UNIVERSITY OF WATERLOO | FACULTY OF ENGINEERING
Department of Systems Design Engineering

2024 Systems Design Engineering Graduate Symposium

Tuesday, April 9, 2024

2nd Floor IDEAS Clinic
E7-2409

Schedule

April 9, 2024
E7-2409

9:00 am-9:30 am

Welcome Coffee

9:30 am-10:30 am

Session 1: Machine Learning & Intelligence and Optimization & Decision Making
Chairs: Nasser Lashgarian Azad and Kumaraswamy Ponnambalam
Speakers: Sajjad Kazemi, Mohammad Ahmed Basri, Thomas Fortin, and Ali Asl

10:45 am-12:00 pm

Session 2: Human Factors and Ergonomics
Chair: Shi Cao
Speakers: Khatereh Shariatmadari, Mustapha Unubi Momoh, Sana Allana, Sheida Marashi, and Wachirawit Umpaipant

12:00 pm-12:30 pm

Pizza Lunch

12:30 pm-1:30 pm

Session 3: Vision, Image, & Signal Processing and Environmental Systems
Chair: Jessie Ma
Speakers: Chun Cheng Feng, Ryan Schmalenberg, Diana Shakhova, and Kirsten Wright

1:45 pm-2:30 pm

Guest Seminar: Dr. Mahdi Alavi - Advanced Systems Design for Electrochemical Impedance Spectroscopy in Engineering and Medical Applications

2:30 pm-3:30 pm

Session 4: Biomedical Engineering, Modelling, Simulation & Systems Theory, and Mechatronic & Physical Systems
Chair: Thomas Willett
Speakers: Jenna Veugen, Pouyan Keshavarz Motamed, Nahid Rahmati, Vidyasagar Rajendran

Session 1:
Machine Learning & Intelligence
and
Optimization & Decision Making

Proximal Policy Optimization for Satellite Collision Avoidance Maneuver Planning in Low Earth Orbit

Sajjad Kazemi

The space domain has experienced increased congestion and competition, heightening the importance of ensuring satellites operate without collisions, which is now a paramount concern for both public and private entities. More specifically, effectively avoiding collisions with residence space objects (RSOs) emerges as a crucial challenge within the space situational awareness(SSA) field. Preventing collisions in space orbits, especially within Low Earth Orbit (LEO), poses a significant challenge due to the limited resources at the disposal of operational satellites. Any maneuver performed inevitably leads to the satellite veering off its nominal orbit, resulting in a definite disruption in service availability. The constraints imposed by scarce resources like fuel and time further limit the feasibility of maneuvers. Hence, planned maneuvers must prioritize efficiency in terms of both time and fuel consumption. This study investigates the use of reinforcement learning (RL) techniques, which hold the potential for addressing the challenges associated with satellite path planning and collision avoidance.

Specifically, the proximal policy optimization (PPO) method, known for its success in various contexts, is selected for its suitability in managing continuous action and state spaces within this research. The idea involves creating a sequence of collision avoidance maneuvers (CAMs) for the satellite eight days before a potential collision, aiming to prevent the collision and maintain proximity to the nominal orbit as much as possible. Subsequently, two distinct neural network architectures are explored for the actor and critic networks: a fully connected linear neural network and a long short-term memory (LSTM) neural network. This study is focused on single-object maneuver planning, where the primary satellite endeavors to evade collisions with secondary objects. In addition to collision avoidance, the satellite is required to minimize deviations from the nominal orbit to prevent disruption of essential services. A customized environment using the OpenAI Gym toolkit was designed and implemented for training, and real conjunction data messages (CDMs) were utilized as the ground truth. The results indicate the promising performance of the trained model, establishing a proof of concept for further exploration of PPO for maneuver planning and collision avoidance in space. While both implemented PPO structures exhibit great performance in satisfying the constraints, PPO with LSTM demonstrates superior results in maintaining a safe distance from secondary objects during close encounters without deviating considerably from the nominal orbit.

Evaluating the Usefulness of Synthetic Data in Healthcare: Applications for Predictive Modeling and Patient Privacy Protection

Mohammad Ahmed Basri

The advent of data-driven approaches in healthcare has opened new horizons for patient care, disease prediction, and medical research. However, one of the significant challenges in this domain is the availability of large-scale, high-quality datasets. Real health data containing sensitive or personal data requires lengthy approval processes and stringent restrictions for access.

Due to privacy concerns and regulatory restrictions associated with patient data, there is a growing need for synthetic data that can replicate the statistical properties of real healthcare datasets. Synthetic data generated using generative adversarial networks is a promising approach to open data for public health and healthcare AI initiatives. Although progress has been made in establishing accepted evaluations for synthetic data models, missing are key holistic metrics for policymakers to aid their decision-making on open data initiatives. In this work, we introduce and demonstrate a privacy risk with an identity disclosure risk (IDR) assessment, a quantitative measure of univariate distribution in Hellinger distance (HD), and a quantitative bivariate measure of differential pairwise correlation (DPC).

