TECHNICAL SESSION #1: Motivating Movement

1.1 Research Abstract: Using SMS message and a Mobile Phone Application to Influence Physical Activity in Hispanic Adolescents

Background: Wireless technologies offer innovative and adaptive methods to intervene in real-time on health-related behaviors such as physical activity (PA). We have previously shown that a real-time intervention using KNOWME networks, a wireless body-area network with a mobile phone interface, was effective in increasing PA in Hispanic adolescents, a population at high risk for obesity and related diseases.

Objectives: We previously found that participants’ PA as measured by accelerometer counts was significantly higher after SMS messages from the research team were received, as compared to when no SMS messages were received. These analyses are aimed at discovering if specific message content prompted PA increases, or whether simply receiving any SMS messages was enough to prompt PA increases.

Methods: Ten Hispanic adolescents (mean age=16.3±1.7 years, mean BMI percentile=97.2±4.4, 50% female) wore KNOWME Networks and an Actigraph accelerometer over a weekend for a 2.5 day pilot study. KNOWME Networks is a mobile phone application that measures PA through on-body sensors and personalized algorithms. Time-stamped activity data was sent from the application to the research team in real-time, allowing researchers to provide timely reflective feedback and engage participants in SMS message conversations.

The SMS coding scheme was adopted from Motivational Interviewing, an intervention approach that focuses on eliciting and strengthening motivation for behavior change[2]. Messages sent by the researchers were post-hoc categorized as 1) prompting question: question that asked participants what they could do to be physically active when sedentary behavior was observed, 2) affirmation: commending participants for engaging in PA, 3) suggestion: providing suggestions for PA options, 4) neutral: messages that were not related to physical activity. Lagged mixed regression analyses were conducted to determine if different types of reflective messages were associated with an increase in PA ten minutes and twenty minutes after receiving the message.

Results: During the 2.5 day pilot study, a mean of 43.1±15.9 total SMS messages, 3.5±2.3 prompting questions, 5.7±3.3 affirmation messages, 1.8±1.9 suggestion messages, and 25.1±5.3 neutral messages were sent to participants. Accelerometer counts were 3332 counts higher in the ten minute period (p<0.001) and 2780 counts higher in the twenty minute period (p<0.01) after a prompting question was sent relative to when no such messages were sent. Accelerometer counts were 3979 counts higher in the ten minute period (p<0.001) and 4065 counts higher in the twenty minute period (p<0.001) after an affirmation message was sent relative to when no messages of this type were sent. No other message types were associated with statistically significant increases in PA.

Conclusions: Prompting adolescents to engage in PA using reflective SMS messages based on real-time data is a potentially effective intervention approach. Additional studies with larger sample sizes and theoretically grounded SMS messages are needed to provide further insights into how this methodology can be adapted to promote PA and other health-related behaviors.

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1.2 Paper: Combining Wearable Accelerometer and Physiological Data for Activity and Energy Expenditure Estimation

Physical Activity (PA) is one of the most important determinants of health. Wearable sensors have great potential for accurate assessment of PA (activity type and Energy Expenditure (EE)) in daily life. In this paper we investigate the benefit of multiple physiological signals (Heart Rate (HR), respiration rate, Galvanic Skin Response (GSR), skin humidity) as well as accelerometer (ACC) data from two locations (wrist - combining ACC, GSR and skin humidity – and chest - combining ACC and HR) on PA type and EE estimation. We implemented single regression, activity recognition and activity-specific EE models on data collected from 16 subjects, while performing a set of PAs, grouped into six clusters (lying, sedentary, dynamic, walking, biking and running). Our results show that combining ACC and physiological signals improves performance for activity recognition (by 2 and 8% for the chest and wrist) and EE (by 36 - chest - and 35% - wrist - for single regression models, and by 18 - chest - and 46% - wrist - for activity-specific models). Physiological signals other than HR showed a coarser relation with level of physical exertion, resulting in being better predictors of activity cluster type and separation between inactivity and activity than EE, due to the weak correlation to EE within an activity cluster.

