UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING
Department of Systems Design Engineering

2026 Systems Design Engineering Graduate Symposium

Tuesday, April 7, 2026

Faculty Hall
PSE (E7)-7303/7363

Schedule

April 7, 2026
PSE
7303/7363

9:30 am-10:00 am

Welcome Coffee

10:00 am-11:00 am

Session 1: Optimization and Mechatronic Systems
Chairs:
Speakers: Amir Taheris, Lin Huang, Cody Raycraft, Narenkrishna Thambidurai

11:15 am-12:30 pm

Session 2: Biomedical Engineering
Chair:
Speakers: Paul Wolfe, Atusa Ghorbani Siavashani, Ana Mahdi, Maomi Loughlin, Noah Franco

12:30 pm-1:30 pm

Pizza Lunch

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

1:30 pm-3:00 pm

Session 3: human Factors, AI and Image Processing
Chair:
Speakers: Marco Moran Ledesma, Fariha Muqtadir, Naomi Paul, Tina Tang, Andrie Perez, James Vandersluis

3:00 pm-3:20 pm

Closing Remarks: Nasser Lashgarian Azad

Session 1:
Optimization and Mechatronic Systems

Comparing Electricity Market Configurations: Transmission, Distribution, and Peer-to-Peer

Amir Hossein Taheri

The landscape of electricity markets is evolving rapidly in response to increasing penetration of distributed energy resources (DER), electrification of transport, and changing consumer behaviours. The utilization of DERs, although beneficial for flexibility, congestion relief, and decarbonization, poses some challenges to the traditional distribution electricity network, particularly because they cannot participate in the traditional wholesale market due to their typically small size, weather-dependent intermittent operation, market eligibility rules set by independent system operators, and market-clearing complexities. Therefore, there is a compelling need for a new market structure to accommodate such participants and accompany the existing market.
As the electrical network architecture transforms to accommodate DERs, changes in the electricity market structure warrant further investigation. At the moment, there is no consensus on the distribution-level electricity market structures or their viability in combination with other electricity markets. Hence, in this study, we examine the addition of P2P transactions and a new distribution-level market to the existing wholesale market and compare their integration with the traditional wholesale market across four scenarios to validate their viability, which helps demonstrate the potential and shortcomings of each market.

This study proposes a mathematical formulation to minimize the total costs of transactions, including both energy generation costs and administrative overhead fees. The simulation evaluates residential, commercial, and industrial consumers. We assessed the integration of localized trading and distribution-level market by comparing four distinct market configurations:

1. A baseline relying exclusively on the traditional wholesale market at the transmission system operator (TSO) level.
2. A combination of the wholesale market with decentralized peer-to-peer (P2P) transactions.
3. Introducing a new market at the distribution system operator (DSO) level alongside the traditional wholesale market.
4. A comprehensive configuration granting participants access to TSO, DSO, and P2P markets.

Relying solely on the TSO as we do today, prices are expected to escalate exponentially. The introduction of DSO and P2P markets helps moderate costs by decentralizing and diversifying the supply, where the combination of TSO and DSO markets yields the lowest total cost among the four scenarios and improves cost efficiency by approximately 62%, compared to the traditional wholesale market.
P2P transactions need to be treated carefully. In the scenarios above, P2P performed well compared to TSO because P2P was able to displace more expensive generation units that would have otherwise been dispatched in their absence. However, the P2P market did not perform as well as the DSO because its costs could not compete at a larger scale. Therefore, the value of P2P is highly sensitive to the specific situation, and its use should be deployed with care.

The proposed model and developed framework of this study serve as a tool for policymakers, regulators, and system operators to evaluate and identify the most suitable market structure. The model can be adapted to different regional electricity market conditions, and allows for comparison between various combinations of localized trading (P2P), distribution-level flexibility (DSO), and wholesale balancing (TSO).

Optimization-Guided Design and Experimental Characterization of a Sub-THz Micro Circular Log-Periodic Antenna

Lin Huang

Terahertz and sub-terahertz antennas are increasingly important for next-generation sensing and imaging systems, yet achieving broadband operation together with compact size remains a significant design challenge. This work investigates the design and experimental characterization of a micro circular log-periodic antenna (MCLPA) for sub-THz broadband thermal radiation detection. The MCLPA is an attractive platform because its compact circular topology preserves the broadband behavior of conventional log-periodic antennas while remaining highly compatible with standard microfabrication processes. In this research, advanced optimization-guided design methods, specifically a multi-objective Genetic Algorithm (GA) framework, are utilized to systematically tailor the complex antenna geometry for improved bandwidth, stable impedance behavior, and enhanced radiation performance.