Further, we examine the use of synthetic data for hyperparameter tuning in healthcare predictive models, particularly in scenarios with limited real data access and constrained computational resources. We found a notable correlation ($p < 5.2e - 7$) between prediction accuracy using real data and synthetic data, suggesting that parameters optimized with synthetic data are applicable to real data for optimal results. Our research focuses on identifying the best hyperparameter combinations for high-quality synthetic data. We use Fidelity evaluation metrics based on the univariate distribution (Hellinger distance) and bivariate differential pairwise correlation (DPC).

Our research demonstrates a strong correlation between fidelity metrics and Machine Learning Efficacy (MLE) in synthetic data generation ($p < 3.59e - 7$). This suggests the potential of using fidelity metrics as efficient objective functions, given that they require less computational resources to calculate compared to MLE metrics.

Scaling Laws for Compute Optimal Biosignal Transformers

Thomas Fortin

Work has been done to develop scaling laws for language transformer models which predict the optimal balance of model size and number of training tokens for a given training compute budget. This has been integral to the recent push to improve the performance of large language models by increasing their size. However, results vary significantly between works depending potentially on variations such as learning rate schedules or specific model architectures which implies that the given scaling laws may not generalize to other tasks.

This thesis investigates the existence and form of a compute optimal scaling law for biosignal transformers. The Biosignal Transformer (BIOT) architecture is studied with scaling laws developed for both accelerometer data and EEG data. The scaling laws are developed by first training many models with varying sizes and number of training tokens. Then, the training loss curves from those experiments are used to create iso-flop profiles for different constant compute budgets. By locating the minimum loss for each of these profiles, a scaling law can be fit to predict optimal model sizes and numbers of training tokens for larger compute budgets. The discovered scaling laws are tested by using the predicted optimal balance for a compute budget 5 times larger than that used in the largest iso-flop profile. An 'optimal' model is then trained, and its performance is compared to models both 4x larger and 4x smaller but with numbers of training tokens set such that a constant compute budget is maintained. It is found that BIOT should be scaled up in number of parameters more heavily than in number of training tokens. This implies that higher performance can be achieved without a significant reliance on additional data collection, but that inference cost will be higher due to the larger increase in model size.

In addition to the discovered scaling laws, the process used to develop them is thoroughly documented and important insights into hyperparameter selection, mitigation of noise in small models, run selection for iso-flop profile development, and infinite data limit charting are provided. This work should be useful both to researchers interested in improving performance on biosignal processing tasks, such as human activity recognition or seizure detection, by training larger BIOT models, as well as those interested in developing scaling laws for other model architectures which have not yet been the subjects of similar studies.

Preference and Performance-Based Adaptive Task Planning in Human-Robot Collaboration (Page 1/2)

Ali Asl

This research delves into a central challenge in human-robot collaboration (HRC): the adaptive task planning of robots to enhance team performance, fluency, and the human agent's perception of both the robot and the collaboration. This research tackles the challenge of proactive task planning and allocation in collaborative scenarios, involving a single human and a single robot working together to accomplish a task. Recognizing the existing gaps in the literature, our focus revolves around balancing human agents' leading/following preferences and their performance, with the aim of fostering collaboration while maintaining a high level of human perception of the robot.

Building upon the results of an initial user study, we propose a framework enabling the robot to estimate the human agent's leading/following preference. However, the human agent's preference is not the sole factor influencing the robot's decision-making process; the human agent's performance is also crucial for adjusting the team's overall performance, particularly in cases of the human agent's poor or suboptimal performance. Consequently, the robot also estimates the human agent's performance. Furthermore, the robot needs to be capable of updating the task state based on both agents' actions and mistakes. With an updated understanding of the human agent's performance, leading/following preference, and task state, the robot updates its plan for task allocation and scheduling to minimize collaboration costs.

Next, we evaluate the adaptability of the task planning framework and algorithm in a simulation environment, demonstrating its effectiveness across various human performance and preference scenarios. Yet, recognizing the unique challenges posed by human participants, the complete evaluation of the algorithm's effectiveness requires real-world scenarios, considering uncertainties inherent in human behavior and decision-making.

Preference and Performance-Based Adaptive Task Planning in Human-Robot Collaboration (Page 2/2)

Ali Asl

Subsequently, we tackle the challenges of implementing the task planning framework on a real robot, a mobile manipulator robot, within a carefully designed collaborative scenario. Providing details on the experimental setup and methodology, a system evaluation study highlights the robot's ability to adapt based on human behavior. Finally, we conducted a user study involving 48 participants, evaluating results from multiple perspectives, including participants' perception of the robot, tasks, and collaboration, participants' actions and performance, and the robot's actions and performance. Results from the study affirm the success of the task planning framework in achieving its objectives: enhancing team fluency by considering the human agents' preferences and performance while maintaining a high level of participants' perception of the robot and the human-robot collaboration.

