates to replace lead. In addition, research studies have paid more attention to bismuth oxide (Bi2O3) nanomaterial due to important features like nontoxicity, high radiation absorption, low cost, etc. Multi walled carbon nanotube (MWCNT) also has been found effective material for various radiations shielding, and it can enhance the radiation shielding performance with mechanical properties improvement because of its outstanding features such as high strength and flexibility.

This study aims to develop a lead-free flexible shielding material with low density, high mechanical strength, and sufficient shielding efficiency. Considering the high flexibility and the radiation shielding properties of polydimethylsiloxane (PDMS), this polymer was applied as polymer matrix. Also, Bi2O3 and MWCNT were selected as nanocomposite fillers, and nanocomposites were fabricated using different weight percentages (wt.%) of Bi2O3 and MWCNT nanoparticles. The mechanical strength of nanocomposites is evaluated by Instron 5548 Micro Tester. Also, x-ray shielding properties are characterized using diagnostic x-ray energies from 60 to 90 keV. To study the effect of the nanocomposite structure on mechanical and shielding properties, multilayer nanocomposites in 2 to 5 layers are also fabricated with alternately PDMS/30 wt.% Bi2O3 and PDMS/5 wt.% MWCNT layers and are characterized by the same methods. The 5-layer nanocomposite improves the mechanical strength from 2.2 MPa in PDMS/30 wt.% Bi2O3 to 2.9 MPa. It is also capable of attenuating 89% of the scattered x-rays generated at a tube potential of 60 keV, with a density 16% lower than that of the conventional PDMS/30 wt.% Bi2O3 nanocomposite. The presented results could be utilized to fabricate wearable, lead-free, high-efficiency, and lightweight x-ray shielding materials.

Development of an all-optical forward-viewing photoacoustic remote sensing endoscope for high resolution label-free imaging

Alkris Warren

This work involves the design and development of the first endoscopic device based on Photoacoustic Remote Sensing (PARS), for label-free, in vivo, functional imaging of microvasculature. In PARS, a short-pulsed excitation laser (on the order of nanoseconds or shorter) is incident on a sample that is absorbing at that wavelength. The absorption of excitation elicits a combined thermal and pressure perturbation in the exposed volume, which in turn generates corresponding modulations in the local optical properties. A secondary probe beam co-focused with the excitation beam captures the absorption induced modulations as changes in backscattering intensity. These backscatter modulations are directly correlated to the local non-radiative absorption contrast1.

A prototype device is designed and developed to show the capabilities of the technology. The prototype PARS endoscope consists of a benchtop system that utilizes an 830-nm wavelength probe beam that is confocally scanned with a pulsed 532-nm excitation beam. With this system design, PARS images are acquired by raster-scanning the proximal end of a coherent, image-guide fiber bundle (IGF) containing 30,000 cores arranged within a 600-μm diameter image circle. A graded-index (GRIN) distal-end achromat objective lens is used to focus and collect the reflected probe beam. The distal end of the prototype has a footprint of 1.6mm. Based on phantom studies, the endoscopy has a maximum resolution of ~1μm. This prototype device represents to the best of our knowledge the first, non-contact, photoacoustic endoscope capable of imaging at cellular and subcellar resolutions.

The initial design presented challenges for in vivo application due to the high numerical aperture and short working distance of the distal objective. Design modifications for in vivo optimization involved the design and development of a custom GRIN doublet that utilizes a mechanical sleeve for alignment, and index-matching gel between interfaces to reduce parasitic reflections from the distal end. According to Zemax simulations, the custom endoscope has a theoretical resolution of ~2μm.

To fully leverage the potential of the PARS mechanism for endoscopy, a 2nd generation design is conceptualized that utilizes a double-clad fibre (DCF) in combination with a distal scanning mechanism (piezoelectric tube). The DCF design has several advantages over the previous design. The design uses a DCF coupler to separate the forward and backward propagating light, has a larger effective collection area due to the outer cladding of the DCF and can be coupled and focused more effectively, leading to better imaging performance.

The PARS endoscope presents numerous promising opportunities for paradigm-shifting applications in both clinical diagnosis and basic research. Future applications may include pre-cancer detection of malignant and premalignant lesions, diagnosis of submucosal abnormalities, and in situ characterization of diseased tissues.

