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Mini-Symposia Title:

Recent Advances in Wearable Sensing and Machine Learning for Biomechanics - A

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Theme:

- ○ 01.Biomedical Signal Processing
- ○ 02.Biomedical Imaging and Image Processing
- ○ 03. Micro/Nano-bioengineering; Cellular/Tissue Engineering & Biomaterials
- ○ 04. Computational Systems & Synthetic Biology; Multiscale modeling
- ○ 05. Cardiovascular and Respiratory Systems Engineering
- ○ 06. Neural and Rehabilitation Engineering
- ● 07. Biomedical Sensors and Wearable Systems
- ○ 08. Biorobotics and Biomechanics
- ○ 09. Therapeutic & Diagnostic Systems and Technologies
- ○ 10. Biomedical & Health Informatics
- ○ 11. Biomedical Engineering Education and Society
- ○ 12. Translational Engineering for Healthcare Innovation and Commercialization

Mini-Symposia Synopsis – Max 2000 Characters

A large portion of the population in the United States and around the world suffer from musculoskeletal injuries and disorders that result in a large number of patient visits, surgical procedures, and arduous rehabilitation protocols. The current paradigm for diagnosing and monitoring such injuries and disorders hinges on a combination of expensive and time-consuming procedures such as the physical examination by a trained physician, physical therapist, or athletic trainer, or medical imaging such as MRI or CT. A major challenge is that, while rehabilitation and treatments may pervade for many weeks or months—and thus therapies should ideally be tailored to meet the changing needs of patients—both physical exam and medical imaging procedures are only suitable to clinical settings, and do not lend themselves to serial measurements that can be used to provide closed-loop therapies and / or titration of care. Wearable sensing systems with associate machine learning algorithms for deriving important measures of joint health hold merit for potentially shifting this paradigm of care for persons with musculoskeletal injuries or disorders. This first session of the proposed mini-symposium will focus on recent wearable system designs and related practical considerations as well as an overview of wearable sensing for biomechanics and its future role in healthcare.

Wearable Systems and Machine Learning Algorithms for Knee Health Monitoring via Knee Acoustic Emissions

Goktug C. Ozmen and Omer T. Inan

Abstract— **Characteristics of knee sounds are potential digital biomarkers of knee health. Researchers have developed wearable sensing systems with acoustic measurement modality to capture knee sounds in uncontrolled settings for knee health monitoring. The captured knee acoustic emissions combined with machine learning algorithms have been used to classify and monitor acute knee injuries. While reported results show successful detection of the presence of knee injuries, they are unable to fully explain the underlying structural changes in the knee. Therefore, it is necessary to investigate the changes in the knee sounds further to build better understanding of underlying structural changes.**

I. Introduction

The knee is one of the most involved joints of the human body that provides stability and has a large range of motion. Knees generate sounds even during simple exercises, which are believed to be indicative of knee health. As knee sounds are thought to arise from joint articulation [1], and the vibrations of intra- and extra- articular components [2], they should contain information about the structural and physiological state of the knee. To address the need for a non-invasive and affordable diagnostic method for acute knee injuries, researchers have developed wearable sensing systems to collect knee sounds [3], and machine learning algorithms have been developed to analyze these acoustic emissions [4]. While these methods were successful in knee health classification, there is a lack of understanding how the changes in knee sounds are related to underlying structural changes. There is reported evidence that the movement of articulating components around the knee are affected by the knee injuries, and eventually alter the vibration characteristics of the joint [5]. These changes can be used to build analytical models of articulating components, such as tibia, which could physically explain the changes in the characteristics of knee sounds. Eventually, these models would improve our understanding of how acoustics relate to the structural changes in the knee following acute knee injuries.

II. Alterations In Vibration Response Of The Knee Following Acute Knee Injuries

As wearable sensing systems have been developed to monitor knee health during rehabilitation, it is necessary to develop signal processing framework that (1) would capture small longitudinal changes in knee sounds, and (2) correlate these changes to underlying structural and physiological changes. Recent efforts have shown the existence of tibial vibration patterns in knee sounds recordings that can be used to detect meniscal tears [6]. Briefly, an analytical tibial vibration model has been proposed that includes tibial stiffnesses and meniscal damping effect. Based on the existing literature, the reported changes in these lumped component values following meniscal tear were incorporated, and directional changes in modal parameters of the system response have been predicted. Then, the repeated patterns in knee sounds recordings have been modeled using transfer function estimation algorithms. The experimental data presented similar directional changes between healthy and injured groups with meniscal tears. This result suggests the feasibility of development of such analytical models that would better explain the underlying structural changes in the knee. Additionally, such analytical models can be used to derive new digital biomarkers of knee health.