This research also explores participants' leading/following preferences in collaboration, revealing a dominant preference to lead the robot. This finding can assist robotics and autonomous systems designers in considering this factor in their designs. Additionally, we evaluated the influence of participants' leadership and followership styles on their collaboration, warranting further and more in-depth future studies.

In summary, this research contributes a proactive task planning framework that takes into account both human leading/following preferences and performance, signifying an advancement in the field of human-robot collaboration. The validation through user studies offers valuable insights, laying the groundwork for future research and applications in the continually evolving domain of human-robot collaboration.

Session 2: Human Factors and Ergonomics

Comparing 2-Level and 3-Level Graded Collision Warning Systems Under Distracted Driving Condition

Khatereh Shariatmadari

This study delves into a comprehensive exploration of driver performance by comparing the effects of a three-level graded collision warning system with those of a two-level graded system. Employing a within-between-subject design, the experiment seeks to unravel the nuanced impact of graded warning levels (2-stage and 3-stage) on driving performance in both normal and critical driving conditions. Forty participants will be recruited to undergo meticulous testing within a controlled driving simulator environment.

The experimental setup involves dividing participants into two groups, each exposed to distinct collision warning paradigms. The first group experiences a two-level graded warning system, while the second group encounters a three-level graded warning system, structured based on time-to-collision (TTC) metrics. Each participant will drive eight scenarios, including four normal and four critical scenarios. All participants will be asked to complete a secondary task to provide driver distraction during all scenarios. This strategic design allows for a comprehensive evaluation of the influence of warning system intricacies on various facets of driving behavior.

The study encompasses an array of dependent variables, including eye-tracking data, wristband-derived physiological metrics, driver response times, and the incidence of collisions. This multifaceted approach ensures a holistic understanding of the drivers' reactions under different collision warning paradigms.

The significance of this research transcends the confines of experimental design, reaching into the realms of practical road safety. By shedding light on how distinct collision warning systems impact driver behavior and performance, especially in scenarios of distracted driving, the study aims to contribute valuable insights. These insights, in turn, hold the potential to inform the development of advanced collision warning systems, ultimately elevating road safety standards and mitigating the frequency of collisions. This research not only expands the current understanding of collision warning systems, but also serves as a catalyst for innovations that align with the evolving landscape of driver safety in an increasingly complex driving environment.

Remote Medical Diagnosis in Virtual Reality: Perceptions from Patients and Physicians (1/2)

Mustapha Unubi Momoh

Virtual Reality (VR) has the potential to enrich patient-doctor interactions and overcome the limitations of existing telehealth platforms. The ideal VR solution for remote patient diagnosis would offer an immersive virtual environment, replicating the experience of both the patient and the physician having a one-to-one meeting in the same physical space. To facilitate the implementation of well-tailored VR solutions and set them up for a broader acceptance, it is necessary to understand the stakeholders' perceptions and expectations as well as identify the concerns and needs that VR telehealth should respond to. Therefore, we address two (2) research questions: RQ1: What are the concerns of patients and physicians about VR telehealth, as opposed to concerns regarding in-person healthcare and traditional telehealth? RQ2: How can VR telehealth respond to the needs of both patients and physicians to improve their experience with telehealth?

Technical challenges were frequently cited in the study; however, they were especially voiced for VR telehealth, owing to the perceived complexity of VR systems relative to traditional platforms. This corroborates the technology acceptance model's (TAM) position that perceived usefulness significantly influences the acceptance of computer systems [15]. Connectivity issues stood out in VR telehealth indicating a heightened concern about bandwidth needed for the transmission of high-quality VR graphics. All six physicians agreed that VR telehealth would be suitable for non-physical examinations including group counseling, psychiatry, and follow-ups. However, they maintained that to improve VR telehealth's appeal, several concerns need to be addressed. These include resolving payment responsibilities in advance and shifting from the current volume-based billing to outcome-oriented billing that incentivizes quality care. They propose that VR telehealth should include features that allow support persons like family members to join VR sessions for patients needing assistance, and allow for smooth integration of remote monitoring devices, like heart monitors.

Remote Medical Diagnosis in Virtual Reality: Perceptions from Patients and Physicians (2/2)

Mustapha Unubi Momoh

Designers of VR telehealth systems must address the identified adoption barriers. To address the issue of payment, the right billing infrastructure needs to be implemented. Moreover, all payment liabilities must be figured out prior to implementation, i.e., whether the government, health insurance company, or the patient will be responsible for payment. Developers should ensure that the telehealth platform is approved by the relevant regulatory bodies. Such approval is necessary to build users' trust in the system as a reliable Software as a Medical Device (SaMD). To foster safe adoption of VR telehealth, the public should be made aware of, and trained on the use, benefits, and limitations of VR telehealth. Telehealth might be best utilized when a hybrid model is followed whereby the initial diagnosis is done in-person, and the follow-ups are done virtually when possible. The system should simplify rather than complicate the existing workflows of physicians.
VR platforms should integrate seamlessly with remote monitoring devices and allow for the inclusion of support persons like family members in VR healthcare sessions.