Design and Control of Active-passive Shoulder Exoskeleton Robot

Ali Nasr

Owing to musculoskeletal disorders, occupational hazards, congenital diseases, and aging, there is much research into assistive devices for recovering the activities of daily living. Exoskeleton robots, which range from fully passive to fully active-assisted movements, have become an essential instrument for assisting industrial employees and stroke rehabilitation therapy. Designing the exoskeleton actuation is challenging and time-consuming due to closed kinematic loops in the 3D human-exoskeleton multibody model, complicated human-robot interactions, and interdependent selection of power transmission features. Furthermore, the closed-loop human- robot system requires developing an effective robotic controller that considers the dynamic characteristics of both the human and the robot as well as human adaptation to the robot.

Firstly, a multibody model was developed using seven components: a MapleSim upper-body musculoskeletal dynamic model (consisting of 20 degrees of freedom and 40 muscle torque generators), a nonlinear model predictive controller (NMPC) as the central nervous system (CNS), a machine learning (ML) solution to static optimization and inverse muscle modeling (InverseMuscleNET), the exoskeleton's rigid components, a passive mechanism, a powered actuator (brushless direct current motor), and an assist-as-needed (AAN) control model. Precisely, the human body is adjustable for different anthropometric measurements and subject body characteristics: sex, age, body mass, height, dominant side, and physical activity.

We simulated the model using ordinary differential equations to study the interaction force/torque. The system design was optimized by choosing features of the passive mechanism and exoskeleton motor such that the human joint active torque, power, muscle metabolic energy expenditure, and actuator electricity consumption were minimized. The resultant optimized active-passive exoskeletons allow for the creation of lighter and smaller wearable robots that reduce the user's muscular activation torque for the tasks being studied.

To interpret human motion intent and high-level control of the exoskeleton, the optimum structures of ML models (artificial, recurrent, convolutional, and recurrent convolutional neural networks) were evaluated for real-time interpretation of surface myoelectric (sEMG) signals. An optimized ML structure as a predictive control-oriented model (RobustMuscleNET)s maps interrupted sEMG signals to future control-oriented signals (robot joint angle and assistive torque).

The human-robot adaptation is simulated using an NMPC as the human CNS for three conditions: initial (the initial session of wearing the robot, without any previous experience), short-term (the entire first session), and long-term experiences. The results showed that the two methods (model- based and fuzzy logic) outperform the traditional proportional method in providing AAN by considering distinctive models of the human and robot. We found that the desired strength of the robot should be increased gradually to ignore unexpected human-robot interactions (e.g., robot vibration, human spasticity).

This research (I) proposed an open-source upper body musculoskeletal model that performs biomechanical analysis of human motion with or without an exoskeleton, (II) proposed a process for dynamic syntheses of passive and active assistive shoulder exoskeletons, (III) developed regression-based ML mapping of sEMG signals to kinematic and dynamic variables, to recognize the intent of the human and to predict the robot motion, (IV) developed a mid-level controller providing assist-as-needed policies in a hierarchical control setting using two novel methods: model-based and fuzzy logic rules. In total, the developed musculoskeletal human model, proposed active-passive exoskeleton, ML interpretation of sEMG signals, and the assist-as-needed model- based control can be used for biomechatronic devices, such as exoskeletons, prostheses, and wearable assistive/resistive robots.

Autonomous Gait Detection and Analysis Using Electromagnetic Waves

Hajar Abedifirouzjaei

In this thesis, leveraging AI and radar technology, I proposed novel non-contact in-home activity recognition (i.e., sitting/standing, vacuuming, washing dishes, in-place movement such as working out or picking objects, and walking) and gait monitoring systems. I developed standalone mm-wave radar systems coupled with deep learning algorithms as the basis of an autonomous in-home free-living physical activity recognition and gait monitoring system. First-of-its-kind in-home real-life datasets, collected in a clutter-rich in-home environment, are provided. Using the mm-wave radar system, human spectrograms (time-varying micro-doppler patterns) are used to train deep Gated Recurrent Network (GRU) to identify physical activities such as walking, standing/sitting, vacuuming, washing dishes and other in-place movements, performed by a subject in his/her living environment. An overall model accuracy of 93% was achieved to classify in-home physical activities of trained subjects in addition to 88% accuracy for a complete new subject. The proposed cloud-based system not only recognizes the type of activity and distinguishes waking periods from other in-home tasks but also records the activity level of the subject over time. An Individual's gait pattern is analyzed in several cluttered environments, such as a long hallway and an in-home environment. A novel gait extraction algorithm based on radar signal processing, unsupervised learning, and a subject detection, association and tracking method is proposed to extract gait parameters in the presence of multipath and ghosting effects caused by stationary objects (i.e., passive clutter). The algorithm functionality is validated by capturing spatiotemporal gait values (e.g., speed, step points, step time, step length, and step count) of people walking in a long hallway. It is shown that the proposed algorithm yields an average absolute error for speed estimation between 0.0040 m/s to 0.0435 m/s.