III. Future Research

As wearable sensing systems are being developed enabling longitudinal monitoring of knee health even in at-home settings, there is an opportunity to develop analytical models to capture longitudinal changes in the knee by using knee sounds measurements. Comprehensive analysis of confounding parameters affecting the vibration response of the knee could help deriving new digital biomarkers of knee health. Such an effort could pave the way for translating the results of machine learning algorithms to clinical settings by developing a bridge of understanding between data scientists and clinical teams.

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Biomechanically-driven machine learning: application to animal behavior recognition

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Abstract— **This presentation highlights the importance of driving machine learning algorithms by biomechanical features to improve the generalization and interpretation of learning models in activity monitoring.**

INTRODUCTION

Machine learning (ML) is often used in biomechanics for the recognition of physical behavior or the analysis of locomotion in humans or animals. The generalization of results in various populations or different animal species remains an important shortcoming of ML. ML algorithms generally aim at minimizing the overall classification error, with the cost of maintaining poor performance for the classification of rare behaviors. Although a review of the classification rules can help adapt them to rare classes, the high number of features and the complexity of some ML models make it difficult to identify the source of misclassification. With this presentation, we want to illustrate the above problems and help to solve them by driving the ML model with biomechanical features. To do so, we consider the context of physical behaviors classification in wild animals.

I. METHODS

We propose a general approach called biomechanically-driven ML (B-dML) for the recognition of physical behavior in wild animals such as meerkats, where the biomechanical features of movement were used to drive a simple ML algorithms. Using a collar equipped with a triaxial accelerometer, data were collected over several hours on wild Kalahari meerkats and annotated using simultaneous video recording [1]. Biomechanical knowledge was used first to specify a limited but meaningful number of categories (e.g. posture, intensity, periodicity). Then, a number of candidates were developed in each category. The best feature within each category, selected by ranking methods was used in a simple ML such as the Support Vector Machine, to hierarchically classify activity from static/dynamic, to vigilance, resting, running, foraging. To benchmark our B-dML model against classical ML we used up to 16 statistical features with classical ML rules (Naïve Byes, K-Nearest Neighbours, Random Forest).

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II. RESULTS

Table 1 compares the performance of B-dML with the best classical ML for three physical behaviors with an imbalanced dataset.

TABLE I. PERFORMANCE OF CROSS-VALIDATION. THE B-dML IS BENCHMARKED AGINST BEST CLASSICAL ML . # BOUTS COORESPONDS TO THE NUMBER OF ANNOATATED WINDOW OF 2 SEC

	Vigilance	Resting	Foraging	
#bouts	31520	3795	46407	Overall Accuracy %
	Sensitivity/Specificity/Precision, %			
B-dML	97/99/98	85/99/87	99/98/98	98
Best Classical ML	97/97/88	65/100/81	99/97/98	96

III. DISCUSSION & CONCLUSION

Separating vigilance (alertness with an upright posture) from rest (lying down with the body flat on the ground) proved difficult for both approaches because of the poor representation of the resting state. Nevertheless, the B-dML approach had a 20% higher sensitivity to recognize rest than the best classical ML approach. If a cross validation was performed with an equally represented behavior, B-dML and the best classical ML would have obtained a closer and higher sensitivity. The best performance of B-dML in an imbalanced dataset is explained by the use of posture knowledge to separate rest from vigilance. Examining classical ML with 16 features to understand the cause of misclassification is not manageable. On the other hand, the results show the possibility of improvement of B-dML, due to the simple structure of ML and the interpretable posture function. Based on comprehensible biomechanical features, combined with simple but robust ML algorithms, the B-dML approach has shown high efficiency in estimating the decision boundaries between classes while keeping interpretability of the model for possible improvement. Similar approach was applied successfully with other type of sensors (magnetometer), other behaviors (digging, searching prey and chewing) and also extended in human activity classification.