Innovation and Technology Acceptance in Community Hospitals: A Human Factors Based Investigation (Page 1/2)

Sana Allana

Health IT (Information Technology) has shown to positively impact patient outcomes, efficiency of care, and reduce administrative errors as well as rates of mortality, infection, and stroke (Alotaibi & Federico, 2017). However, despite Canada's increase in health spending from 11% to 13% of GDP (Gross Domestic Product) in 2022, only 3% is allocated to health technology, ranking 60th out of the 72 countries involved health technology spending (Hamoni et al., 2021). This scarcity of funds correlates with low technology adoption rates (Hamoni et al., 2021). Additionally, population density has been shown to affect health technology adoption, with the highest levels of adoption found in densely populated urban areas like Toronto, Vancouver, and Ottawa (Hamoni et al., 2021). Conversely, rural and community healthcare facilities face challenges due to insufficient resources, like infrastructure, funding, and specialized staff, exacerbated by their remote locations (Kijsanayotin et al., 2009).

Health systems can be defined as complex adaptive systems. The often-hidden relationships in these systems challenge the ability to control, predict, or even understand them in their completeness (Ellis et al., 2019). Thus, health systems should be planned and organized from a systemic perspective (Ciasullo et al., 2020). Therefore, a systemic discipline such Human Factors and Ergonomics (HFE) can provide valuable concepts, methods, and tools to improve the performance and quality of health systems. One can argue that given the sociotechnical nature of healthcare, HFE approaches should be a key element in the development of healthcare systems, providing a more complete understanding of work processes (Carayon et al., 2021). HFE aims making tasks easier, safer, and more effective. Consequently, HFE methods and principles are applicable in different phases of a system development. For instance, focusing on the application of Artificial Intelligence based technologies in healthcare, (Asan & Choudhury, 2021) highlight that still little research has been dedicated to real-world translations with a user-centered design approach, and AI studies in the healthcare have often ignored critical factors of ecological validity and human cognition, creating challenges at implementation (Asan & Choudhury, 2021).

Innovation and Technology Acceptance in Community Hospitals: A Human Factors Based Investigation (Page 2/2)

Sana Allana

In recent years, the integration of technology into healthcare has witnessed significant advancements, particularly in the realms of personalized medicine and the utilization of big data. Technological innovations, driven by processes such as streamlining, decision support, and automation, hold substantial promise for enhancing clinical practices related to diagnosis, treatment, and public health awareness. However, despite these promising developments, the widespread adoption of such technologies may not be uniformly positive, giving rise to disparities in healthcare access.

This research aims to uncover the perceptions, expectations, cultural nuances, and barriers to technology adoption at a community-level hospital in Ontario. To this purpose, we plan to apply methods like Cognitive Work Analysis (CWA) and Functional Resonance Analysis Method (FRAM) to better understand the integration of technology in the clinical workflow and workers' perceptions of these transformations. We expect the results will help identify barriers to technology implementation and support

Design and Evaluation of an App for Workplace Task Management for People with Mild Cognitive Impairment/Dementia

Sheida Marashi

Mild cognitive impairment (MCI) and dementia affect working capabilities in various ways, ranging from learning abilities to communication, speech, and even personality changes. Such alternations negatively impact a person's employment. Presently, most of the technology, services, and policies concerning MCI and dementia are centered on individuals with advanced dementia (e.g., late onset) who are beyond retirement age. As a result, technology design efforts for people living with dementia have primarily focused on safety, tracking, reminiscence, and communication with younger family members or caregivers. However, there has been limited research exploring the needs and requirements of people with MCI and dementia below the age of 65 (early onset dementia or EOD), especially toward technology design.

This Ph.D. research was inspired by a larger interdisciplinary and cross-Atlantic project, MCI/EOD@Work, which aimed to understand the work experiences of people with MCI/EOD and explore ways to facilitate their challenges through the lenses of engineering, psychology, occupational therapy, social science, and legislation. From a human-factors engineering/human-computer interaction perspective, we conceived and co-designed a novel task-documentation app named taskIt, aimed to provide a user-friendly format for people to create and store cheat sheets for their tasks. We co-designed and evaluated taskIt with both MCI/EOD and non-MCI/EOD participants, exploring its features, functions, and user experiences of potential users living with and without MCI/EOD through a qualitative approach. This seminar presentation discusses the background, co-design, and usability testing phases of taskIt's development and introduces an evaluative study planned to better assess the app's usability over the course of six weeks. To our knowledge, this study is among the first to involve people with MCI/EOD in every stage of a mobile app's design. We hope that the findings of this research will illuminate future design considerations for this population and encourage their inclusion and engagement in mobile app design.

