Ultra-Low-Profile 10 mm Pre-Impact Threat Sensing Subsystem for Dynamic Smart Armor and Concussive Traumatic Brain Injury Mitigation

Principal Investigator: Frederick K. Amina III (*Brain Cells LLC*, famina@braincells.io)
Systems Architect: Binh Phan (*Studio PxG LLC*, systems@studiopxg.com) · **Jurisdiction:** Hawaii (EPSCoR)

Overview

Traumatic Brain Injury (TBI) and concussive trauma remain catastrophic hazards for Warfighters and contact athletes. Existing ballistic helmets and tactical armor are strictly *passive and reactive*: energy dissipation begins only after mechanical contact occurs, transmitting destructive peak stress waves and rotational accelerations to the cranium. Brain Cells LLC is developing an ultra-low-profile (≤ 10.0 mm), edge-intelligent **Pre-Impact Threat Sensing Subsystem** that integrates an 8×8 SPAD Time-of-Flight (ToF) optical matrix with a 360° radial embedded optical fiber network. The subsystem senses incoming high-velocity projectiles or blunt impacts in flight, computing closing vectors ($v \in [5, 850]$ m/s) and executing an active electromagnetic pre-trigger pulse within $\Delta t_{\text{total}} \leq 0.852$ ms prior to physical impact. This pulse triggers instantaneous viscoelastic phase transitions in magnetorheological (MR) smart fluid layers, proactively redistributing kinetic energy.

Intellectual Merit

The intellectual merit focuses on resolving foundational high-risk scientific barriers in microsecond electro-photonic sensing and transient smart material rheology: (1) *High-Ambient Photon Rejection*: Developing optical spatial-temporal filtering algorithms to preserve > 18 dB signal-to-noise ratio under 100 klux solar illumination and ballistic obscurants; (2) *Transient Rheological Kinetics*: Modeling and measuring sub-millisecond particle chain alignment in field-responsive magnetorheological fluid suspensions under pulsed micro-coils, achieving a yield stress jump from $\tau_0 \approx 0.2$ kPa to $\tau_y > 85$ kPa in < 0.85 ms; and (3) *Sub-Millisecond Edge Kalman Kinematics*: Embedding deterministic state-estimation routines on ARM Cortex-M7 hardware to achieve trajectory estimation and trigger firing within $< 1.0\,\mu$s of signal capture.

Broader Impacts

The broader impacts encompass national security, neurological medicine, civilian worker safety, and regional STEM equity: (1) *Warfighter Survivability*: Mitigating the primary mechanical etiology of blast/ballistic TBI, reducing peak head acceleration by $> 55\%$ and Head Injury Criterion (HIC_{15}) below concussive thresholds; (2) *Dual-Use Commercialization*: Direct scaling into automotive crash envelopes, law enforcement tactical vests, and industrial/sports safety headwear; and (3) *Broadening STEM Participation*: Led by a Native Hawaiian founder in an EPSCoR jurisdiction (Hawaii), this project partners with the Hawaii Technology Development Corporation (HTDC) and local academic laboratories to establish advanced defense manufacturing, smart materials testing, and embedded hardware engineering capabilities in underserved Pacific communities.