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Wearable Systems and Robotics for Rehabilitation Technologies

Paolo Bonato

Author Biography: Paolo serves as Director of the Motion Analysis Laboratory at Spaulding Rehabilitation Hospital, Boston MA. He is an Associate Professor in the Department of Physical Medicine and Rehabilitation, Harvard Medical School, and an Adjunct Professor of Biomedical Engineering at the MGH Institute of Health Professions, Harvard Medical School. He has held Adjunct Faculty positions at the Massachusetts Institute of Technology, the University of Ireland Galway, and the University of Melbourne. At the Wyss Institute for Biologically Inspired Engineering, he brings his experience in rehabilitation technology with special emphasis on wearable technology and robotics.

Dr. Bonato serves as Member of the Advisory Board of the IEEE Journal of Biomedical and Health Informatics and as Associate Editor of the IEEE Journal of Translational Engineering in Health and Medicine. He served as Founding Editor-in-Chief of the Journal of NeuroEngineering and Rehabilitation. Dr. Bonato served as an Elected Member of the IEEE Engineering in Medicine and Biology Society (EMBS) AdCom (2007-2010) and currently serves as IEEE EMBS Vice-President for Publications (2013-present). He served as President of the International Society of Electrophysiology and Kinesiology (2008-2010). He also served as Chair of the 33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (2011) and as Chair of the IEEE EMBS Technical Committee on Wearable Biomedical Sensors and Systems in 2008, a committee of which he was a founding member in 2006 and on which he served until 2012. He received the M.S. degree in electrical engineering from Politecnico di Torino, Turin, Italy in 1989 and the Ph.D. degree in biomedical engineering from Universita di Roma "La Sapienza" in 1995.

Presentation content is to be decided.

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A wearable device to measure EMG and electrical impedance myography simultaneously

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Synopsis: Surface electromyography (EMG) is common used technique to investigate the activation of muscle during contraction. Electrical impedance myography (EIM) is a non-invasive technique for the assessment of muscle health that is based on the measurement of the electrical impedance characteristics of muscle. Combination both techniques in one wearable device may give us new possibility to assess muscle contraction and estimate muscle force. For this purpose, we have developed a device which is able to measure EMG and EIM simultaneously over the same electrodes. The system was designed in several modules with the chips AFE4300 for EIM and ADS1298 for EMG. The device is wearable, light, and wireless.

Validation tests have shown ability of the device to measure EMG and EIM simultaneously. The EIM module is able to measure bioimpedance values between 20Ω and 200Ω with an error of less than 5%, which is comparable to commercial devices. The EMG module is able to capture EMG signal between 20Hz-150Hz with an SNR of 67dB. The whole system reads and transfers the data of both modules every 1ms over RF (868 Mhz) with a baudrate of 500kbps.

For further validation, we performed measurements on three healthy volunteers on a mechanical test-bench for the upper leg, as well as during sit-to-stand and walking. Test results showed that the change in the EIM signal during contraction was bigger at lower excitation frequencies. At higher excitation frequencies, the morphological change of the muscle has a stronger influence in the EIM signal's change. The sit-to-stand test showed that the force exerted by the muscle is related to the amplitude of the EMG and EIM signals.

