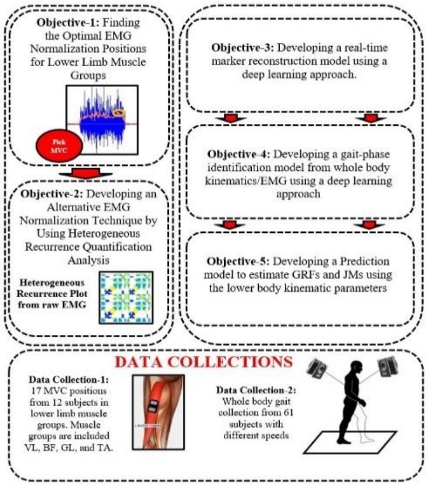
Research Statement

My research focuses on machine learning (ML), artificial intelligence (AI), human factors and ergonomics (HFE), computational biomechanics, complex systems, nonlinear dynamics, biomedical signal processing, and time-series analysis in healthcare systems and applications. Healthcare systems and their applications have been used for various purposes to significantly improve treatment efficacy, patient care, and neuromuscular diagnostic techniques. My current research goal is to address the limitations of traditional healthcare applications by developing a user-independent DL-based biomechanical gait analysis system. In my future research, I will develop cost-effective, portable, and user-friendly healthcare and manufacturing applications. I will specifically focus on the fields of AI, mixed reality technologies (e.g., VR/AR), biomedical signal processing, robotics, complex systems, and HFE. Initially, the NSF Major Research Instrumentation Program (MRI) will be a key grant program to support instrument acquisition and development. I plan to apply a diverse portfolio of funding opportunities, including the NIH R01, NSF ERI, CRII, FW-HTF, AHRQ, and CAREER awards, as well as internal grants.

In the following sections, I will initially present a summary of my research accomplishments, and my ongoing projects. Following, I will dive into my future research directions and grant application details.

I. Research Accomplishments and Ongoing Projects

There is currently no consensus in the literature regarding the optimal isometric maximum voluntary contraction (MVC) positions for EMG normalization. To address this, I collected and examined 17 different MVC positions for the major lower limb muscles in MoCap systems. During this phase, my advisor, Dr. Sinan Onal, and I collaborated with Dr. Bryan K. Smith from our Applied Health department and published our results in the Journal of Medical and Biological Engineering and presented them at the IISE conference. The traditional EMG normalization method relies on peak MVC, causing EMG signals to be investigated solely through linear analysis. To tackle this limitation and surface more information from EMG signals, I first developed an alternative EMG normalization technique using recurrence quantification analysis (RQA), in collaboration with Dr. Cheng-Bang Chen from the University of Miami. While the results were promising, the RQA method has limitations in analyzing complex spatial domains. Consequently, we advanced our research by introducing a novel EMG normalization method using heterogeneous RQA (HRQA). Unlike RQA, which only investigates homogeneous behaviors in recurrences, HRQA allows the examination of chaotic EMG signals in various states in their state-space trajectories. Our findings have been submitted to the Biomedical Signal Processing and Control and are currently awaiting the second round of review.



General framework of the research methodology.

As part of my next Dissertation project, I aimed to eliminate the need for force plates in MoCap systems due to their high installation costs and limited mobility. My objective was to reduce the amount of time required for gait analysis and address the system's limitations for subjects with disabilities. To achieve this, I initially employed 1D-CNN architecture to harness the rich information of time-series data. Subsequently, to speed up the learning accuracy in the target domain, I incorporated a transfer learning strategy (TL). TL model is trained by synthetic data which is generated from the actual data for the pre-training phase of my proposed DL framework. Compared to the model without TL, the TL approach helped us to decrease the rRMSE (relative RMSE) results on our predicted data from 18.00% to 8.63%, and also eliminate the dependency on large datasets. Our research findings, achieved in collaboration with Dr. Banafsheh Rekabdar from the Department of Computer Science at Portland State University, have been published in the International Journal of Biomedical Engineering and Technology.

The missing marker problem is another inherent limitation of MoCap systems. Recognizing the proven efficacy of transformers in numerous healthcare applications, I've mitigated this problem by harnessing the capabilities of transformers for my multivariate missing marker data. The preliminary results have been promising, and I presented these findings at the IEEE BHI conference last October in Pittsburgh. I am currently refining my work on unsupervised transformers, introducing new parameters like a new loss function and time continuity constraints. Subsequently, I aim to benchmark these improvements against state-of-the-art frameworks (e.g., LSTM, BiLSTM) outlined in the literature.