Dynamic Alert Design Based on Driver's Cognitive State for Take-over Request in Automated Vehicles

Wachirawit Umpaipant

As automated driving technology and Advanced Driver Assistance Systems (ADAS) continue to improve and become increasingly widespread, it becomes crucial to understand and optimize the transition between automated driving and manual driving, known as takeover, in critical situations. It is important to consider the annoyance associated with alerts presented during takeover to optimize the effectiveness of the alert as alert higher intensity during the takeover could induce annoyance that may influence the performance while lower alert intensity is perceived as less urgent. (Gonzalez et al., 2012).

This study explores the effect of different takeover request alert designs tailored to cognitive state and vigilant level of the driver. The research undertakes dynamic alert design based on driver's vigilance level and workload with assumption to enhance urgency perception and hazard situation awareness without compromising the takeover performance and determine how different alert levels influence driver perceptions of urgency and their ability to execute takeover maneuvers effectively.

The experiment utilizes large-scale immersive driving simulation in Autonomous Vehicle Research & Intelligence Laboratory (AVRIL). The takeover alert design incorporates two levels of alert: mild and strong multimodal alerts, combining audio and visual message alerts on the dashboard. Participants engage in driving tasks using ADAS, specifically Adaptive Cruise Control (ACC) and Autopilot (AP), in four different highway scenarios. They are instructed to take over control upon encountering potential hazards on the road.

Participants are assigned a secondary task (typing) during the third and fourth scenarios to stimulate lower vigilance levels and higher mental workload while driving. One group receives a single set of alerts across all scenarios, with or without the secondary task, while another group receives two sets of alerts paired with the assigned secondary task. Quantitative data focuses on takeover performance, including driver reactions in braking, steering, lane positioning, and collision, along with physiological data on heart rate variability and eye tracking during the takeover period.
Qualitative data are also collected to assess participants' perceptions of the urgency and effectiveness of the alert. Underway investigation focuses on whether utilizing multiple levels of alerts corresponding to driver conditions can enhance the driving experience and improve takeover performance.

Session 3: Vision, Image & Signal Processing and Societal & Environmental Systems

Eliminating the Need for Ground Truth Information in Photometric Calibration (Page 1/2)

Chun Cheng Feng

Photometric calibration is a critical process that ensures uniformity in brightness across images captured by a camera. It entails the identification of a function that converts the scene radiance into the pixel values in an image. The goal of the process is to estimate the three photometric parameters - camera response function, vignette, and exposure time. Essentially, there are two primary approaches to photometric calibration - the joint optimization method and the sequential method.

The joint optimization method, as its name suggests, simultaneously optimizes the three parameters, leading to an inherent ambiguity known as exponential ambiguity. This ambiguity is a significant challenge in photometric calibration, particularly when attempting to simultaneously recover the camera response and exposure ratios from the intensity mapping which has multiple possible solutions. In contrast, the sequential method estimates these three parameters independently. This independent optimization, along with the assumption that the inverse response to be a polynomial function, effectively circumvents the exponential ambiguity inherent in the optimization process. However, previous implementations of the sequential method still relied on the ground truth of exposure time. In response to this, our model is constructed upon the sequential method, with further enhancements to improve its performance.

As mentioned, the current methods of photometric calibration rely heavily on ground truth information of exposure time in both approaches. This dependency poses significant challenges, as obtaining accurate ground truth information can be complex and resource intensive. Additionally, in most cases, the videos we want to work on don't come with ground truth. Therefore, our research presents a novel approach to photometric calibration that obviates the need for ground truth information by initializing the exposure ratio through pixel intensity.

Eliminating the Need for Ground Truth Information in Photometric Calibration (Page 2/2)

Chun Cheng Feng

Our experiments demonstrate that our method achieves similar results to those that utilize ground truth information, as evidenced by comparable root mean square (RMS) errors of the three photometric parameters. This indicates that our approach maintains the accuracy of photometric calibration and may be used for arbitrary videos where ground truth information is not provided. Furthermore, we have integrated our photometric calibration algorithm with a pixelwise trackers, such as PIPs, TAPIR, and MFT, enhancing the robustness and reliability of the system. We have conducted experiments combining these trackers with both joint optimization method and sequential method. Particularly, MFT shows the best results using the jointly optimization method, and it also works well with the sequential method. This combination of a robust tracker provides robust trajectories that lead to improved calibration results.

In conclusion, our research signifies a considerable advancement in the field of photometric calibration. We introduce a novel and effective method that not only addresses the challenges associated with the traditional reliance on ground truth information but also circumvents the exponential ambiguity problem inherent in the optimization process. Furthermore, we incorporate the use of a robust tracker, which enhances the trajectories of feature points, thereby improving the overall performance of our method.

