Speaker 1: Multimodal Sensors in the Wild: Case Studies from Dementia Care and Post-hip Surgery

Shehroz Khan

Abstract— **Wearable sensors provide a great opportunity to detect physical and physiological indicators of human body, including motion, heart rate, electro-dermal activity, muscle movements, and EEG. These indicators are of great value to clinicians and people who are using them to detect adverse events (e.g. falls), monitor progress (e.g. mobility), or changes in health conditions. A major concern with wearable devices is the user compliance in wearing them for intended times to collect meaningful data. If researchers are interested in measuring more than one vital indicators, then traditionally speaking, more than one wearable devices may be needed. In long-term monitoring studies in the wild, this type of approach is unrealistic and may not fetch desired results. A plausible solution to this problem is the use of a wearable device that can combine multiple sensors in one gadget or use wearable device with single/multiple sensors along with other sensors, such as ambient and computer vision sensors. Besides detecting different types of vital signs, multi-modal sensors could also lead to more robust classifiers for a specific problem. In this talk, I will discuss two studies – one completed and one up-coming, which involve deploying multi-modal sensors in the wild for dementia care and post-hip surgery patients.**

I. DEMENTIA CARE

People living with dementia (PwD) often exhibit behavioral and psychological symptoms of dementia, with agitation and aggression being the most notable [1]. Agitated PwD can harm themselves, other residents and staff in the long term care. These long term care centers are often under-staffed and such incidents prohibit them to focus on care of other residents. The traditional method to assess agitation is to use clinical scoring methods; however, those methods are retrospective and cannot detect or predict agitation events [2]. We conducted a study at the Specialized Dementia Unit at Toronto Rehabilitation Institute, and collected more than 600 days' worth data from 20 PwD using Empatica E4 watch that collects body acceleration, blood volume pulse, electro-dermal activity and skin temperature. The nurses were trained to provide information in their charts mentioning start and end timings of the agitation events. This helped in getting accurate labels for the agitation events. Fifteen video cameras were also installed in the unit. These video feeds are used to fine tune the start/end of agitation events. We hypothesized that combining multi-modal wearable sensor data can help in building better classifiers to identify agitation in PwD in comparison to a single sensor. The results from the pilot study on data from 14 patients showed that agitation can be detected by combining multi-modal sensors with 0.85 AUC. These preliminary results give strong evidence that multi-modal sensing approach outperforms single sensors in detecting agitation in PwD.

The lessons learnt from dementia care project led to several innovations in terms of developing an IoT platform that removes humans from data collection process and streaming data directly to the cloud. We also developed a novel software suite to handle multi-modal sensors, and providing maintenance and feedback to researchers / users in real time, which is being used in the post-hip surgery project described below.

II. SOCIAL ISOLATION AND FUNCTIONAL DECLINE

Patients normally get great care after post-hip surgery in a rehabilitation hospital. However, once they are discharged, it is very hard to track their progress. Social isolation and physical mobility are major risk factors for cognitive decline in older adults (OAs) post-hip fracture. The primary aim of this project is to develop a clinically validated multi-modal sensor system to assess changes in social isolation and physical function in OAs following discharge from inpatient rehabilitation. We will recruit a sample of OA hip fracture patients and install a suite of sensors into their homes and collect various types of data (e.g. biometric, mobility, sleep quality) over 2-months. A trained research assistant will conduct clinical assessments of social isolation and physical mobility every 2 weeks during this period. This project is the first step to building a scalable sensor system that can collect and assess social and physical aspects of OAs in the community which will ultimately support cognitive health and aging-in-place.

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Measuring hand use in the home after spinal cord injury (SCI) using egocentric vision

Andrea Bandini and José Zariffa

Abstract— **The functional use of the upper limbs is one of the top recovery priorities of individuals with cervical spinal cord injury (cSCI). Wearable cameras and computer vision methods have emerged as technological solutions to extract objective outcome measures that reflect hand function in a natural context. However, the validation of this technology in a home environment is necessary. This presentation will focus on the first results obtained in an uncontrolled environment (i.e., at home), where participants with cSCI recorded videos during their normal daily activities.**

I. INTRODUCTION

Cervical spinal cord injury (cSCI) results in the paralysis of upper and lower limbs and trunk, reducing quality of life and community participation of affected individuals. The functional use of the upper limbs is one of the top recovery priorities of individuals with cSCI [1]. Wearable cameras and computer vision methods have recently emerged as technological solution to extract objective outcome measures that reflect hand function in a natural context, overcoming the limitations of accelerometer-based devices. Previous studies were conducted in a highly controlled environment and may not be indicative of the actual hand use of individuals with cSCI living in the community [2], [3]. Thus, we evaluate the performance of an egocentric video-based system in detecting hand-object interactions in a natural setting, in individuals with cSCI.