In addition to this exciting unsupervised transformers research, another study I am engrossed in focuses on the phase detection of gait analysis using IMU and EMG sensors. In this research, I consider using the application of the

Teager-Kaiser energy operator to increase the signal conditioning and visibility, which should have a positive impact on the training accuracy of my proposed DL framework. I will also be developing a signal processing toolbox to make it publicly available in different programming languages such as MATLAB and Python. I am targeting to submit my studies to the following journals such as "Biomedical Signal Processing and Control" or "Neural Computing and Applications". These works are still ongoing under the supervision of Dr. Sinan Onal and Dr. Chao Lu from the Department of Electrical, Computer and Biomedical Engineering at Southern Illinois University Carbondale.

Outside of my doctoral research, I've also had the opportunity to collaborate with Dr. Sohyung Cho from Kennesaw State University. In this collaboration, I mentored his graduate student during the data collection of MoCap systems, manuscript writing, and editing. The data from this collaboration has been used in the assessment of ergonomic risks and potential injury predictions via data envelopment analysis (DEA). Our results were published in the 2023 IISE conference as a 6-page proceeding, and the results of our improved DEA model were recently accepted for publication in the Journal of Applied Research on Industrial Engineering.

Recently, I have developed an interest in Industry 4.0. This interest led me to conduct independent research in my free time, delving into the technologies associated with smart healthcare systems, including Big Data, AI, VR/AR, Internet of Things (IoT), and Cloud Computing. Thus, I decided to author a conference proceeding independently for the 2024 IISE Conference. This paper is centered around the concept of Healthcare 5.0. My proposed framework will address current challenges and discuss the future directions of Healthcare 5.0 and its emerging technologies.

II. Future Research

My research vision focuses on the development of cost-effective, portable, and user-friendly applications in healthcare and manufacturing. These contributions aim to respond to societal needs, particularly for people with disabilities, frontline healthcare workers, military professionals, and the manufacturing workforce, by providing them with innovative tools and technologies that enhance productivity, ensure safety, and improve quality of life. Given my extensive research background in the fields of AI, HFE, biomedical signal processing, time-series analysis, complex systems, and nonlinear dynamics, I strongly believe that I can pursue my exciting research projects and emerging applications with interdisciplinary collaborations in the future. In the sections that follow, I detail three strategic areas that I plan to investigate in the future.

1) Cost-Effective and User-Centric Wearable Sensors for Healthcare and Manufacturing Environments

Leveraging the potential of wearable sensors and AI-driven tools across both healthcare diagnostics and manufacturing sectors forms the core of my research vision. In healthcare, my aim is to design wearable sensors for the early detection of neurological disorders like Parkinson's Disease (PD). The same design can be transposed to the manufacturing environment, where the emphasis shifts to improving worker safety, ergonomics, and productivity. For instance, by applying these wearable sensors to analyze the physiological and biomechanical states of workers, we can identify ergonomic risks, monitor for overexertion, and optimize manufacturing processes to reduce fatigue and improve overall efficiency.

The design aims to extract irregular dynamic patterns and quantify spectral complexities from chaotic time-series signals. While current literature often emphasizes traditional approaches like sample entropy, these methods have certain limitations, especially in the local phase space reconstruction. Therefore, this motivates me to use advanced non-linear feature extraction methods like HRQA. These methods offer greater detail in local recurrence regions by treating the signal heterogeneously, which can be pivotal for detecting subtle signal abnormalities. Subsequently, these extracted features will be integrated into AI systems for further analysis to work as a sophisticated learning algorithm. Meanwhile, I aim to optimize the number of wearable sensors used on workers/patients to a minimum, ensuring that accuracy isn't compromised and that workers/patients can perform their daily routines comfortably. In the next phase, the cost-effective and user-centric system will be adapted into a portable version that seamlessly integrates with smartphones and other smart devices. Prioritizing user interface and experience will be crucial to enhancing efficiency and user-friendliness. Such integration promises to elevate the precision of diagnostic procedures and manufacturing settings, which could have an important impact on the fields of AI, IoT, Robotics, and Big Data analytics.

Given the fact that this project's need for hardware and software expertise requires a collaborative, interdepartmental approach, involving local hospitals for patient recruitment in IRB-approved human trials, and local manufacturing companies for applying and validating wearable technology in real-world settings. Academically, collaborations are planned with the Departments of Electrical and Computer Engineering for sensor development, and Computer Science for sensor integration on smartphones and other smart devices. Additionally, the Motion Capture and Analysis Laboratory will be key for data collection.

