

Department of Engineering Science

IIT Hyderabad

Brochure for PhD admission

July 2026

Abstract of the proposed research topics

** For more details, please email to the respective
project investigators

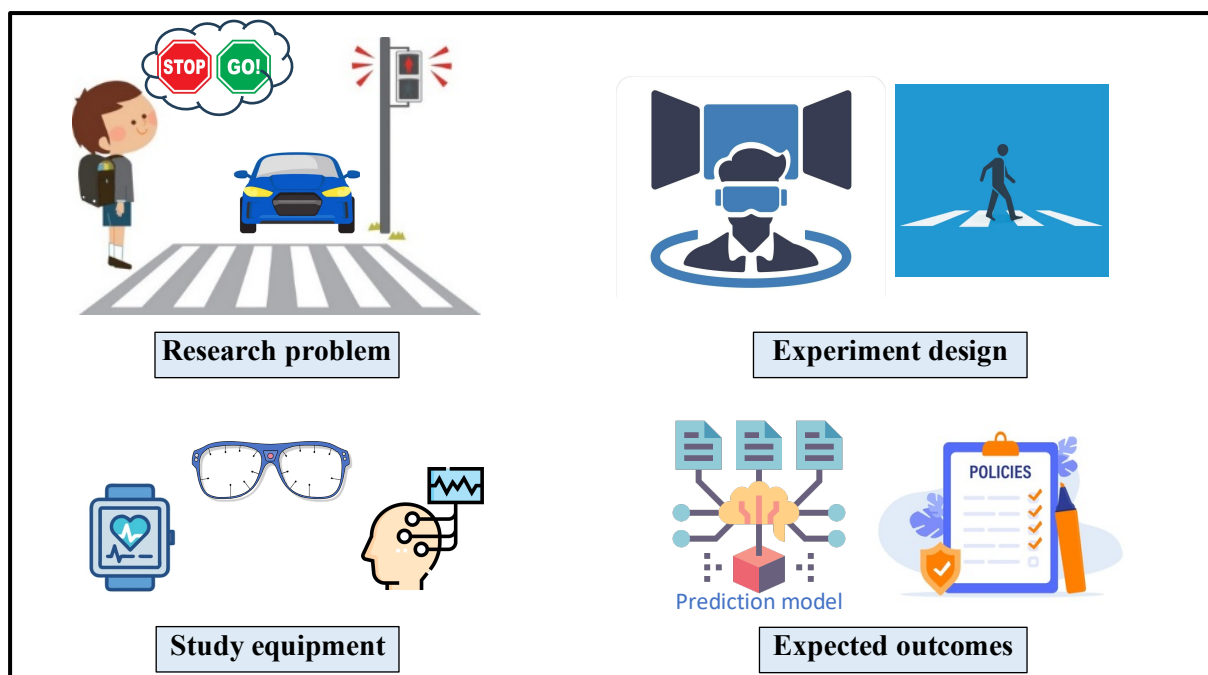
Understanding Child Decision-Making at School Zone Crossings: A Cognitive-Behavioral Approach

Dr. Digvijay S. Pawar and Dr. Neeraj Kumar

School zones in India remain high-risk environments for child pedestrians, with national crash statistics indicating a disproportionate number of injuries occurring during road crossings near educational institutions. Unlike adults, children exhibit developing perceptual-motor coordination, limited second-order information processing, and immature risk evaluation capabilities, which may impair their ability to accurately judge vehicle speed, acceleration, and available crossing gaps. Conventional road safety interventions in school zones are largely infrastructure-driven and rarely account for the cognitive and neurobehavioral mechanisms underlying child decision-making.

This proposed interdisciplinary Ph.D. research aims to integrate traffic engineering and cognitive science to investigate how children perceive, interpret, and respond to dynamic traffic environments during road crossing. Building on established gap acceptance modeling at uncontrolled mid-block crossings, the study will examine perceptual thresholds, reaction times, motor planning, and spatial judgment errors among school-aged children. Experimental paradigms may include controlled field observations, virtual reality simulations, eye-tracking, and cognitive load assessment to quantify decision latency, misjudgment of vehicle approach speed, and unsafe gap selection.