Camera Calibration from Out-of-Focus Images

Ryan Schmalenberg

Our goal is to validate out-of-focus camera calibration methods proposed by previous authors, and to determine which methods return the greatest accuracy from out-of-focus blurred images. Using Zhang's method, we set out to validate Phase-shifted Circular Gradient (PCG) calibration patterns by comparing them to small circle, and concentric circle grids. To compare these methods, we measured the pixel value differences, and percentage differences in retrieved focal lengths when subjected to varying degrees of out-of-focus blur vs. an in-focus baseline for each method. To ensure repeatability and synchronization between experiments, a 7-DOF robot arm is used to facilitate calibration target positioning. The recorded set of poses is also used to mirror conditions in synthetic experiments. Real world experiments are also performed using a color E-Ink display to eliminate camera refresh rate synchronization issues.

Real-world experimental results show that when compared to grids of small yet still detectable circles, there is no relative advantage to using PCGs, even when using concentric circle correction methods. However, the averaged differences in focal lengths for PCGs vs. small circles are shown to be only 0.05% apart. It is hypothesized that the E-Ink display is unfavorable for use with PCGs due to its inability to render true grayscale, instead using display dithering to simulate grayscale. Synthetic experiments mirroring the real-world setup confirm that the averaged differences in focal lengths between PCGs and small circles are very close (0.048%), and accuracy is still slightly in favor of the small circles. However, the advantage of PCGs is confirmed to be continued detectability vs. small circles under higher levels of defocusing. These findings partially validate the work of previous authors.

In this work we use the Canny edge detector as the basis for ellipse fitting and center point localization. However, additional investigation using concentric circle patterns reveals that all methods are sensitive to the overall ellipse fitting techniques and parameters that are chosen. From here, further work can be undertaken to determine if better ellipse fitting techniques, such as Structured Forests edge detection can enhance either method. Fundamentally different localization methods such as techniques based on conservations of gradient flows could also be employed to determine if better localization is possible.

EV Charging Demand Optimization in Ontario

Diana Shakhova

In recent years, the penetration of electric vehicles (EV) significantly increased. The integration of the increasing number of EVs into the power grid is an open issue. The increasing and uncoordinated electrical load due to EV charging imposes significant challenges for the stable operation of the power grid. This thesis presents an Agent-Based Modeling (ABM) framework that incorporates survey-based travel data to predict the temporal distribution of EV charging demand within the province of Ontario. Multiple vehicles with varying battery capacities and usage profiles are simulated within the model.
By considering the purpose of each simulated trip from the data, assumptions can be made regarding the availability of charging infrastructure at specific destinations, facilitating realistic charging scenarios. Through simulation of parking durations, opportunities for EV charging during periods of vehicle stoppage are identified.To overcome the challenge of limited 1-day travel survey data, the simulation extends over 9 days to provide a comprehensive understanding of realistic battery levels and demand profiles on the 10th day.

In this context, time-varying pricing strategies are recognized as a pivotal tool to harness the flexibility of EV users, aligning their charging behavior with grid conditions and renewable energy availability. Dynamic pricing for EV charging can be seen as a special form of demand response, which refers to a procedure that motivates end users to change their electricity consumption, in response to financial incentives. Thus, integrating dynamic pricing strategies to simulate how pricing influences the decision-making process of EV users and, consequently, the 24-hour demand pattern, is the next goal.

In essence, this thesis represents a concerted effort to advance our understanding of the evolving dynamics of EV adoption and sets a base for implications for renewable energy integration and grid management. It aims to inform policy-makers, industry stakeholders, and researchers alike, as they navigate the transition towards a more sustainable and resilient energy future.

From Owners to Tenants: Financialization in an Agent Based Urban Model with Agglomeration Effects

Kirsten Wright

In the context of a widely-felt housing crisis, we explore how the capture of urban value by financial actors through the financialization of the housing market affects ownership patterns in urban areas, and the ultimate implications of these processes for urban productivity. We hypothesize that financialization induces a shift towards tenancy among the urban workforce that is likely to result in decreased urban productivity through a range of channels. To examine this hypothesis, we construct an agent-based model with a land market and production sector in which productivity scales superlinearly with city population. This work brings together urban agglomeration effects, Ricardian rent theory and a spatially explicit land market model in a novel way.

In our model, transportation costs determine the size of the city, and the available locational rents. Rising productivity increases wages and urban land values, so increased productivity is transferred to land owners. Investors attempt to capture these productive gains by purchasing land. These financial actors can bid against residents to purchase urban land. The interaction of agents determines the distribution of property ownership, city size, and wages. City size and wages provide a measure of urban productivity. The evolving pattern of property ownership tells us how residents are distributed between the tenant class and the owner class.

We then explore how financialization is likely to result in decreased urban productivity through a range of channels. When we add this link in the model, we see that financialization not only transforms the class structure of the city and the distribution of urban wealth, it disrupts the relationship between population growth and productivity, reducing the wealth and resilience of the urban system. To illustrate the uses of this kind of computational model for economic policy analysis, we run six policy experiments with and without the productivity link.

Contributions of this work include: integrating classical rent theory into an agent-based urban model; linking urban rent dynamics with urban productivity, and population growth; incorporating urban scaling literature into the model framework; examining the impacts of financialization on wealth distribution and urban productivity, creating a framework for a broader understanding of public policies in an urban system, and examining the qualitative effects of various public policies on wealth distribution, productivity, and class.