Heartbeat detection from the upper arm: a step towards developing wearable devices for cardiac activity monitoring

Nargess Heydari Beni

The global number one cause of death is cardiovascular disease. Therefore, there is an acute need for constantly monitoring the cardiac conditions of people. The current clinical electrocardiogram (ECG) recording systems are challenging to use because of the requirement of precise placement of ECG electrodes on the body of a patient, which is usually performed by a trained medical professional. This requirement of precise electrode placements has severely limited the possible application scenarios of ECG systems. Hence, there is a need for wearable devices to detect possible cardiac abnormalities with minimal or no need for intervention from healthcare professionals.

There is a significant body of literature focusing on denoising ECG signals and detection of different types of abnormalities. Inspired by those previous studies, it is possible to develop devices and algorithms that can provide cardiac information from the upper arm. In this study, bio-potential signals were recorded from 20 healthy participants using high-density electromyogram (EMG) electrodes attached to the upper arm. The acquired data was analyzed with the aim of heartbeat detection. The primary objective was to select optimized location of electrodes for different contraction levels of the upper arm muscles for further implementation in the wearables. The secondary objective was to detect heartbeats from the selected channels at different contraction levels. One pair of electrodes was selected for no muscle contraction (rest) condition with the highest similarity to ECG in terms of correlation coefficient (CC) averaged on all the participants. Another pair was identified for muscle contraction condition using the same criterion. Detection of heartbeats was done using the selected channels for different conditions. The performance of the implemented algorithms was promising, and they can be further used towards the goal of abnormality detection from the upper arm using a wearable device.

Session 3:
Human Factors

Interactive Training Tool for Injury Assessment of a Human Joint

Marco A Moran Ledesma

Manual musculoskeletal assessments allow rehabilitation practitioners to identify soft tissue injuries (e.g., knee ligament tears) though visual and haptic cues. However, becoming proficient at assessing patients' joint integrity through manual physical exams is difficult due to 1) the wide range of joint conditions and 2) the limited practice opportunities on injured clients. Shortage of trainers in a clinical academic environment and ethical issues surrounding training involving patients also limit practitioners' exposure to a large number of injuries and cases. Novice students, for instance, find themselves limited to practicing on their peers' limbs, typically healthy, or relying on learning materials, such as lectures or demonstrations. How could we increase access to hands-on rehabilitation practitioners' education and training? How can we increase the number of controlled, low stakes learning opportunities that practitioners are afforded to improve and develop their clinical evaluation skills?

We propose to design and implement an artificial human-like joint on which practitioners train in injury assessment. Together with a clinical instructor, we have carefully defined a set of design considerations that suggest our tool should 1) attempt to resemble the skin look and feel of a human leg, 2) emulate the biomechanics of healthy and injured human knees, and 3) simulate different grades of ligament injury. We also aim to carefully consider trade-offs in cost, ease of fabrication, assembly, and performance in order to make our tool readily available for, and accessible by, a large audience of instructors and practitioners.

We have implemented version 1.0 of our tool with an affordable passive human knee joint model, 3D printed attachments, silicone-based skin layers, and off-the-shelf electronic components. In the near future, we will be conducting formal evaluation sessions of the tool with clinical instructors and kinesiology students.

Our work could have implications for further research and education:

1) How could educators formally deliver remote/in-person courses and hands-on laboratories with it? Teaching anatomy has historically been based on lectures, cadaveric dissections, and illustrated printed materials, which students often find difficult to understand. Our work may help address this challenge, but a thorough understanding of the feasibility, benefits, and challenges of delivering hands-on laboratories or online courses with an artificial human-like joint is necessary.

2) Is our approach valid for other human joints? The human body is composed of a large number of joints. It will be worth exploring whether our approach followed for the knee joint can be applied to build other joints (e.g., ankle, elbow, etc.).

3) How could we make our joint customizable? Practitioners are required to be proficient at assessing joints of people of all ages, for which we may work towards a set of different 1) sizes of 3D models of bones, 2) ligament structures, and 3) skin layers that practitioners use to assemble and assess a toddler's joint, a senior's, a young adult's, etc.