Beyond the theoretical design stage, this work heavily focuses on the practical engineering challenges of experimentally validating fabricated sub-THz antennas in the absence of conventional vector network analyzer characterization in the target frequency range. The proposed measurement approach utilizes broadband blackbody radiation as a thermal source. Quasi-optical coupling, achieved through PTFE interference elements and a plano-convex focusing lens, is employed to shape the incident wave. Subsequently, a high-impedance DC readout system is used to probe the integrated antenna-detector response. This framework enables a relative, frequency-averaged evaluation of antenna performance under strictly controlled thermal excitation.

A major emphasis of the study is the development of a robust measurement methodology tailored for extreme weak-signal detection. At the sub-THz spectrum, the authentic microvolt-level electrical response can be entirely obscured by millivolt-level environmental electromagnetic interference (EMI), thermal drift, contact instability, and alignment errors. The experimental work therefore aims to establish highly reliable procedures for calibration, signal averaging, repeatability testing, and active noise mitigation. Specifically, the integration of custom low-noise pre-amplification and physical shielding is explored to extract the true DC response. Key performance indicators to be examined include sensitivity, directional response, temporal stability, and relative radiation efficiency under identical illumination conditions.

By connecting optimization-guided antenna design with experimentally feasible sub-THz

characterization techniques, this work contributes both a highly compact broadband MCLPA platform and a practical, reproducible validation methodology. Ultimately, this framework bridges the gap between electromagnetic simulation and real-world testing, supporting future thermal detection and sensing applications.

Towards more robust, non-invasive, blood oxygen measurement, and malaria detection.

Cody Raycraft

Vision is hugely important for human life and well-being, and blood oxygen has been shown to be a valuable biomarker for many critical ocular diseases, including age-related macular degeneration, diabetic retinopathy, and glaucoma. This project aims to develop two tools for ophthalmic research and development. The first tool is microfluidic channels with bifurcating elements that can simulate the retinal veins and arteries, with controlled and known blood oxygen levels. The second tool is a near-infrared photon-absorbance remote sensing (NIR PARS) system that aims to be able to accurately differentiate between oxygenated and deoxygenated blood of the retina using non-visible near-infrared wavelengths.

The microfluidic channels created a platform for testing and evaluating different retinal oximeters, with controlled blood oxygenation and flow speed. The designed channels feature 4 different designs, each of which targets a different challenge faced when using in-vitro phantoms for evaluation. The first design features a straight channel that is clear on both sides, which is beneficial for general use in both transmission and reflection-based optical systems. The second design features a bifurcating channel meant for evaluating blood flow, particularly with optical coherence tomography angiography (OCTA). Finally, the third and fourth designs repeat, but use an opaque surface on one side for a better signal when used with reflection-based systems, such as visible PARS. The size of these channels is 30 μm in depth, and 100 μm in width for the straight channel, and between 64 μm and 32 μm in width for the bifurcating channel. This gives a size profile similar to that found in retinal arteries and veins, and the channels are also compatible with the range of speeds found in retinal arteries and veins. The microfluidic channels are also being used in a study exploring blood oxygen measurement and malaria detection, in the presence of a magnetic field, in a process similar to that of an MRI. This study has shown a decrease in flow rate through the channels with the presence of a magnetic field, with simulated malaria.

The NIR PARS system aims to be a more robust ophthalmic system that focuses on using light that is non-visible to cause less potential discomfort to the patient. This system uses 3 different wavelengths of light: 760 nm, 800 nm, and 850 nm as excitation wavelengths. These are centred around the isobestic point of oxygenated and deoxygenated hemoglobin at 800 nm, to allow for easier blood oxygenation measurement. For the collection of the PARS signal, a 970 nm detection laser was also selected to minimize the potential chromatic aberration between the excitation and detection wavelengths.

Overall, this project aims to create two tools for better oximetry research by improving the effectiveness of in-vitro phantoms for optical design and creating a retinal oximeter capable of non-invasively and invisibly determining blood oxygen.

Robotic Closed-Loop Navigation of Ultrasound-Guided Magnetic Microrobots

Narenkrishna Thambidurai

Magnetically actuated microrobots have significant potential for minimally invasive medical procedures, including targeted drug delivery and intraluminal diagnostics. These robots are typically wireless, externally actuated systems operating at micrometer to sub-millimeter scales, enabling navigation through confined biological environments without onboard power or tethering. Recent studies have demonstrated the promise of magnetically steered miniature robots for biomedical tasks such as localized therapy and navigation in confined anatomical environments [1], while emerging robotic systems have begun exploring integrated imaging and navigation frameworks for microrobot control [2]. Despite these advances, practical deployment of such systems requires reliable closed-loop control that integrates real-time imaging, localization, and actuation within a unified robotic framework.

This project presents the development of an automated control pipeline for magnetic microrobot navigation that integrates ultrasound-based imaging, magnetic actuation, and robotic manipulation into a coordinated system architecture. The proposed system combines an external magnetic actuation platform with ultrasound imaging to enable microrobot localization and guidance within a confined lumen environment. A magnetic actuator consisting of a permanent magnet mounted to a motorized mechanism generates controllable magnetic fields used to steer the microrobot, while robotic positioning platforms enable precise and repeatable placement of both the actuation system and imaging device.