Session 4: Biomedical Engineering (BME), Modelling, Simulation & Systems Theory, and Mechatronic & Physical Systems

Photon Absorption Remote Sensing Probe for High Resolution Label-Free In Vivo Imaging

Jenna Veugen

In 2020, there was an estimated 18 million people newly diagnosed with cancer. Of those diagnoses, lung and colorectal cancer are the first and third most prevalent. Diagnosis in hard-to-reach places, such as the gastrointestinal tract or the lungs, typically includes endoscopic biopsies. However, most of the endoscopic procedures performed today have not changed in the past decade and still use white light and a camera to offer rudimentary images with little information. Hence, there is significant motivation to develop a method for optical biopsies where a diagnosis can be made in real-time with no resection required. However, no technology exists to date which can provide gold standard, real-time images for cancer diagnosis in-situ.

PARS is a recently developed imaging technique that relies on an excitation laser and detection beam to create absorption-based, all-optical high-resolution images in a label-free, non-contact format. The versatility and impact of PARS has been demonstrated in other works, including gold standard comparable histology-like images, retinal vasculature imaging and functional oxygen saturation measurements. However, this work has all been constrained to bulky benchtop systems, restricting the applications and clinical use of PARS in hard-to-reach regions such as the gastrointestinal tract or lungs.

This research looks at translating PARS to an endoscopic form factor using optical fiber. Previous work developing fiber-based PARS systems used both single mode fiber, and image guide fiber showing success in phantoms, however, neither achieved in vivo vasculature images using PARS. This work overcomes previous limitations by using a double-clad fiber for improved transmission and collection. This design also leverages a 532nm pulsed excitation to target hemoglobin in vasculature systems, while using a 515nm continuous laser as the detection beam. As chromatic aberration is a significant challenge in co-focused, multiwavelength systems, particularly when size constraints restrict the use of correction lenses, we opted to use two wavelengths as close as possible. Through combining both the dual green system and the double clad fiber, we demonstrate an improved all optical, absorption-based imaging probe with high resolution and excellent contrast. These improvements enabled the first successful in vivo imaging of vasculature using a PARS imaging probe and lay the groundwork towards a PARS endoscope to one day permit optical biopsies for real-time in-situ cancer diagnosis.

Developing a Validated Numerical Tool to Predict Cancer Cell Occlusion Location in a Circulatory System (Page 1/2)

Pouyan Keshavarz Motamed

Despite significant advances in early metastasis diagnosis, where, when, and how a secondary tumor is formed in a distant organ still puzzles scientists. The hematogenous spread of metastasis, one of the main ways of metastasis progression, occurs when primary tumor cells enter the bloodstream and circulate throughout the body. Therefore, studying genetic, biochemical, and biomechanical factors contributing to the spread of metastasis via the bloodstream could unravel the mentioned long-lasting question. Among these factors, the hemodynamic forces in the blood are instrumental in spreading metastasis, for the blood flow is the leading cause of transporting the circulating tumor cells (CTC) in the bloodstream throughout the body.

Besides, CTC survival, intravascular arrest, and extravasation are significantly impacted by shear stresses originating from their synchronous interactions with blood plasma, blood cells, and endothelial cells forming the inner layer of blood vessels. Although it is crucial to understand the impact of such interactions in the hematogenous spread of metastasis, superficial knowledge has still been obtained due to the elusive nature of the related phenomena. In-vivo and in-vitro experimental methods successfully replicate the microenvironment of CTCs in the bloodstream and have proved their capability to track cancer cells' fate. However, none can provide detailed insight into the mentioned interactions.

Developing a Validated Numerical Tool to Predict Cancer Cell Occlusion Location in a Circulatory System (Page 2/2)

Pouyan Keshavarz Motamed

Advanced numerical methods capable of accounting for the high deformability attribute of CTCs and fluid dynamic flowing in the delicate microcapillaries are put forward a promising technique to decipher CTCs' responses to the hemodynamic forces exerted on them in their microenvironment. Therefore, the primary purpose of this thesis is to take steps to develop such a numerical tool that can predict the CTC's fate till they are physically occluded after they are introduced to an arbitrary circulatory system. This tool benefits from the outcomes of a substantial numerical investigation into the relationship between the cell fate and mechanical factors existing in the blood, such as plasma flow rate, cell deformability, capillary geometry, and cell size when the cell is floating in (a) a capillary whose size is less than CTCs size (b) diverging bifurcated capillaries (c) converging bifurcated capillaries. For the tool to be validated, first, we developed a parameter identification method to realistically model the cell deformation behavior measured in a correspondence experiment. Then, we experimentally measured cancer cell motion and deformation behavior using constricted microfluidic channels and developed validated numerical cell models based on the experimental data.