Prediction of Situation Awareness and Takeover Performance using Eye Tracking Features in a Semi-Autonomous Vehicle Simulator

Wendy Ding

Semi-autonomous vehicles provide drivers the opportunity to do secondary tasks like reading or gaming during their driving tasks which free drivers from constantly focusing and decreases the cognitive load needed for driving, easing the driving fatigue. However, when facing specific occasions, like hazards detected ahead of the road, the autopilot vehicle will give a takeover alert and the drivers are requested to put aside their current tasks and transfer their attention to the driving task. During this disengagement process, the drivers' Situation Awareness status has a significant influence on their takeover performance and determines the takeover time and the hazard perception time. Takeover time and hazard perception time refer to the time it takes the driver to take over control back and detect hazards after the takeover alerts were given. Previous research has shown that the takeover time and hazard perception time have close relevance to driving safety, and many studies used them as quantification of takeover performance. Several factors can affect the takeover time and hazard perception time, such as driving situations, and driver's demographic information. Some studies have used the human-generated data, which can be collected by wearable devices like eye trackers and GSR, to predict the takeover time and hazard perception time and have got good accuracy.

While there're many studies focusing on the assessment of factors like Situation Awareness status, takeover time, and hazard perception time, little research has been done to examine the relationship between those factors and Eye motion behaviors under different driving conditions. Eye motion behaviors have been proven to be able to indicate drivers' cognitive status, thus it could be used to predict takeover performance in semi-autonomous vehicles.

In this study, 24 young, 24 mid-aged, and 24 old drivers are recruited, and they are asked to drive an L3 semi-autonomous vehicle in a driving simulation system. The driving scenarios involve various road types and road geometries, and some of them require the drivers to perform secondary distraction tasks during the driving simulation. The drivers' eye motion is recorded, and their Situation Awareness scores will be calculated based on a questionnaire after each trial. 24 features are extracted from the eye tracking data by calculating the total number, average level, or standard deviation of eye fixation, eye saccade or pupil size. The data analysis starts from the ANOVA analysis upon various driving conditions and eye tracking features. This part of the work can clarify how eye motion behaviors are affected by different conditions in various driving scenarios. Afterward, a new deep learning model for predicting drivers' takeover performance, including a SA score, the takeover time, and hazard perception time, from eye tracking behaviors is proposed. Before feeding the data into the model, exploratory analysis and feature engineering are implemented on the eye tracking dataset and 6 features are selected for the deep learning models. In future work, more features could be involved like the gaze time upon the rear left, and right mirrors. If more information could be included in the input matrix, it's more likely that we will have a higher accuracy of the deep learning model.

Evaluation of Laban Effort Features based on the Social Attributes and Personality of Domestic Service Robots

Ebru Emir

In today's world, it is not uncommon to see robots adopted in various domains and environments. From manufacturing facilities to households, robots take over several roles and tasks. For instance, the adoption of robotic vacuum cleaners has drastically increased in the recent decades. During their interaction with these embodied autonomous agents, humans tend to ascribe certain personality traits to them, even when the robot has a mechanoid appearance and very low degree- of-freedom. As the social capabilities and the persuasiveness of robots increase, design of robots with certain personality traits will become a significant design problem. The current advancements in AI and robotics will led to development of more realistic and persuasive robots in the foreseeable future. For this, it is crucial to understand people's judgment of the robots' social attributes since the findings can shape the future of personality and behavior design for social robots.

Therefore, using only a simple and mono-functional robotic vacuum cleaner, this study aims to investigate the impact of expressive motions on how people perceive the social attributes and personality of the robot. In order to investigate this, the framework of Laban Effort Features was modified to fit the needs and constraints of a robotic vacuum cleaner. Expressive motions were designed for a simple cleaning task performed by iRobot's Create2. The four movement features that have been controlled for robot include velocity, path planning behavior, vacuum power, and radius of curvature at rotational turns. Next, participants were asked to rate the personality and social attributes of the robot under several treatment conditions using a video-based online survey. Participants were recruited through the crowd-sourcing platform, Amazon Mechanical Turk, and received $8.00 compensation for their time. The data gathered from the Robotic Social Attributes Scale (RoSAS) were analyzed by performing five-way mixed effects ANOVA, and the data gathered from the Mini-IPIP personality questionnaire were analyzed using a four-way repeated measures ANOVA.

The results indicated that people's ratings of personality and social attributes of the robot were influences by the robot's movement features. For social attributes, there were two main findings. First, velocity influenced ratings of the robot's warmth and competence. Second, path planning behavior influenced ratings of the robot's competence and discomfort. In terms of robot personality, the results indicated three main findings. First, random path planning behavior was associated with higher Neuroticism ratings. Second, the factor combination of random path planning behavior, low radius of curvature and high velocity yielded higher Extraversion ratings. Third, the factor combination of random path planning behavior, low radius of curvature, low velocity and low speed of vacuum power yielded higher Intellect ratings.