II. METHODS

9 participants with cSCI were recruited for this study (7M, 2F; age: 50.0±7.7 years; months from injury: 113.1±90.3; AIS: A-D; UEMS: 19.8±6.2). Participants recorded common daily activities with a head-mounted camera (GoPro Hero5) over 2 weeks in their homes. Videos were processed offline to automatically detect hand-object interactions. The processing pipeline was composed of 2 steps: 1) Hand localization, to focus the processing on hand regions only; 2) Interaction detection, to classify whether the hands are interacting with objects. The present evaluation focused on the interaction detection step, using ground truth hand locations. Two approaches were compared: 1) A state-of-the-art multi-stage approach that combines color, shape, and motion features to detect the interactions using a random forest classifier [3]; 2) A pre-trained convolutional neural network (CNN) fine-tuned on our dataset to detect the interaction without intermediate steps [4]. Both approaches were trained and tested on the same dataset of images: ~88k frames from 6 participants (plus additional subjects captured in a home simulation lab) were used as training\validation set; ~15k frames from 3 participants were used as test-set. All frames were manually labelled by a trained annotator. Accuracy and F1-score were used to assess the classification performance.

III. RESULTS

The CNN-based approach offered better performance with less processing steps than the multi-stage approach (accuracy: 0.73 vs 0.65, respectively; F1-score: 0.82 vs 0.76). These results demonstrate the feasibility of automatic hand-object interaction detection at home.

IV. DISCUSSION & CONCLUSION

This work showed promising results on a small sample of individuals with cSCI living in the community. The expansion of the dataset and the use of temporal models (e.g., 3DCNN and recurrent neural networks) will allow improving the performance of the interaction-detection algorithm with the goal of enabling continuous assessment for individuals with cSCI living in the community.

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Speaker 3: Using Egocentric Video Data for Fall Risk Assessment in The Wild, Towards Fall Prevention in Older Adults

Mina Nouredanesh, Alan Godfrey, James Tung

Abstract— **Falls in older adults is one of the most important public health problems world-wide. To complement wearable inertial measurement units in the context of fall risk assessment in the wild, models developed based on video data acquired by body-mounted cameras can be used to automatically identify environmental fall-related hazards (e.g., stairs, different terrains). Moreover, egocentric video data can be utilized to estimate spatiotemporal gait parameters (e.g., step width) by locating feet in 2D RGB frames. These approaches aimed to eventually inform clinical decisions on the most appropriate prevention interventions to reduce fall incidence in older populations, which are being discussed in the symposium.**

I. Introduction

It is estimated that one in three older adults (OA, >65yrs) falls at least once each year. However, to date, there has been no method that can precisely anticipate falls. Fall risk assessment (FRA) is the initial step for fall prevention programs. In particular, clinicians aim to understand what factors, i.e., environmental or biological, put each senior at a high risk of falling to inform the selection and timing of interventions (e.g., strengthening program). The explosion of inertial measurement units (IMUs) has facilitated the emergence of free-living FRAs to monitor gait and balance in the wild. However, IMUs capture little or no information on the properties of the environment, which leads to general assumptions about gait performance in the wild. For instance, a high variability in the amplitude of acceleration signals may be interpreted as an increased risk of falls or may be linked to locomotor adjustments to avoid collisions on a crowded sidewalk. Egocentric video data complements IMU data by providing contextual information. Moreover, egocentric video data can be used to estimate spatiotemporal gait parameters (e.g., step width) by locating feet in the frame sequences.

II. Proposed Methods

Using the data collected from a chest-mounted camera and young healthy adults, models based on Gabor barcodes and ConvNets were developed to automatically detect environmental fall-related hazards [1,2], such as slope changes (e.g., stairs) and surfaces (e.g., gravel, grass, concrete). For instance, Gabor Barcodes [2] achieved 88.5% detection accuracy for 17 different classes.

To estimate spatiotemporal gait parameters (especially step width), in [3], a markerless framework, i.e., FootChaser, was proposed to automatically locate feet in video frames collected from young healthy adults. The FootChaser consusts of two key parts: 1) FootRegionProposer, a ConvNet that proposes regions in RGB frames with high probability of containing feet, and 2) LocomoNet, a ConvNet that examines the optical flow content corresponding to those regions and filters out the false positives. The framework achieved promising results in extracting trajectories of feet centers over time and detection of compensatory balance reactions.