A key component of the system is an imaging-based feedback pipeline developed for ultrasound guidance. Image processing methods are used to identify the lumen structure, detect the microrobot within the imaging field, and determine navigation targets along a desired path. These outputs enable continuous microrobot tracking and provide positional feedback that informs the actuation system during navigation.

Preliminary integration demonstrates the feasibility of linking ultrasound-derived microrobot localization with magnetic actuation commands, establishing the foundation for automated microrobot guidance. By connecting imaging feedback with robotic actuation within a unified control framework, the system moves toward enabling closed-loop navigation of microrobots in constrained biological environments.

Narenkrishna Thambidurai

Future work will focus on implementing real-time processing and integrating robotic manipulation of the ultrasound probe to complete a fully autonomous imaging-actuation loop. Such a system would enable ultrasound feedback to dynamically guide magnetic actuation, supporting precise microrobot navigation for biomedical applications.

References

[1] A. Khabbazian et al., “Kidney stone dissolution by tetherless, enzyme-loaded, soft magnetic miniature robots,” Advanced Healthcare Materials, vol. 14, no. 23, Art. no. 2403423, 2025, doi: 10.1002/adhm.202403423.

[2] E. Luk et al., “RENAL: Robot enhanced navigation and localization,” in Proc. Int. Conf. Manipulation, Automation and Robotics at Small Scales (MARSS), 2025, pp. 1–5, doi: 10.1109/MARSS65887.2025.11072738.

Session 2: Biomedical Engineering

Neuromodulatory Enhancement of BCI Critical EEG Features: Site Specific iTBS Effects on Movement Related Cortical Activity

Paul Wolfe

Self-paced voluntary movement triggers a coordinated cascade of cortical activity that can be measured through the movement-related cortical potential (MRCP) in the time domain and event-related spectral perturbations (ERSP) in the time–frequency domain. The MRCP arises mainly from the supplementary motor area (SMA) and primary motor cortex (M1), while ERSP reflects desynchronization and synchronization in frequency bands such as alpha and beta rhythms during movement preparation and execution. These signals form the basis of several brain–computer interface (BCI) systems used in neurorehabilitation, but their effectiveness depends on high signal quality, which is often limited by low signal-to-noise ratio (SNR). Although many studies aim to improve detection algorithms, few have attempted to enhance the neural signals themselves.

Intermittent theta burst stimulation (iTBS) offers a non-invasive method to transiently increase cortical excitability. This research investigates whether applying iTBS to M1, SMA, or both regions sequentially can enhance the neural correlates of movement preparation and execution, thereby improving MRCP and ERSP salience. Across three experiments, participants performed a self-paced ballistic grip task before and after iTBS. MRCP components: readiness potential (RP), negative slope (NS′), motor potential (MP), and peak negativity (PN) were quantified, and ERSP changes in alpha and beta bands were analyzed during pre-movement and post-movement windows aligned with MRCP timing.

iTBS significantly modulated both MRCP and ERSP features, with distinct effects depending on stimulation site. Sequential M1+SMA iTBS enhanced the NS′, while M1 iTBS increased the MP. These differences suggest that sequential stimulation may preferentially influence intracortical SMA–M1 pathways. SMA iTBS produced a different pattern, suppressing the PN and leaving other MRCP components unchanged. Although the RP was unaffected across all experiments, SMA iTBS increased beta ERD during early preparation, whereas sequential iTBS reduced beta ERD in the same window. Following movement onset, sequential iTBS facilitated both alpha and beta ERS, while M1 iTBS showed a trend toward beta-specific ERS enhancement. SNR analyses revealed that only sequential iTBS significantly improved MRCP SNR, while alpha and beta SNR remained unchanged across all interventions.

Overall, the findings demonstrate that iTBS can meaningfully modulate neural signatures of motor planning. SMA-involving protocols appear effective for influencing early preparatory processes, which is valuable for many neurorehabilitation and BCI applications. Importantly, the results highlight that different iTBS protocols offer distinct advantages rather than a single optimal approach. Frequency-based BCIs may benefit from SMA-induced beta ERD enhancement, while MRCP-based systems may gain from the robust NS′ facilitation produced by sequential stimulation. By exploring three novel stimulation strategies, this research advances understanding of how iTBS can shape motor preparatory activity and improve the salience of neural signals relevant to rehabilitation and neuromodulation.