The project will further explore neurocognitive correlates of crossing behavior, including sensory-motor learning and attentional allocation patterns, to develop predictive behavioral models tailored to school zone environments. Outcomes will include age-specific safety thresholds, cognitive-based design recommendations, enhanced school zone traffic calming strategies, and evidence-based policy inputs. By integrating infrastructure analysis with cognitive neuroscience, the research aims to redefine school zone safety from a purely geometric problem to a human-centered cognitive systems challenge.



Non-Invasive Peripheral Neuromodulation for Real-Time Regulation of Acute Stress: A Brain-Body Systems Approach

Dr. Neeraj Kumar and Dr. Nagarajan Ganapathy

Stress is an important factor that determines mood, behavior, and overall health. Prolonged exposure increases the risk of cardiovascular disease, cognitive and behavioral disorders. In daily life, all individuals experience acute stress which induces measurable alterations across the brain-body dynamic's, including shifts in cortical electrophysiology, changes in hemodynamics, elevated heart rate, respiratory modulation, electrodermal activation, and peripheral vasoconstriction. Conventional stress management methods namely pharmacological approaches can reduce stress related symptoms but their applicability to acute stress is limited by side effects and lack of real-time adaptability. This limitation addresses the need for targeted, non-invasive neuromodulation technique capable of modulating autonomic tone during acute stress.

Transcutaneous Median Nerve Stimulation (tMNS) offers a peripheral, wrist-accessible neuromodulatory interface which mitigates acute stress by activating afferent sensory fibers that engage central autonomic control networks, resulting in suppression of sympathetic outflow and restoration of brain-body homeostasis. The overall block diagram for investigating stress induction and its modulation through tMNS is illustrated below in Figure 1.

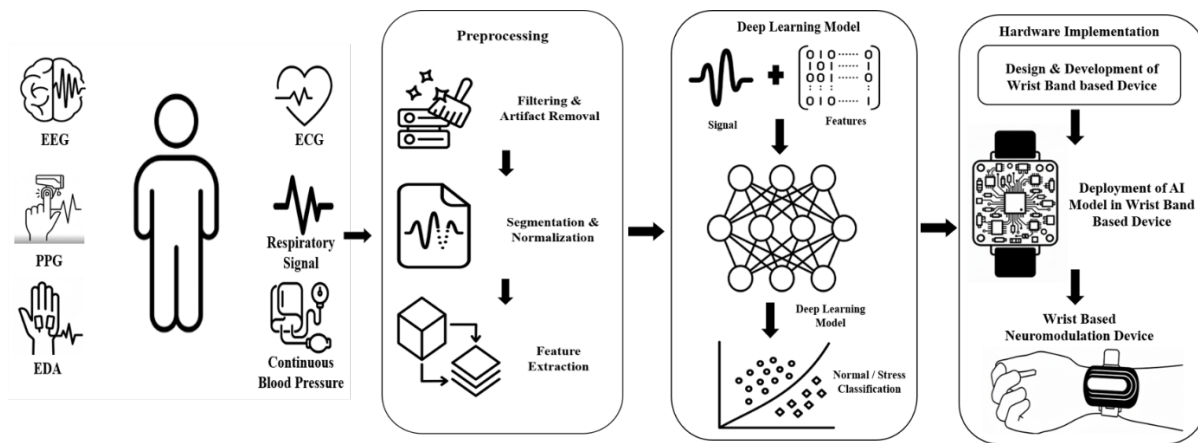


Figure 1: Overall block diagram for investigating stress induction and its modulation through tMNS

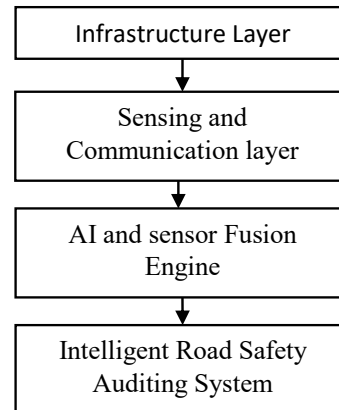
The proposed work aims to quantitatively characterize brain-body dynamics during acute stress and determine how peripheral neuromodulation regulates these interactions using synchronized multimodal physiological measurements, including electroencephalography (EEG), electrocardiography (ECG), photoplethysmography (PPG), respiration (RESP), electrodermal activity (EDA), and blood pressure (BP). The anticipated outcomes include to develop a wristband based peripheral neuromodulation wearable capable of continuous stress monitoring and targeted stimulation to enable real-time, closed-loop modulation of stress, thereby establishing a foundation for wearable, non-invasive neuromodulation systems for real-time stress regulation.