Limitations of this study are related to the experimental design and the technical constraints of the robot. An initial screening was not used to ensure gender balance in the sample. The number of males and females were equally distributed among the treatment conditions; however, the total number of female participants was approximately one third of the male participants. Kinematic constraints like the robot's degree of freedom limited the design of some movement features, as originally suggested in the framework of Laban Effort Features. Also, there were bugs in some commands of the development software provided by the robot's manufacturer. These limitations might have potentially impacted the results.

This study showed that the framework of Laban Effort Features can be applied to fit the cleaning task of a domestic service robot, and that the framework's application makes a difference in how humans perceive the robot's personality and social attributes. Overall, the findings should be considered in human-robot interaction when incorporating expressive motions into social robots.

Examining Computer-Generated Speech for Aeronautical English Accent Testing and Training

Hyun Su Seong

A language issue such as miscommunication between pilot and air traffic control (ATC) is as prevalent and high stakes as any other latent threats that jeopardize flight safety. Unfortunately, it is relatively overlooked even though its impact is manifold (e.g. phonetic decoding failure, increased workload, confusing lexical meanings) and can manifest abruptly at any phase of a flight. Miscommunication in pilot-ATC conversation due to improper use of aeronautical English has long been identified as a major cause of flight accidents (ex. Tenerife Airport Disaster). A suprasegmental feature of speech such as accent is identified as a specific contributing factor but has not been a focus in relation to processing fluency of pilots in contemporary literature. The primary goal of the thesis is to investigate the feasibility of computer-generated English accents as a potential training solution for future pilots. In this thesis, the author specifically focuses on whether computer-generated accents can improve processing fluency of listeners. It first synthesizes literature that span across three disciplines (aviation, linguistics, and human factors) to identify current issues in aeronautical English training for pilots. Then a series of controlled experiment is designed where participants will be trained with computer-generated accent and human accent, followed by an accented speech recognition test with two scripts: semantically anomalous (or neutral) script, pilot-ATC communication script. Their accent listening comprehension scores from two types of accents, along with linguistic backgrounds, will be compared for analysis. The hypothesis is that computer-generated accents will serve as a practical substitute to those of human and improve their adaptation to internal varieties of English accents. The author also argues that accents should always be a part of aeronautical English training curriculum. The thesis is currently a work in progress and is at a preparation stage. The thesis, however, speaks to a larger gap unattended by contemporary research – the degree to which accents impair pilot-ATC communication.

Freezing of Gait: Biomarkers, Detection, and Prediction using EEG

Fatemeh Karimi

Freezing of gait (FOG) is a sudden episodic gait disturbance in Parkinson's disease (PD), during which the patient is not able to effectively initiate gait or continue walking, despite the intention to walk. The mystery of the FOG phenomenon is still unsolved as it seems to occur in the absence of any unique known cause. Recent studies have revealed abnormalities in cortical activity and neural network dynamics associated with FOG, which emphasizes the importance of dysfunction at the cortical level and cortical-subcortical communication in PD with FOG patients. Therefore, exploring simplified yet novel aspects of the involvement of the cortical dysfunction in FOG provides insight toward uncovering the underlying mechanism of FOG as well as identification of non-invasive and reliable FOG biomarkers. In this project, various EEG features are investigated in four groups of participants: PD patients with severe FOG, PD patients with mild FOG, PD patients without FOG, and healthy age-matched controls during ambulatory tasks to determine cortical processing abnormalities associated with FOG and its severity.

The investigated features include amplitude and phase-based features of EEG over a wide range of frequency bands such as movement-related cortical potentials (0.05–5 Hz) and brain oscillations (1–50 Hz) and distributed cortical regions. The EEG features before and during simple and more complex gait related tasks were compared across all groups. The results indicated significant differences between patients with severe freezing of gait compared to healthy controls and patients without freezing of gait. In addition, patients with mild and severe freezing represented cortical activity differences and similarities. The EEG features identified in this project are indicative of important freezing of gait clinical characteristics such as severity and contribute to a better understanding of the underlying neurophysiology of the mysterious phenomenon of freezing of gait.

Effect of the Six Basics of Emotions and Neutrality on Trust and Dependence on Operators in the Petrochemical Industry

Siti Nandiroh

Emotional problems may not be a general problem discussed in the industry. However, during the COVID-19 pandemic, emotion became a concern to all parties. The aim of this study is to identify and measure how emotions especially sadness, happiness, fear, anger, surprise, disgust, and neutrality affect trust and reliance on automation. Furthermore, develop a model that explains the formation of trust in the domain of the petrochemical industry, where process automation is widely used.