Enabling Human-Exoskeleton Co-Adaptation During Gait via Game Theory

Atusa Ghorbani Siavasgani

Mobility impairments continue to pose a significant global health challenge, with far-reaching consequences for both affected individuals and healthcare systems. Robotic exoskeletons have emerged as a promising alternative to conventional rehabilitation approaches, offering a potential for personalized gait training that can promote neuroplasticity and support functional recovery tailored to individual needs. Despite notable advancements in exoskeleton technology, a key remaining limitation is the lack of adaptability to the inherently dynamic and individualized nature of human gait. Most existing lower-limb exoskeleton controllers operate under the assumption that a user's motor capabilities and interaction patterns are static or evolve in a uniform and predictable manner across users. This oversimplification fails to capture the complex and unique progression of motor behavior during rehabilitation, particularly in individuals with incomplete Spinal Cord Injury (iSCI), who continuously adapt to the mechanical assistance provided by the exoskeleton. In this context, human-exoskeleton interaction should be conceptualized as a co-adaptive process, wherein both the user and the exoskeleton mutually adjust to optimize performance and recovery. The primary objective of this research is to deepen the understanding of co-adaptive control mechanisms in human-exoskeleton systems, with a focus on developing strategies that facilitate ongoing mutual adaptation. Such approaches hold significant potential to benefit a wide range of users, from older adults relying on exoskeletons for daily mobility to individuals with iSCI undergoing rehabilitation.

Furthermore, critical research gaps remain unaddressed in the use of exoskeletons for neurorehabilitation. First, since accurate modeling of human motor adaptation is complex, nonlinear, and varies across individuals, traditional models often fail to capture it. As a result, most control frameworks overlook human–exoskeleton co-adaptation, limiting their effectiveness in dynamic rehabilitation. Second, the objectives of the human central nervous system, which underlie adaptive behavior, are largely unknown. Inverse optimal control can infer these internal objectives, but its high computational cost makes it impractical for real time use. Finally, the role of biofeedback in shaping and accelerating co-adaptation, particularly during gait training with hip and knee exoskeletons, has been largely overlooked.

To address these gaps, this work first proposes a cooperative and a non-cooperative game theory-based controller that both conceptualize the human and the exoskeleton as two distinct yet interdependent optimal controllers, possibly allowing for a realistic representation of their interaction. Trajectory tracking performance as well as robustness to human behavior uncertainty for the proposed controllers are verified and compared via simulation. The non-cooperative game theoretic controller significantly outperformed the cooperative version. Subsequently, co-adaptation within this framework was then facilitated by iteratively updating the human cost function, thereby capturing the evolving nature of motor behavior. As verified by simulation, enabling co-adaptation reduced the trajectory tracking RMSE of the hip and knee joints by 16.6% and 25.3%, respectively. Moreover, pilot tests on one able-bodied user have further validated the suitability and performance of the proposed controller in real time. I hypothesize that with the proposed controller, co-adaptation of the human and the exoskeleton is enabled and can be effectively regulated by incorporating biofeedback, leading to enhanced rehabilitation outcomes.

A Robotic Rollator for Sit-to-Stand Transfer and Walking Assistance: Design, Biomechanics, Perception, and Clinical Feasibility

Anas Mahdi

Maintaining independence in older age depends heavily on safe sit-to-stand (STS) transfer and walking, yet many older adults with mobility limitations struggle with both tasks and face increased fall risk, physical effort, and reliance on caregivers. This PhD research addresses this problem through the development and evaluation of human-centered robotic mobility assistance built around SkyWalker, a robotic rollator designed to support both STS and overground walking. The work began with the design of a lightweight assistive robot that combines forward motion, vertical handle support, and walking assistance in a single platform intended for use in indoor and outdoor environments. Initial studies with healthy participants were used to establish the core assistance strategy and evaluate how predefined robot-guided STS trajectories influence biomechanics, comfort, and movement quality, while also confirming the feasibility of the platform for walking and maneuvering in realistic environments. Building on this foundation, the PhD then addressed the challenge of understanding the user's state in real time during close human-robot interaction. A vision-based perception framework was developed to estimate STS motion from close proximity using a depth camera and a reduced set of 14 kinematic features derived from visual skeleton tracking. Validation against motion-capture data showed that this approach could support real-time STS phase recognition with about 89% accuracy and a small phase-transition delay. This was important not only for monitoring, but also for enabling adaptive STS support, allowing the robot to respond to the user's current movement phase rather than relying only on hard-coded timing or fixed assistance behavior. The same perception framework was then extended into a dual-modular safety system for fall detection, combining regular STS phase classification with detection of irregular motion patterns associated with falling. This system achieved about 92% STS phase-classification accuracy, near-perfect offline fall classification, and an online delay of about 0.49 s before detecting abnormal motion. Most importantly, the work moved beyond laboratory validation to older adult patients with mobility challenges. In a clinical study conducted in a rehabilitation hospital, six older adult patients completed testing with robotic assistance and a conventional rollator. Robotic assistance reduced average perceived exertion, and biomechanical analysis showed that a Linear assistance profile produced more repeatable load transfer and was more robust than an S-shape profile. User feedback was generally

positive but varied across individuals, showing that feasibility alone is not enough and that assistance must better match user confidence, coordination, and comfort. These findings directly informed a second-generation robot that is now being built to address the challenges identified by older adults through improved user-centered design. Overall, this PhD contributes an integrated path from robot design and biomechanics to perception, adaptive control, and safety for safer mobility assistance in aging populations.