Data-Driven Road Safety Auditing Using Vision and Connected Vehicle Data

Dr. Digvijay S. Pawar and Dr. Abhinav Kumar

Road safety auditing (RSA) remains largely a manual and expert-driven process, conducted at multiple project stages by reviewing compliance with IRC codal provisions and through field inspections. While effective, this approach is time-consuming, subjective, and limited in capturing dynamic roadway-user interactions. With increasing traffic complexity, heterogeneous vehicle behavior, and the advent of connected mobility, there is a pressing need to transition from static compliance-based auditing to data-driven, real-time infrastructure assessment.

This proposed PhD research aims to develop an AI-enabled road safety auditing framework using multimodal sensing technologies such as vision-based systems, LiDAR, and vehicle-to-vehicle interaction analytics. By integrating roadside cameras, sensor fusion techniques, and communication-based vehicle trajectory data, the framework will automatically detect non-compliance in signage, geometry, sight distance, and pedestrian facilities while also quantifying risky maneuvers, unsafe headways, and conflict-prone zones. The project will bridge transportation engineering and intelligent sensing systems, enabling dynamic, evidence-based safety auditing. The expected outcomes include automated audit tools, real-time safety indices, scalable deployment models, and high-impact journal publications, positioning graduates at the intersection of transportation safety, AI, and smart infrastructure systems.

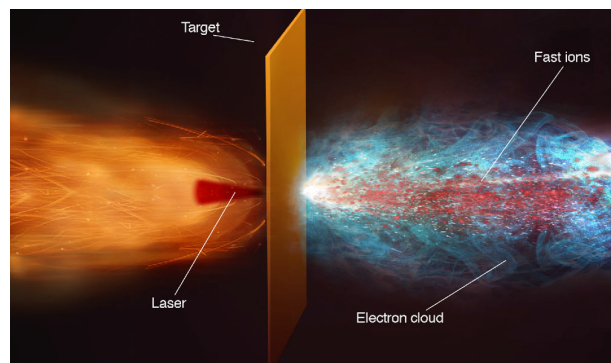


Intense Laser–Matter Interaction with Metamaterials

Bhuvanesh Ramakrishna and Himanshu Joshi

The interaction of ultra-intense femtosecond laser pulses with solid-density matter represents one of the most dynamic frontiers in high-energy density physics and relativistic plasma science. In recent years, advances in high-power laser systems have enabled access to extreme regimes where electromagnetic fields approach or exceed the internal fields binding electrons to atoms. Under such conditions, matter is rapidly ionized, forming dense plasmas in which relativistic electron dynamics, strong-field effects, and nonlinear processes dominate the interaction. However, efficient control of laser energy absorption and particle acceleration in such regimes remains a significant scientific challenge.

This PhD research aims to explore how engineered metamaterials — artificially structured materials with sub-wavelength features — can fundamentally modify and enhance intense laser–plasma interactions. Unlike conventional flat solid targets, metamaterials provide precise control over optical properties such as local field enhancement, resonant absorption, impedance matching, and spatial energy deposition. By tailoring nanoscale architectures, it becomes possible to manipulate electromagnetic fields at the interaction surface, thereby influencing plasma formation, electron heating mechanisms, and ion acceleration dynamics.



The central hypothesis of this research is that metamaterial structuring can significantly enhance laser energy coupling efficiency and enable controlled generation of hot electrons and energetic ion beams at reduced laser intensities. Periodic nano-arrays, plasmonic resonators, graded-density structures, and dielectric–metal composites will be designed and fabricated to systematically study their influence on relativistic laser absorption and plasma expansion. Special emphasis will be placed on field localization effects, resonance-driven absorption mechanisms, and the transition from pre-plasma to overdense plasma regimes.