In characterizing operator emotion, subjective methods using Qualtrics were used. Other variables that may affect automation trust considered in the model are propensity, self-perceived and machine reliability, reliance, age, experience, and knowledge.

Fifty-two participants in this study are operators who have worked at petrochemical companies for different years. Their ages range from 18 to 50, have a minimum education of high school level, and have worked for the company for at least one year.

The operators were asked to fill in a demographic survey, general health form, and consent form. This study consists of one session to complete a questionnaire to express their emotions, trust, and reliance on automated systems based on their everyday experiences. Operators will not be exposed to emotional manipulation because it could disrupt operators or impair the flow of normal factory operations.

The results showed that the operator's highest emotional score when he was about to start working with an automated system was happiness, which means he really liked his job by 70%. The most extreme condition of the operator was discomfort in disgust which had the lowest score of 4%. Most of the operators stated that the automatic machines used were very reliable. However, when the operator feels surprised and happy, the trust in the machine is reduced.

The findings will support the understanding of the effect of emotion and provide suggestions for designers and decision-makers to manage and improve human-automation system performance.

Session 4:
Systems Modeling and Simulations

Top-Down versus Bottom-Up Modeling and Simulation of Grey-, Green-, and De-Growth Economies for The Natural Resources' Dependent Economies

Muna AlAteibi

Within grey-growth economy, the natural resources' dependent economies are vulnerable to external shocks, and sudden price fluctuations due to the large foreign exchange inflows and pronounced volatilities in commodity prices. It also subjects to resource depletion for which consumption rate is higher than resources' recovery rate. As a result of that, unemployment rate and selective out-migration are higher which discourage investment, limit job opportunities, decline the economy, and shrink the urban area. Therefore, transitioning toward different economic models are needed and expected. An economic model aims to generate testable hypotheses about economic behavior by simplifying reality. Because economic outcomes cannot be measured objectively, the design of an economic model must necessarily be subjective. When it comes to determining what is required to explain their view of reality, various economists will arrive at different conclusions. We select three major different economic models to be analyzed as possible transition pathways. The grey-growth model as current baseline economic model and green-growth and de-growth as possible alternatives. Green-growth is an economic growth associated with improvement of human wellbeing, social inclusiveness, and environmental quality, while de-growth is an economic stationary steady-state (post growth) achieved by trimming throughput (natural resources, production & consumption rate). We identified main indicators for each model and select the common ones for modelling and simulation purpose. Since economy is a complex system in which many heterogeneous variables are interacting, we select bottom-up approach namely agent-based-modelling (ABM) for modelling two case-studies (Newfoundland province in Canada, and Emirate of Abu Dhabi in the UAE) and simulating twelve different scenarios. The aim is to study the impact of natural resources dependency on GDP, government revenue, employment, population growth by modelling the interaction among people, households, businesses, and industries variables. The results of the model will be compared with well know and used top-down approach specifically Input-Output accounting.

Interaction Forces of Coupled Magnetic Pendulums

Mariam Lahlou

Coupled magnetic oscillator systems are very interesting not only for energy harvesting but also for helping researchers have a better understanding of the vibration of atoms in a lattice. Magnetic pendulums are a type of coupled magnetic oscillator system and consist of oscillating pendulums with magnets attached at their ends hence coupled magnetically. Studies have suggested using coupled magnetic pendulums to better understand the Josephson junction which is used for coupling energy between two superconductors. Josephson junction weak links are interesting because of their wide variety of existing and potential applications such as in quantum computing. With memory cell circuit design in quantum computing being based on coupled arrays of Josephson junctions, studying coupled magnetic pendulums can ultimately help better understand this fairly new and more efficient computing technology.
In this research, we investigate the non-linear motion and magnetic forces in a chain of magnetic pendulums with cylindrical magnets to eventually better understand the behaviour of Josephson junctions-effect devices. We studied the nonlinear motions of our system through the interaction forces between the magnets and analytically derived the equations of motion with the aim of simulating the dynamics of the system. To obtain the natural frequencies of our analytical system, we linearized the equations of motion. Finally, we validated the accuracy of our simulated system's response by comparing its behaviour to that of an experimental setup consisting of two coupled magnetic pendulums.
Ultimately, we solved for the equations of motions of our magnets and integrated the magnetic forces from the magnetic field function. We also experimentally validated the nonlinear response of the system as well as its equilibrium points and natural frequency. The results we obtained through comparing the simulated system response and the designed experiment response indicated that our analytical model can accurately predict the behaviour of such a system.