Distinct functional profiles of severe medial knee osteoarthritis during gait: A clustering approach

Naomi Loughlin

Knee osteoarthritis (OA) is a heterogeneous condition that often leads to compensatory movement patterns, yet conventional radiographic and clinical assessments do not fully capture this functional diversity. The aim of this study was to identify clusters of severe knee OA gait to investigate functional heterogeneity within the cohort. This study employed principal component analysis (PCA) on sagittal- and frontal-plane knee angle waveforms collected during walking from 153 individuals with severe medial knee OA and 24 asymptomatic controls. Two distinct subgroups of severe medial knee OA were identified using hierarchical clustering applied to gait speed, age, and the principal components accounting for a cumulative 80% of the variance in knee joint kinematic metrics across each plane. Clusters were compared based on patient demographics, clinical features (i.e. OA severity), and gait kinematics. Statistical Parametric Mapping (SPM) was applied to compare gait patterns across clusters with those of asymptomatic controls and to assess bilateral asymmetry.

Cluster 1 (n = 93) was 48% female, had faster gait speeds (1.10 m/s), a smaller proportion of severe contralateral knee OA (26%), more asymptomatic contralateral knees (28%), and displayed distinct gait deviations compared to Cluster 2 (n = 60), which was mostly female (70%), showed slower gait speeds (0.81 m/s), had a higher proportion of severe contralateral knee OA (47%), and fewer asymptomatic contralateral knees (15%). Significant inter-cluster differences were observed in gait speed, knee flexion features, sex distribution, and contralateral knee OA severity. SPM analysis showed that both clusters had altered frontal-plane kinematics throughout the gait cycle compared with asymptomatic controls ($p<0.001$) but differed significantly in sagittal-plane patterns ($p<0.05$). Bilateral asymmetry analysis showed that Cluster 1 exhibited significant ipsilateral-contralateral differences in frontal plane kinematics ($p<0.001$), suggesting active load redistribution, while Cluster 2 showed symmetric bilateral impairment.

These results show distinct gait-based phenotypes within severe knee OA, characterized by different compensation capacities and bilateral disease patterns, underscoring the limitations of traditional clinical variables and supporting the potential of gait-based analyses to refine OA classification and guide personalized interventions.

Microrobotic-mediated Gallstone Dissolution

Noah Franco

Cholecystectomy, the surgical removal of the gallbladder, is a common treatment for gallstones and their complications, including pain, infection, and inflammation. Despite its widespread use, with more than 330,000 procedures performed annually in North America, this treatment pathway has seen little innovation over the past 20 years, even though gallstones affect approximately one in three women and one in five men. The gallbladder plays important roles in both digestion and immune function, meaning its removal can have significant long-term consequences. Studies have linked cholecystectomy to increased risks of colorectal cancer, post-cholecystectomy syndrome, reduced quality of life, and limited treatment options for high-risk patients who are not eligible for surgery.

This research aims to propose a novel, non-surgical pathway to treat gallstone disease using millimeter-sized robots by dissolving stones locally using physical and chemical methods in a minimally invasive manner. The robots are fabricated with a PEGDA hydrogel with a permanent micromagnet embedded. A rotating magnetic field (RMF) can be used to actuate microrobots within a human body and propel them forward in a desired path. When combined with ultrasound imaging, these microrobots can be ingested orally or introduced through a catheter into the biliary system and navigated to the gallbladder. The navigation will be validated with a gallbladder-on-a-chip (GOAC) model as a microfluidic device fabricated with the biocompatible photopolymer, Cyto-Clear, developed in conjunction with CreativeCAD Inc. This research is composed of three main objectives: the dissolution of cholesterol gallstones by Ursodiol-β cyclodextrin complex; the remotely controlled navigation of the magnetic wireless microrobots through an anatomical model of the biliary system and gallbladder; as well as the integration of the highly localized drug delivery and mechanical disruption of the stones mediated by the robots within the GOAC device. The development of this proposed treatment will allow for dissolution of gallstones, as a safe, minimally-invasive surgery, without requiring the removal of the gallbladder.

