The City College of New York
Office of Research

CCNY College-wide Research Vision (CRV) Initiative Concept White Paper

AI and Machine Learning Enabled Miniaturized Multimodal Medical Sensing

Project Team:

Principal Investigator: Dr. Nicholas Madamopoulos, Associate Professor
Department: Dept. of Electrical Engineering, Grove School of Engineering, The City College of New York
Other Key Personnel: Dr. Bingmei Fu (BME/GSOE); Dr. Karen Hubbard (Bio/Science); Dr. Sang-woo Seo (EE/GSOE); Dr. Jie Wei (CS/GSOE); Dr. Zhigang Zhu (CS/GSOE)

Project Concept Description: (Maximum 2 pages)

Keywords: Medical optics and photonics, artificial intelligence, machine learning, remote sensing, multimodal sensing/computing, photonic integrated circuits, non-contact medical diagnostics, miniaturized sensor, personalized and precise medicine, public health.

Objective: The proposed AI and machine learning (ML) enabled miniaturized multimodal medical sensing (AI/ML-M^{3}S) system will address the following three themes: (1) Design and fabrication of an integrated multimodal sensory system with a miniaturized vibration sensor array microsystem and electro-optic/infrared (EO/IR) sensory modalities for automating and complementing the vibration sensing; (2) Development of effective AI/ML tools, especially deep learning (DL) methods, that identify personalized and precise cardiovascular conditions with multimodal sensory data; and (3) Characterization and validation of the miniaturized sensing system and the intelligent computing software system. We envision that the system will be able to collect multimodal data (e.g., vibration, color, thermal data at the carotid artery) in a non-contact manner, send the measured data to a computing system to extract cardiovascular parameters and vital signs (including pulse spectrum, pulse wave velocity, blood flow velocity and pressure waveforms, blood oxygen levels, heart beat rate, breath rate and body temperature) through AI/ML based signal processing, data analysis, and ML, especially DL algorithms.

We will also seek an embedded solution, which embeds an integrated unit in the miniaturized system to obtain these parameters directly in a cost-effective manner. Under this context, the project opens up new opportunities for the next phase of the project, through the development of photonic neural networks, which have the potential to provide the technology leap for surpassing speed and energy efficiency of cutting-edge GPUs. Hence, the sensory system and the photonic neuromorphic computer can co-exist on the same platform, and with the support of AI/ML algorithms and processes, enable next generation medical assistance devices.

Approach: Built on an advanced photonic technology, AI/ML based data processing and analysis, our research will make the following transformative breakthroughs in sensing designs: (1) A cost-effective hand-held photonic integrated circuit (PIC) based Laser Doppler Vibrometer (LDV), combining EO and/or acousto-optic (AO) interactions of light and matter, photonics signal processing in the infrared (IR) spectrum (e.g., 1550 nm), and electronics digital signal post-processing and communication, will enable real-time non-contact and precise multimodal (LDV/EO/IR) cardiovascular parameters and vital sign sensing and perception. (2) With a rich multimodal dataset, AI/ML approaches, especially DL techniques, such as ensemble learning, compressive sensing, Convolutional Neural Net, Recurrent Neural Net, Generative Adversarial Net, Contrastive DL, and attention based Transformers, combined with physics-based signal processing methods, will yield hetero-geneous data fusion and biometric feature extraction, which are crucial to identify various cardiovascular conditions and aid in the non-contact and individualized prevention and early detection of cardiovascular diseases. (3) Through signal characterization and validation, deeper insights into the communication and correlation of our sensors and algorithms form a feedback loop to fine-tune, calibrate and adapt our novel hardware and software sensing system for personalized health monitoring and diagnosis. The diagrammatical details of the proposed system is depicted in Fig. 1. The project will be managed by PI Prof. ***Madamopoulos*** in an agile model with weekly meetings, bi-weekly sprints, and quarterly stakeholder meetings so that the PI, co-PIs, the students, and other collaborators and advisors can brief their progress and roadblocks in a timely manner, and provide guidance to be on the right track. Three sub-teams will be formed with different tasks: the ***hardware sub-team***, Profs. ***Madamopoulos*** and ***Seo***, will focus on the miniaturized photonic sensor design; The ***AI/ML sub-team***, Profs. ***Wei*** and ***Zhu***, will ensure the cutting-edge AI/ML methods used in the system are both effective and robust; the ***medical sub-team***, Profs. ***Fu*** and ***Hubbard***, will be responsible for the medical insights, definition of device specifications and requirements, as well as the viability of the sensor in its medical applications. We envision that the proposed research direction will attract researchers from other disciplines, e.g., biophysics, chemistry, mechanical engineering, to join our sub-teams and further enrich our core expertise and potential applications.