Model-Based Simulation and Control of Upright Balance in Lower-Limb Exoskeletons

Keaton Inkol

Background/Goals:

Recently, interest in robotic lower-limb exoskeletons as a solution to different mobility deficits has grown. In 2012, there were 288,800 wheelchair users in Canada, with that number likely having increased due to an aging population [1]. The prospect of having these individuals use an exoskeleton is interesting, but in practice, performance suffers from poor upright stability. To compensate, an additional device is used to balance, e.g. crutches, limiting free-use of the arms. The goals of my PhD thesis are as follows: 1) Simulate human balance recovery biomechanics using feedback optimal control; 2) Dynamic modeling of lower-limb exoskeletons and human-exoskeleton interactions; 3) Design and real-life implementation of assistive balance control to remove the need for crutches when using a lower-limb exoskeleton (ExoH3; Technaid, Spain).

Methods:

Simulations of human balance recovery following a perturbation require a multibody dynamic model of standing biomechanics with features like muscle models (muscle torque generators, MTGs) and anthropometric scaling of inertia. Inputs to the MTGs were obtained using nonlinear model predictive control (NMPC). Here, we examined how specific objective criteria embedded within an NMPC scheme generated different categories of human balance recovery strategies. Model-based exoskeleton control requires a dynamic model capturing the device inertia and friction. Dynamic parameters specific to the Technaid ExoH3 were obtained through a combination of direct measurement and optimization methods, the latter being based on experiments optimized to yield accurate parameter estimates. With parameter values, simulation studies were performed examining stability of the human-exoskeleton given actuator limits. With that established, optimal model-based ExoH3 balance controllers based on human balance simulations, e.g. NMPC, constrained MPC, etc., will be tested experimentally with healthy users using Dr. Andrew Laing's robotic platform (CCCARE). Note: all models were designed in MapleSim (Maplesoft, Canada) such that symbolic equations of motion could be extracted.

Results/Conclusions:

NMPC-based simulations revealed that the balancing strategy could be adjusted within assistive controllers via reweighing of objective criteria. The parameter identification experiment for the ExoH3 will address the following: i) which curve parameterization methods are optimal for obtaining device dynamic parameters, ii) do inverse or forward dynamics methods of identification yield better parameter estimates. Lastly, the results of the platform experiments will highlight real-time performance of proposed controllers in addition to how users may adapt to the controllers. Based on earlier simulation experiments, we expect the proposed controllers will be succesful in preventing users from falling, but will not perform as well as healthy users (without the device) in terms of limiting center of mass deviations due to delays, device limitations, and modeling error. Ultimately, for lower-limb exoskeletons to be adopted as a viable alternative to wheelchairs, the balancing problem must be addressed. Results from simulation experiments herein suggest that optimal control methods can be implemented to prevent users from falling following a perturbation. Final experimental testing is expected to take place soon.