The anticipated outcomes include enhanced laser absorption efficiency, controlled electron temperature distributions, increased proton cutoff energies, and improved repeatability of laser-driven acceleration processes. Such advances could significantly lower the intensity threshold required for efficient ion acceleration, enabling compact and cost-effective particle sources. Additionally, the research may open pathways for improved high-harmonic generation, bright X-ray emission, and novel radiation sources.

INVESTIGATING ANTIMICROBIAL PEPTIDES AND APTAMERS AGAINST ANTIMICROBIAL RESISTANCE USING AN INTERDISCIPLINARY APPROACH

Suhanya Duraiswamy¹ and Himanshu Joshi²

Antimicrobial resistance (AMR) is one of the top global health crises contributing to about 9% of all global deaths. It occurs when the bacteria, viruses, fungi and parasites no longer respond to antimicrobial medicines due to enzymatic degradation, efflux pumps, and biofilm formation. Antimicrobial peptides (AMPs) are 1-50 long amino acid that hold promises as a viable therapeutic approach against AMR. However, their effective translation to clinics is yet to be achieved. At the same time, aptamers *i.e.* short DNA or RNA molecules (20–70 nucleotide) that specifically bind to target molecules has been also proposed for combating AMR, although most applications are currently at the preclinical or diagnostic stage. Combinedly, these biopolymers (AMPs and aptamers) can be potentially used in three major ways: diagnostics, therapeutic inhibition, and targeted drug delivery.

In this project, we propose to integrate artificial intelligence (AI), physics based multiscale molecular modeling, microfluidic and microscopy techniques to enable rational design of AMPs and aptamers. AMPs primarily disrupt bacterial membranes or intracellular pathways, while aptamers offer highly specific binding to resistance proteins or virulence factors. Interactions of lipid and protein with the AMPs and aptamers will be investigated with systematic integration of computational design and rapid experimental validation.

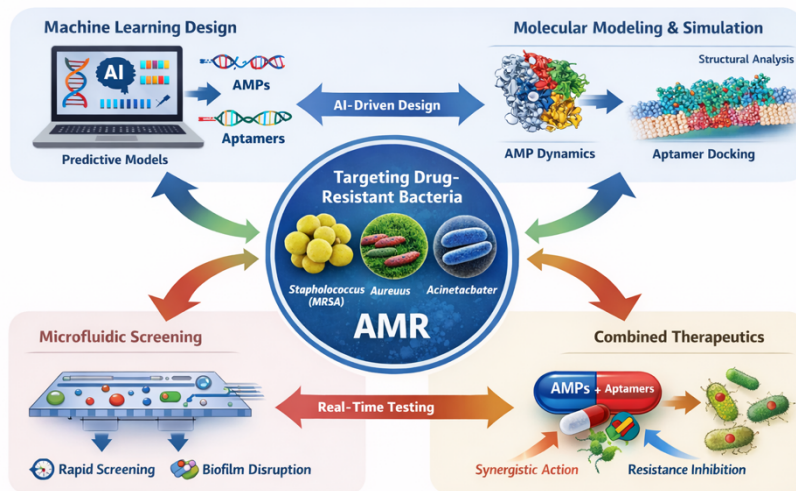


Figure: Investigating the biopolymers for combating AMR (AI generated image)

Synergistically combining the wide experience of both the PIs in soft matter research and resources available in their respective labs, this project is expected to help in developing scalable to evaluate the potential of AMPs and aptamers for translational antimicrobial discovery.

Reference:

1. Murray, Christopher JL, et al. "Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis." *The lancet* 399.10325 (2022): 629-655.
2. Wan, F., Wong, F., Collins, J.J. et al. Machine learning for antimicrobial peptide identification and design. *Nat Rev Bioeng* 2, 392–407 (2024). <https://doi.org/10.1038/s44222-024-00152-x>
3. Ulmschneider, Jakob P., and Martin B. Ulmschneider. "Molecular dynamics simulations are redefining our view of peptides interacting with biological membranes." *Accounts of chemical research* 51.5 (2018): 1106-1116.
4. Ni, Shuaijian, et al. "Recent progress in aptamer discoveries and modifications for therapeutic applications." *ACS Applied Materials & Interfaces* 13.8 (2020): 9500-9519.