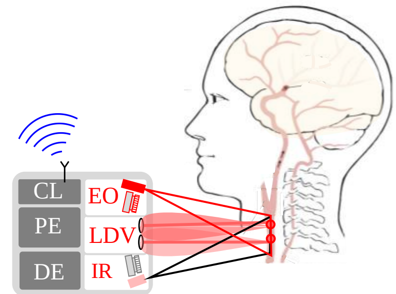

Fig. 1 Conceptual diagram of the AI/ML-M^{3}S system. EO: Electro-optic, IR: Infrared, LDV: Laser Doppler Vibrometer, DE: Driver electronics, PE: Processing electronics, CL: Communication link.

Outcomes: The Following 3 outcomes will be produced at the end of this project:

1) **Working system**: Integrated and user-friendly AI/ML-M^{3}S as a hardware system and software package will be deposited to a repo in *GitHub*, *GitLab* or *Bitbucket* for research of biomedical faculty and other researchers with well-annotated documentation, source code, testing reports and reproducible results.
2) **Big data with annotated ground truths**: Our studies on multimodal phenomenology, statistics, data representation/fingerprint, and algorithmic analysis will be thoroughly reported from our sensing, computing, knowledge extraction and decision assistance subsystems. We will make the data publicly available online.
3) **Publications**: At least three papers will be published per year in premier conferences and journals in sensing, computing, smart device, biomedical engineering disciplines.

Merits: The proposed AI/ML-M^{3}S system will offer crucial support for precise cardiovascular parameters and vital sign collection, analysis, and knowledge extraction to help patients and doctors make real-time on-site decisions. Basic science research will create novel sensor structures to enhance sensing capabilities and develop compact sensors that can be deployed for various field applications. The multimodal sensors, together with the associated signal processing, data analytics, and AI/ML computing algorithms, will contribute to more effective and safe operations. The innovative combination of the state-of-the-art AI/ML techniques, miniaturized multimodal sensors, and medical insights made available by this unique cross-disciplinary team of five active and productive computer scientists, electrical engineers, and biomedical engineers will make a significant leap by cross-fertilizing our complementing expertise.

Impact: The underpinning breakthroughs of this proposed work is the recent revolutionary DL techniques in well-publicized AI/ML algorithms, photonic integration and precision medicine. The current COVID-19 pandemic badly called for low-cost, non-contact and precise remote sensors to be widely applied to more people, our AI/ML-M^{3}S system provides a timely answer to this urgent need at the right time with our expertise on AI/ML, smart device, and biomedical engineering. Results of this project will equip us with the proof-of-concept and evidence to apply AI/ML to smart medical sensors of crucial interest to the current national and international needs for public health. This unique multidisciplinary project will enable the interdisciplinary team to train highly motivated students with backgrounds in computer science, data science, optics/photonics, electrical, and biomedical engineering. Trainees will be given the opportunity to understand, harness and exploit their learned knowledge and techniques in systems of practical importance to a broad spectrum of applications.

Milestones:

Months 1-6: The PI and Co-PIs will work together to plan and design the hardware, software and medical analysis for the system. The AI/ML sub-team will develop data processing, indexing and classification algorithms based on conventional machine learning and DL approaches. The hardware sub-team will focus on the study of the designs with the full suite of simulation tools in our labs. These tools allow us to fulfil the following tasks: (a) Design the application specific PIC LDV; (b) fabricate the elemental components and characterize them. Vibration data will be collected from ~100 subjects by the existing LDV and will be processed by the AI/ML software and analyzed by the medical sub-team.

Months 6-9: The hardware sub-team will (a) perform device simulations using measured component performance, for redesign and optimization; and (b) start the design of the optical module to include the PIC, laser, detector. The AI/ML and medical sub-teams will work together to integrate the existing hardware and software for optimal performances. More annotated data will be collected to test the medical validity of the software and hardware. More AI/ML will be conducted to address issues that arise in the initial collection and testing.

Months 9-12: The hardware sub-team will prepare mask layout and run design verification consistent to nanofabrication, and finish the optical module design. The AI/ML sub-team will develop corresponding algorithms to integrate the newly available device, which yields the initial AI/ML-M^{3}S system prototype. Intensive validations will be further conducted by all three sub-teams in the practical use of the prototype system. Currently available industrial (large and expensive) LDV system in our lab will provide ground truths for the proposed miniaturized system. The collected thermal and color data by the AI/ML-M^{3}S will be validated by the commercially available non-contact thermometer and contact oximeter. These results will be used to calibrate and optimize the PIC LDV performance.

Budget (Maximum Budget $200K/year):

Personnel Costs: (please list key positions and estimate budget required)

- Key Personnel (PI, Co-PI, senior personnel) $75,000
- Students:
    - PhD: $50,000
    - MS: $25,000
    - Undergrad: $20,000

OTPS Costs:

Supplies and fabrication costs (for the PIC LDV): $30,000