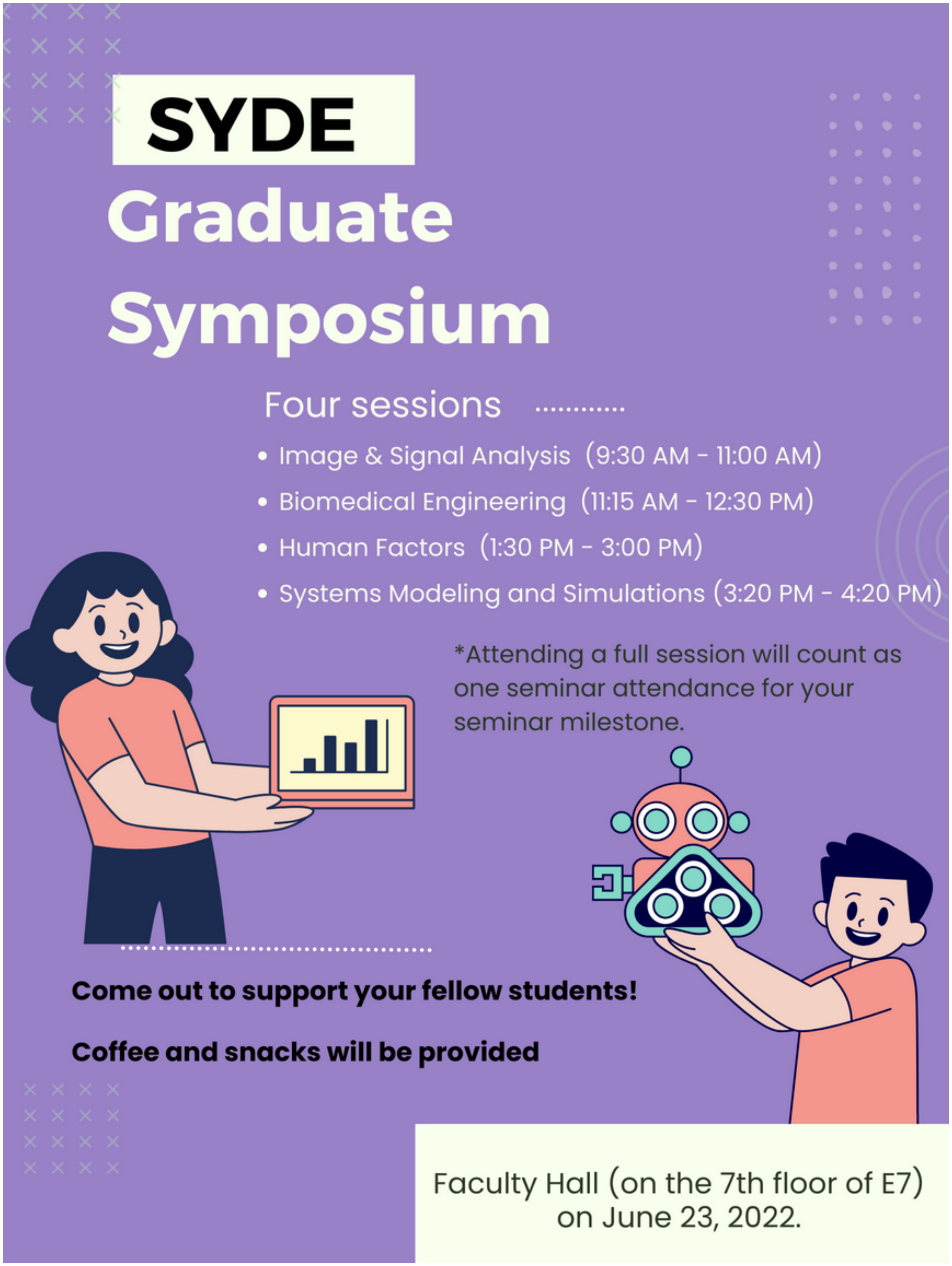
Stochastic Finite-Element Modelling and Global Sensitivity Analysis of Human Middle Ear

Arash Ebrahimian

The middle ear plays a vital role in the hearing process by conveying the sound waves from the ear canal to the inner ear. Models of the middle ear can be widely used for a myriad of purposes including forecasting how the middle ear will respond to pathological changes, studying the mechanics of the middle ear, and optimizing the hearing devices and implants. The majority of the finite-element middle-ear models in the literature are deterministic models. Deterministic models cannot take into account the uncertainties in the mechanical and geometrical parameters of the structures in the middle ear. The inter-individual variability of these parameters, as well as our lack of knowledge about them, might both contribute to these uncertainties. Therefore, in order to increase the reliability of the current finite-element models, it is crucial to develop these models in such a way that they can account for these uncertainties. In the first part of this study, we employed stochastic finite-element modelling to explore the impacts of these uncertainties on the middle-ear vibration outputs. The results reveal that the uncertainties in the input parameters can be magnified up to more than three times in the model outputs at some frequencies. In the second part of this study, we used our stochastic finite-element model to implement global sensitivity analysis techniques to analyze the importance of each parameter of the middle ear model. Unlike the one-at-a-time sensitivity analysis methods that explore the parameter spaces locally and are not able to find interactions, the global sensitivity analysis methods consider the variations of all parameters simultaneously and provide us with the global impact of each parameter as well as the significance of the interactions among the model parameters. The outcome of the global sensitivity analysis can be extremely helpful for modellers as they can focus solely on the parameters with the most considerable impact when tuning their finite-element models. These findings may also be utilized to determine which structures in the middle ear model deserve more detailed investigation for exploring their mechanical/geometrical properties. Based on the global sensitivity analysis results, the most influential parameters include the Young's modulus of the tympanic membrane and stapedial annular ligament, the thickness of the tympanic membrane, the Young's modulus of the ossicles, and the damping of the stapedial annular ligament.

Poster winner

Ipsita Parida (MEng)



Sticker winners

Ana Lucia Diaz de Leon (MASc)
Nargess Heydari Beni (PhD)