Design and Evaluation of Haptic Simulators for Hands-On Clinical Examination of Ligament Injuries

Marco Moran Ledesma

We present the design and development of Flex-Knee, a low-cost ($400 CAD), scalable, and modular haptic knee model to support training in manual musculoskeletal injury assessment. The model is designed to help novice practitioners learn the valgus test, a clinical procedure used to assess medial collateral ligament (MCL) injuries through tactile cues such as soft tissue resistance and abnormal valgus motion. This test is typically practiced on classmates, who are usually healthy, limiting exposure to injury conditions and anatomical variability. Training with injured individuals is rare due to liability concerns and, even when available, represents only a single case among many possible injury possibilities. Developed in collaboration with a certified clinician, the model incorporates a generic mechanical joint (universal joint), silicone materials approximating the look and feel of human skin, a metamaterial-based approach to simulate MCL injuries, and embedded pressure sensors to capture applied forces. The system was evaluated in three stages: internal calibration with a clinician using a psychophysics procedure to configure four conditions (healthy and grades 1–3 injuries), acceptance testing with six additional clinicians, and a classroom showcase with kinesiology students. Certified clinicians distinguished between healthy, partially torn, and fully torn MCL conditions with sensitivities of 0.83, 0.75, and 1.00, respectively. Students were also able to perceive these differences, though further refinement is needed to better distinguish between grades 1 and 2 injuries. Participants particularly valued the model's realistic skin texture and anatomical form. This work demonstrates the potential of low-cost haptic simulators to provide standardized, safe, and repeatable training experiences, while enabling exposure to a wider range of injury conditions without relying on real patients.

A Structured, 360° VR Video–Based Evaluation Approach for Assessing the Communicative Effectiveness of eHMI Signals in Unsignalized

Fariha Muqtadir

The integration of Fully Autonomous Vehicles (FAVs) into mixed traffic environments presents significant challenges for pedestrian safety, particularly at unsignalized crossings where conventional driver-based cues are absent. Pedestrians often rely on subtle driver behaviors, eye contact, and other social signals to make safe crossing decisions; the absence of these cues in FAVs increases uncertainty and potential risk. External Human–Machine Interfaces (eHMIs) have emerged as a potential solution for facilitating FAV–pedestrian communication by explicitly conveying vehicle intent and actions. However, current evaluation efforts remain fragmented and lack methodological standardization. Common research methods, such as the Wizard of Oz technique, VR simulators, and video/photo-based studies, often rely on simplified behavioral measurements that fail to capture the complexity of real-world interactions. Many studies adopt ad hoc procedures to address narrow objectives, such as examining pedestrian crossing behavior in specific contexts or comparing preferences for visual, auditory, or multimodal signals, which limits systematic comparison, generalizability, and alignment with regulatory priorities.

This study develops an integrated evaluation approach that combines standardized metrics, scenario design, and immersive 360° VR video–based testing to assess the communicative effectiveness of eHMI designs under controlled yet realistic conditions. The framework incorporates human-centered parameters organized into two core constructs: usability—encompassing effectiveness through correct perception rate (CPR), efficiency through decision time (DT), and satisfaction, guided by ISO 9241-11—and safety, measured through situation awareness (SA) and surrogate collision risk (CR), aligned with U.S. Department of Transportation (USDOT) safety evaluation guidelines. By integrating perceptual and behavioral measures within a structured, replicable framework, this approach provides a comprehensive basis for evaluating pedestrian–FAV interactions across different scenarios and participant populations.

To ensure real-world relevance, a scenario-based framework was developed by analyzing patterns and contributing factors from a dataset of 8,000 pedestrian–vehicle collisions at unsignalized intersections in Toronto. This framework prioritizes conditions where signal clarity must not be compromised, specifically across vehicle maneuvers (straight, left, right), lighting conditions (day / night), visibility (clear / low) and age-based perceptual variability.

Three experimental studies were designed to demonstrate the applicability of the approach: (1) a planned comparison between 360 VR video-based testing and real-world field

experiments to examine ecological validity and assess the fidelity of immersive VR environments, (2) An investigation of vehicle embodiment effects, contrasting a low-profile Golf Cart AV with a full-sized SUV-type FAV, to evaluate the generalizability of eHMI signal interpretation across vehicle types. This study examines whether a single eHMI design can be consistently understood across different vehicle embodiments, and safety, and (3) an age-stratified assessment to explore perceptual and cognitive differences across participant groups, highlighting potential variations in eHMI comprehension and decision-making.

By enabling controlled, replicable, and systematically comparable assessments across vehicle embodiments and diverse participant groups, this work provides a regulation-aligned and reproducible approach for evaluating eHMI communicative effectiveness. The approach supports evidence-informed design decisions, offers a methodological foundation for subsequent empirical validation, and contributes toward more systematic, standardized evaluation of pedestrian–FAV interactions, providing guidance for both researchers and policymakers in the development and assessment of safe autonomous vehicle technologies.