III. Ongoing Research

To date, there has been no publicly available egocentric video dataset being collected from OA in free-living conditions, while targeting fall risk assessment. To address this limitation, we have been preparing a unique dataset, i.e., Multimodal Gait and Fall Risk Assessment (MAGFRA). OA fallers and non-fallers participated in this study and they wore IMU(s) and a camera on their waist: 1. in the gait laboratory with Vicon system (in-clinic version or MAGFRA-C) and 2. in the public environments of the institute and in their homes (in-the-wild version or MAGFRA-W). The MAGFRA-C is intended to be used for the validation of FootChaser model in OA. Moreover, patches from frames in MAGFRA-W were cropped and annotated according to the enclosed surfaces: (a) outdoor: 1. hard and smooth (asphalt, cement, bricks, tiles), 2. coarse (gravel, stone, pebble), 3. foliage/grass, 4. soil, and 5. snow, and (b) indoor: 1. polished (hardwood, tiles) and 2. unpolished (carpet, fabric). These patches were used as the test dataset. A training dataset was separately prepared by combining/preprocessing of data from relevant datasets, which was used to fine-tune deep models, e.g., MobileNet.v2. Initial results are promising and will be discussed in the symposium.

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The project has received ethics clearance, reference number 17589/Northumbria University.

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Speaker 4: Neurodegenerative disease biomarker development using multimodal wearable sensor systems in the wild

James Tung

Abstract— **Neurodegenerative diseases (NDD), including Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis (ALS), and Huntington's disease, affect millions of people worldwide. Without available treatments to reverse disease progression, the focus of this research is to develop behavioural biomarkers to inform early diagnosis. This symposium talk will focus on two projects investigating multimodal wearable sensor systems: 1) the Voice, Activity, and Location Monitoring for Alzheimer's disease (VALMA) project, and 2) on-going development with the ONDRI@Home project. Discussion will focus on interdisciplinary research initiatives to speed development and clinical impact.**

I. Introduction

Functional and cognitive assessments are vital tools to inform the diagnosis and management of neurodegenerative diseases (NDD). Early diagnosis provides time to enact intervention strategies to mitigate the impact of NDD. While biomarkers preceding clinically-detectable symptoms exist, diagnoses are largely dependent on judgements based on clinical observation informed by test batteries and patients and/or caregivers' reports of changes in areas of cognition, function, and language. Not only are such assessments prone to bias and unreliable due to stress, worry, or forgetfulness, even cognitively intact individuals may have difficulty remembering events and/or trends that may be relevant to preclinical diagnoses, including changes in dietary, mobility, cardiac, medication, or sleep habits.

Research developing technologies to continuously monitor motor and cognitive behavior, largely with in-home or ambient sensor technologies (i.e., smarthomes), has yielded promising findings. Studies employing home-based sensor technologies (e.g., bed sensors, computer use, motion sensors) have demonstrated reliable longitudinal measurement of behavior among healthy older adults, and sensitivity to cognitive and functional declines associated with NDD. For example, large samples of walking speeds and minutes of daily computer use have shown sensitivity to incident conversion to mild cognitive impairment (MCI) [1]. However, in-home sensor systems remain costly, require installation, and are limited to monitoring in-home behaviors. Furthermore, identifying specific individuals that live in multi-person homes remains a challenge.

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Advances in *wearable sensor systems* (WSS) offer a complementary approach to in-home systems for continuous measurement of motor and cognitive behavior. Worn on the body, WSS are relatively inexpensive and can provide continuous measurement beyond the confines of the home linked to an individual, addressing key limitations of home-based systems. Recent studies have explored accelerometer-based WSS metrics to quantify physical activity, sedentary, sleep, and gait behaviors for dementia research (e.g., [2]–[4]). Similarly GPS localization has been used to measure global mobility behavior, sensitive to declines in functional capabilities [5]. However, the scope of validated WSS metrics are limited to a small sets of largely activity-based metrics (i.e., physical activity, mobility, sleep patterns), limiting their utility for management and prevention of NDD.

The objective of this talk is to discuss past and on-going research projects conducted at the University of Waterloo pursuing ***large-scale, interdisciplinary development of novel wearable sensor-based biomarkers for early diagnosis and treatment of neurodegenerative diseases.***

The symposium talk will focus on: 1) the Voice, Activity, and Location Monitoring for Alzheimer's disease (VALMA) project, and 2) on-going development on the ONDRI@Home project. Both projects aim to investigate developing novel sensor-based biomarkers reflecting biological targets (i.e., movement, sleep, cardiovascular function). Discussion will focus on interdisciplinary research collaborations to afford knowledge translation, create environments for discovery, and examine implications for clinical practice.

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