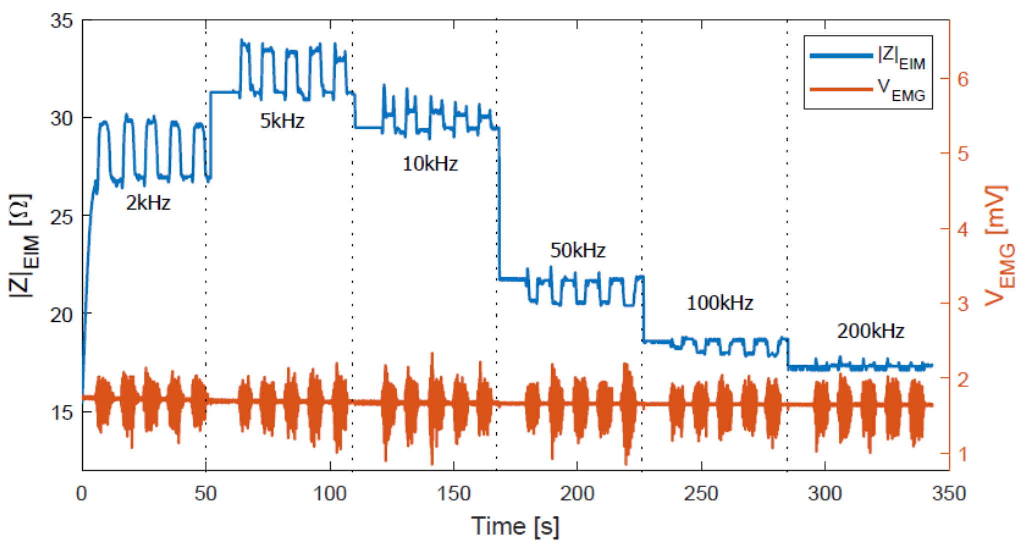

Fig 1: EIM (blue) and EMG (red) of a volunteer during leg extension with 7 kg weight. The EMG amplitude is significantly higher during contraction. The EIM is measured at different frequencies.

Robotics in Biomedical Applications

Conor Walsh

Author Biography: Conor Walsh is the Gordon McKay Professor of Engineering and Applied Sciences at the John A. Paulson Harvard School of Engineering and Applied Sciences and a Core Faculty Member at the Wyss Institute for Biologically Inspired Engineering. He is the founder of the Harvard Biodesign Lab, which brings together researchers from the engineering, industrial design, apparel, clinical and business communities to develop new disruptive robotic technologies for augmenting and restoring human performance. This research includes new approaches to the design, manufacture and control of wearable robotic devices and characterizing their performance through biomechanical and physiological studies so as to further the scientific understanding of how humans interact with such machines. Example application areas include, enhancing the mobility of healthy individuals, restoring the mobility of patients with gait deficits, assisting those with upper extremity weakness to perform activities of daily living and preventing injuries of workers performing physically strenuous tasks. His multidisciplinary research spans engineering, biology and medicine and has led to multiple high impact scientific papers. His group's work is highly translation focused, has multiple partnerships with industry, with technologies already licensed, and one being sold as a product.

Conor is passionate about educating future innovators and he has established the Harvard Medical Device Innovation Initiative that provides students with the opportunity to collaborate with clinicians in Boston and emerging regions such as India. In addition, his research group is also dedicated to STEM education and have launched the Soft Robotics Toolkit that is an open source resource to promote and disseminate materials for soft robotics.

The vast majority of alumni have gone on to paths in academia and high tech R&D positions in industry. His work has been recognized with multiple awards including the MIT Technology Review Innovator Under 35 Award, the Early Academic Career Award in Robotics and Automation from the IEEE RAS, the Rolex Award for Enterprise and the MIT 100K Entrepreneurship Competition Grand Prize.

Conor received his B.A.I and B.A. degrees in Mechanical and Manufacturing engineering from Trinity College in Dublin, Ireland, in 2003, and M.S. and Ph.D. degrees in Mechanical Engineering from the Massachusetts Institute of Technology in 2006 and 2010.

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Wearable Technologies for Mobile and Personalized Health

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Ivan is a recipient of the NSF CRII Award (2018) and the NIH Trailblazer Award for Young Investigators (2018). His work has won a number of cover-page/featured article awards, best paper awards, best demo awards, and runner-ups at premier academic venues including IEEE TNSRE, IEEE JBHI, ACM SenSys, and ACM MobiSys. He is currently an Academic Editor of PLOS ONE and an Associate Editor of the IEEE OJEMB. He is also serving as an elected Standing Member of the Technical Committee on Wearable Biomedical Sensors and System of the IEEE EMBS. Ivan has served as technical program committee members and workshop chairs for several flagship conferences in the area of wearable computing and health informatics. Ivan also frequently serves on scientific review panels for funding agencies such as the NSF, NIH, and DARPA.

Professor Lee's research interests are in Mobile & Personalized Health, focusing on the use of digital technologies to understand health conditions and promote health behavioral change in individuals with motor/cognitive impairments, such as stroke, Parkinson's disease, traumatic brain injuries, osteoarthritis, etc. With a primary focus on evolution, his specific research interests include 1) developing novel sensors and remote monitoring solutions that are motivated by practical medical needs, 2) design appropriate human studies, and 3) applying human-centered approaches to quantitatively and qualitatively analyze the efficacy of the developed solutions.

Presentation content is to be decided.

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