Session 3:
Human Factors,
AI and
Image Processing

A Design Thinking Process for Digital Storytelling: An Example of Tipi Teachings in Virtual Reality

Naomi Paul

Digital storytelling is a modern twist on the narrative tradition which involves creating and sharing stories using digital tools and technology, including 360 cameras and extended reality. It is an extension of traditional oral storytelling that has the potential to influence and innovate the future of education. However, existing research which investigates the use of extended reality for education solely emphasizes learning outcomes such as presence and motivation rather than the process for developing the educational materials, leading to a lack of guidance on how to create digital stories including best practices and guiding principles.

For my work which aims to use digital storytelling to preserve and share Indigenous Knowledges, particularly within STEM fields at the post-secondary level, I have created a modified design thinking process for digital storytelling - specifically for the development of 360-degree videos and cinematic virtual reality - based on the six steps of the design thinking process, a common approach in the larger field of Research through Design. What makes this modified approach unique is that it places Indigenous Research Values, specifically Jo-Ann Archibald's 'Storybasket' values, at the foundation of the process, rather than as an add-on, with the goal of showing respect and minimizing the misinterpretations, appropriations, and weak translations that often result from the recording of stories.

I will present this process through an example titled 'Tipi Teachings'. Tipi Teachings is a 360-degree digital storytelling video created in the Spring of 2025 which shares a conversation between Elder Myeengun Henry (Chippewas of the Thames) and Kevin George (Kettle and Stony Point First Nation) about the knowledge and importance of the Tipi in Indigenous Engineering, including the values and ceremonial aspects of the Tipi that cannot be separated from its design. This example will be used to demonstrate how design thinking and co-creation can be successfully applied to digital storytelling.

A Human Factors Study on Gamelike Elements in End-of-life Decision-Making Tools

Tina Tang

Human Factors on Gameplay Mechanics of Serious End-of-Life Decision Making Tools

Background/Introduction

Serious end-of-life (EOL) games offer psychologically safer pathways for EOL conversations and in decision-making, using playful mechanics to reduce emotional barriers and facilitate value clarification. This project examines serious games as socio-technical tools, focusing on 3-7 existing EOL-related games (e.g., The Bite Size Future Kit, Hello Game, Life Café). The study investigates how gameplay structures interact with human factors, emotional processes, and care contexts to support or hinder EOL decision making.

The aim is to systematically characterize EOL serious games by identifying each game's purpose, intended users, use contexts, and design intent, while analyzing how specific mechanics (prompts, humour, rules, and artefacts) engage human factors like emotional safety, trust, and perceived control through gameplay observations and participant feedback. It seeks to quantitatively compare tools through usability and acceptance measurements, capture emotional and psychosocial responses (e.g., isolation, openness) and relate them to design features and contexts, evaluate practical and ethical considerations for EOL shared decision-making, and map relationships between gameplay experience and EOL decision-making factors using causal loop diagramming to reveal underlying feedback dynamics and design leverage points.

A mixed-methods approach combines a scoping review characterizing EOL serious games with qualitative interviews and workshops involving social workers, palliative care support staff, and palliative nurses. Workshop participants complete SUS (usability) and TAM (acceptance) surveys after each round of play and discuss patient impacts in groups. Survey data, based on Likert scales, receive descriptive statistical analysis. Interview data are recorded, transcribed, and undergo thematic analysis through semantic coding focused on game mechanics, human factors, and system constraints.

The study anticipates identifying game mechanics that reliably enhance emotional safety, trust, and patient engagement while revealing barriers such as cultural mismatches or workflow disruptions. SUS and TAM scores will enable quantitative comparison across tools, highlighting which games meet clinical adoption thresholds. Thematic analysis will capture psychosocial outcomes (reduced isolation, increased openness) and relate them to design features and contexts. Causal loop diagrams will map relationships between gameplay experience, human factors, and EOL decision-making factors, visualizing reinforcing loops (comfort → engagement → normalized EOL talk → confidence in EOL decision-making) and balancing constraints.

This systems engineering approach transforms EOL serious games from educational artefacts into engineered interventions that lower barriers to timely, values-aligned end-of-life decision-making. It supports a systems perspective that can reveal design patterns which strengthen or weaken conversations across different clinical and community contexts. The expected outputs will help designers, clinicians, policymakers, and other stakeholders better integrate serious games into broader EOL care systems and inform the next generation of decision-support tools. By mapping mechanics, human factors, and gameplay experiences across multiple games with differing structures, the study will identify design strengths, gaps, and leverage points to enhance the effectiveness, appropriateness, and scalability of both current and future EOL conversation tools.

Comprehensive Development and Signal Processing Advancements in Functional Optical Coherence Tomography: From System Design to Hemodynamic Preservation

Andrei Perez

Optical Coherence Tomography (OCT) has revolutionized non-invasive biomedical imaging by providing high-resolution, cross-sectional visualizations of biological tissues. As the technology evolves from structural imaging to functional modalities capable of quantifying blood flow dynamics, the engineering demands on both hardware and signal processing have increased exponentially. This abstract summarizes a comprehensive research endeavor spanning the development pipeline of a functional OCT system, from initial software architecture to advanced spatiotemporal denoising algorithms.