It's worth mentioning that the in vitro microvascular networks are the first circulatory platform on which this tool will be applied since the capillary networks, fluid features, and cell motion can be captured quite accurately in such a platform.

Computational Study of Cancer Cell Adhesion in Curved Vessels Due to Wall Shear Stress Variations (Page 1/2)

Nahid Rahmati

Metastatic disease, characterized by the spread of cancer cells from a primary tumour to distant organs, remains the leading cause of mortality among cancer patients. Circulating tumour cells (CTCs) play a critical role in the metastatic process, with their behaviour in the bloodstream being a significant determinant of metastatic success. This study presents a quantitative investigation into the adhesion mechanics of CTCs in curved vessels, aiming to elucidate the factors contributing to secondary tumour formation. Using computational fluid dynamics, blood plasma and deformable CTCs were simulated in a curved microvessel employing the lattice Boltzmann method and a spectrin-link membrane model. This allowed the examination of fluid-structure interactions and cellular adhesion using the immersed boundary method within the Hemocell framework. The results show that CTC adhesion dynamics differ significantly between curved and straight vessel environments due to variations in wall shear stress (WSS). In a curved vessel, WSS varies, rising by 58.5% at the maximum shear section and falling by 25% at the minimum shear section. These fluctuations result in distinct patterns of cell adhesion and migration. Specifically, in curved vessels, force fluctuations range from 50.41 pN at the minimum shear section to 195.98 pN at the maximum shear section, which is significantly different from the constant 75.41 pN force observed in straight vessels. Additionally, the axial velocity of CTCs varies significantly, with a decrease from 0.84 mm/s at the minimum shear section to 0.29 mm/s past the maximum shear section in curved vessels, as opposed to a uniform 0.68 mm/s in straight vessels. Consistent shear stress in straight vessels leads to predictable CTC deformation and interactions with endothelial cells. However, in curved vessels, the fluctuating WSS leads to unstable adhesion dynamics in regions of low shear and increased bond formation in high-shear regions, which may enhance the likelihood of metastasis. Our results demonstrate that the architectural complexities of blood vessels, such as curvature, significantly influence the adhesion and migration behaviour of CTCs. The variability in WSS due to vessel curvature not only affects the physical integrity of CTCs but also their interaction with the vessel wall, which could lead to varied metastatic outcomes. Additionally, our study highlights the potential of vessel tortuosity as a predictive measure for metastasis risk. Increased tortuosity amplifies the mechanical stimuli on CTCs, leading to greater deformation and slower movement in high-shear regions, which could facilitate extravasation.

Computational Study of Cancer Cell Adhesion in Curved Vessels Due to Wall Shear Stress Variations (Page 2/2)

Nahid Rahmati

Our findings also suggest that there is an optimal cellular stiffness for CTC extravasation, as cells that are too soft or too rigid demonstrate reduced adhesion, highlighting the complexity of the metastatic process. In conclusion, our study provides a detailed computational model that advances our understanding of the mechanical aspects of CTC behaviour in microcirculatory conditions. By identifying the impact of vessel architecture on CTC adhesion and survival, this work lays the groundwork for the development of personalized therapeutic strategies aimed at mitigating metastatic spread based on individual vascular and tumour cell characteristics.

Towards Humanoids Using Personal Transporters Designed for Humans

Vidyasagar Rajendran

Human bipedal locomotion is efficient, robust and versatile, but typically reserved to reach targets in the close vicinity. As soon as larger distances have to be covered, humans tend to rely on wheeled modes of transport in the form of cars, bikes, scooters etc. Having the flexibility to choose a personal transporter (PT) such as a Segway when needed, is also an interesting option for humanoids operating in the real world, but it requires the ability to control a device that has its own complex dynamics.

Implementing methods to endow bipedal humanoids with the skills to operate personal transporters (PTs), such as scooters, Segways (Segway Inc., New Hampshire) and electric skates is an option with several advantages. First, it keeps the humanoid's form-factor close to a human's and maintains bipedal walking capabilities. Secondly, it allows humanoids to conserve their energy while efficiently travelling longer distances.

Operating PTs with humanoids is challenging. However, like many other humanoid tasks, it can be broken down into subtasks such as environment recognition, state estimation, path planning and whole body motion computation. To operate a PT, humanoids should be able mount and dismount the PT, sit or stand on the PT stably and control its command inputs (e.g., handlebar for steering and pedals for linear velocity). In this work, we synthesize controllers for the the humanoid robot REEM-C to ride a Segway in simulation, motivated by human Segway riding. We perform motion capture experiments of a human riding a Segway and identify human whole-body behaviour as well as the Segway's internal controllers. We then show that the REEM-C can successfully generate translational, rotational and mixed motions of the Segway in simulation. The Segway is controlled by targeted motions of the REEM-C using an inverted pendulum based LQR controller for pitch control and an admittance controller for the LeanSteer to command a yaw-rate. After these promising simulation results, the next step will be implementation on a real Segway and the REEM-C humanoid.