2) Transforming Healthcare and Workplace Safety with Soft Exoskeleton Suits

Another intriguing research venue in robotics involves the development of wearable robotic exoskeleton suits. In recent years, there has been a growing focus on the development of "soft" exoskeleton suits. These suits mimic the human body's biomechanics using lightweight and flexible materials, thus reducing weight, enhancing mobility, and improving the range of motion while minimizing discomfort and skin irritation. The control mechanism of these soft exoskeleton suits, managed by wearable sensors, aims to track changes in joint angles, movement direction, and gait speed. Robotics, kinematics, dynamics, and control research fields (e.g., rigid body motions and dynamics, kinematic chains, stability, and feedback control) are employed in the development of the technology. Therefore, a collaborative approach with the Department of Mechanical and Mechatronics Engineering is essential. This research aims not only to assist the elderly and individuals with disabilities, such as stroke survivors, but also to significantly benefit the manufacturing and industrial sectors. By providing workers with enhanced physical support and reducing the risk of injury during exhaustive manual tasks, these exoskeleton suits can improve workplace safety, prevent occupational hazards, and increase efficiency. Additionally, they offer military professionals the opportunity to reduce the daily metabolic costs associated with walking, lifting, and running. This cutting-edge application highlights the potential of soft exoskeleton technology to transform both healthcare mobility aids and ergonomic support in manufacturing workplaces, fostering a safer and more productive workforce.

3) Shaping the Future of Medical and Manufacturing Workforces with Mixed Reality Training Programs

Beyond the development of soft exosuits, the use of mixed reality (e.g., VR/AR) technologies is rapidly growing in the healthcare, manufacturing, and education fields. While studies have yet to assess the skill development and capabilities of medical students through extended VR and AR training, the potential for these technologies in industrial training and skill development is equally promising. My goal is to create an AI-driven assessment tool based on training outcomes, followed by systematic guidelines to target underdeveloped skills. This approach aims to design training programs, potentially improving the performance and motivation of individuals in both medical and manufacturing sectors over the long term. For example, low-skilled manufacturing workers can refine their technical skills and gain experience through efficient training programs in a virtual environment. A similar approach can be adopted for the training of medical and dental students, enabling them to undertake extensive training to sharpen their surgical skills. For this research, I plan to collaborate with the School of Medicine and the Department of Biomedical Engineering. The School of Dental Medicine could serve as a focal point for dental students to practice their skills in dental procedures. These efforts could be extended to health science programs for nursing programs. Likewise, local industries can contribute their expertise to the development of effective training programs in manufacturing environments.

III. Grant Applications

In the long term, my goal is to develop my own independent laboratory under the department with the help of internal and external grant opportunities. Initially, the NSF MRI will play a crucial role in supporting the acquisition and development of instruments. With the support of the NSF MRI grant, the prospective lab space will be designated as the Human-Computer Interaction Lab (HCI Lab), featuring state-of-the-art equipment such as wearable sensors, mixed-reality technologies, and robotic devices. These tools will enable the development of innovative applications in both manufacturing and healthcare fields. Additionally, the laboratory will serve as a resource to enhance the understanding of engineering concepts among undergraduate and graduate students. Beyond research, the lab's focus on mixed reality technologies will likely spark students' interest in this emerging field, potentially leading to the creation of a course dedicated to inclusive teaching practices and the support of term projects and engineering design courses.

Beyond the NSF MRI, I aim to apply for the NIH Research Project Grant (R01) to support my research activities. Another NSF grant opportunity, "Engineering Research Initiation (ERI)", aims to assist new investigators at non-R1 institutions with awards of up to $200,000 over a 24-month period. Additionally, the NSF offers the Computer and Information Science and Engineering Research Initiation Initiative (CRII) for early career academics, providing up to $175,000 for a period of 24 months. The Future of Work at the Human-Technology Frontier: Core Research (FW-HTF) program is another NSF grant that could be pursued with interdepartmental collaborations. The Agency of Healthcare Research and Quality (AHRQ) also offers grant opportunities for healthcare projects improving quality, effectiveness, accessibility, and cost-effectiveness. Lastly, I intend to apply for the prestigious NSF CAREER Award.

For internal funding, I aim to apply for Transitional and Exploratory Projects, and the Research Equipment and Tools Funding Program to support the laboratory's establishment and growth.