The first phase of this research focused on the architectural design and software implementation of a custom swept-source OCT system operating at a 1060 nm central wavelength. A robust software framework was developed from the ground up to acquire, digitize, and process raw interference fringes into volumetric structural images in real-time. Building upon this structural foundation, the system's capabilities were expanded to capture Optical Coherence Tomography Angiography (OCTA) signals.

Despite the success in capturing structural and angiographic data, the extraction of reliable, time-resolved functional metrics from 4D-OCT (volume over time) remains fundamentally bottlenecked by intrinsic speckle noise. Standard denoising techniques, such as Block-Matching 3D (BM3D), rely heavily on spatial self-similarity. While highly effective for cleaning static structures, these methods act as aggressive low-pass temporal filters. When applied to in vivo data, they flatten rapid, physiologically significant intensity fluctuations, such as the cardiac cycle, thereby destroying the temporal coherence required for accurate hemodynamic/functional analysis.

To overcome this critical limitation, the final phase of this research introduced Inverse Eulerian Video Magnification (iEVM) as a novel pre-processing framework. Operating in the spatiotemporal frequency domain, iEVM decouples structural frequencies from functional flow. By applying a frequency-selective damping mask, the algorithm aggressively suppresses high-frequency speckle noise while maintaining unity gain for the physiological flow band (estimated around 1–5 Hz).

Experimental validation on our custom OCT system demonstrated that iEVM not only achieves state-of-the-art structural speckle suppression but also actively preserves over 94% of the signal energy during significant intensity transitions. This allowed for the successful recovery of underlying hemodynamic waveforms and the high-contrast spatial mapping of distinct vascular columns that are otherwise completely washed out by standard spatial filters.

Ultimately, for functional 4D-OCT to reach its full clinical potential, denoising strategies

must look beyond static image quality. This research demonstrates that iEVM provides a robust, real-time solution that successfully decouples noise suppression from signal attenuation. By respecting physiological spectral boundaries, the developed end-to-end system achieves structural clarity while enabling the high-fidelity visualization of blood flow dynamics, paving the way for advanced, non-invasive extraction of functional biomarkers.

Optimizing Hybrid Primitive and Non-Primitive Rendering: A Cross-Platform C++ and WebGPU Architecture

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The evolution of the web into a high-performance application platform, fueled by WebGPU and WebAssembly (Wasm), challenges the historical dichotomy between global accessibility and the raw computational power of native C++ environments. Parallel to this architectural shift, 3D Gaussian Splatting (3DGS) has emerged as a transformative technique for photorealistic rendering, overcoming the geometric and labour-intensive limitations of traditional triangular meshes. While 3DGS enables real-time rendering, its heavy memory and computational demands pose significant challenges in resource-constrained environments. Current solutions include Gaussian model compression or hybrid approaches that enable the use of both primitive-based meshes and non-primitive models in the same scene. Although recent literature establishes the feasibility of hybrid rendering using C++ and the WebGPU Dawn backend, there is a distinct lack of actionable architectural guidance on low-level implementation details, such as vertex generation strategies and memory alignment. Furthermore, these hybrid pipelines lack rigorous performance validation concerning the trade-offs between reconstruction quality, computational cost, and memory usage.

This thesis addresses these gaps by presenting the design, implementation, and rigorous validation of a novel cross-platform rendering engine built with C++ and the Dawn WebGPU backend. To advance the development of high-performance web graphics, this research makes three primary contributions. First, we provide a comprehensive architectural blueprint for the rendering pipeline, explicitly detailing the geometric construction of splats as planar quadrilaterals (quads), per-splat quantization strategies, and hybrid scene compositing. Second, we evaluate the performance benefits of primitive-based meshes versus non-primitive models, empirically confirming that traditional meshes remain vastly more efficient for structural geometry than their volumetrically converted counterparts. Finally, we present what is, to our knowledge, the first rigorous empirical benchmarking of the compressed SPLAT format. Through extensive evaluation on the Synthetic NeRF dataset, we compare the inherently 8-bit (U8x4) SPLAT format and third-degree Spherical Harmonic (SH) PLY format utilizing full-precision (F32x4), half-precision (F16x4), and 8-bit (U8x4) colour quantization, against the reference implementation baselines to quantify the precise trade-offs between the various techniques. We identify that F16x4 quantization for PLY models yields significant memory reductions with negligible impact on perceptual quality, offering an optimal balance. Conversely, while the SPLAT format achieves the highest computational and memory efficiency, our evaluation reveals a distinct perceptual cost that restricts its viability to strictly

resource-constrained scenarios. Ultimately, this thesis delivers concrete, validated architectural guidance for deploying photorealistic, high-performance hybrid graphics on the modern web.