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1.3 Invited Talk: Theory Meets Reality: Motivating Physical Activity in Adolescents Using Social Media and Gaming

Mobile health technologies typically focus on egocentric theories of behavior change, such as self-efficacy theory, the health belief model, or the transtheoretical model. However, sustained health behavior change requires more than just the patient: families, neighborhoods and communities are important stakeholders in a behavior change intervention. The need to involve stakeholders is particularly true for adolescents, whose self-perceptions are intimately tied to peer opinion and who lead highly structured lives governed by parents and teachers. In our work studying adolescent physical activity, we have specifically focused on the role of peer social support as a motivator in a pervasive fitness intervention. We are particularly interested in how online social identity and collaborative gaming can motivate behavior change.

In this talk, we discuss our experiences implementing a wireless health system with social features in mind. Together with students and teachers from a low-SES majority-minority school, we developed and deployed StepStream, a social fitness intervention for middle school students. StepStream featured wireless pedometers, a social network site with collaborative gaming, and regular after-school meetings. We recently completed a four-week deployment of StepStream with 42 students in a public middle school. Students wore the pedometers daily, and met weekly in the school computer lab to use the website, address any pedometer or login issues, and hang out. On the website, students could chat with each other, check their own physical activity, and play a racing game with friends.

In designing our study, we paid attention to the role of non-competitive peer social support in motivating behavior change. In StepStream, users could not see each other’s raw step counts, and the game in the system was specifically designed to let students play “alongside” each other rather than against each other. We extended this design theme to the structure of the deployment as well, focusing in-person meetings on social chat and play rather than celebration of individuals or leaderboard-style rankings.

Our initial findings are encouraging. Overall, we found that StepStream users improved their sense of social support for fitness, and that the least active students improved their physical activity more than the most active. Most encouragingly, our social approach appeared to encourage individual motivation: students who used StepStream reported greater levels of social support for fitness, as well as increased self-efficacy for some physical activity measures.

Our study indicates that a wireless health system can effectively incorporate peer-based social support to motivate attitude and behavior change. We encourage others in this space to consider and design for the many complex social networks in adolescents’ everyday lives.

Andrew Miller (Georgia Tech, US)
Beth Mynatt (Georgia Tech, US)
2.1 Paper: Feasibility of Personalized Nonparametric Analytics for Predictive Monitoring of Heart Failure Patients using Continuous Mobile Telemetry

Nonparametric model-based analytics personalized to the physiology of each patient are investigated for predictive monitoring of exacerbation in heart failure patients at home. Multivariate vital sign data are provided by means of continuous bio-signal acquisition with a mobile phone-based wearable sensor system worn by patients for several hours a day in the home ambulatory environment. Perturbation analysis demonstrates that individual patient physiological behavior is indeed effectively learned by the analytics, with high sensitivity to changes in physiological dynamics. Comparison of the analytics results with absence of unplanned medical events and self-reported wellness during regular patient follow-up demonstrate a very low false alert burden, suggesting this approach is efficient for remote clinical surveillance.

R. Matthew Pipke (VGBio, US)
Stephan Wegerich (VGBio, US)
Abdullattah Saidi (George E. Wahlen Veterans Medical Center Salt Lake City, US)
Josef Stehlik (George E. Wahlen Veterans Medical Center Salt Lake City, US)

2.2 Research Abstract: Predicting Use of Remote Health Monitoring Systems in a Cohort of Patients with Chronic Heart Failure

BACKGROUND: The use of remote health monitoring systems has grown exponentially and has improved patient-provider communication, shared decision making, activation, and self-management in patients with Chronic Heart Failure (CHF). Despite these promising prospects, actual exposure to the use of wireless technologies – defined as accessing the intervention (first use), engaging in the intervention for a substantial period of time (prolonged use), and revisiting the intervention (sustained use) - remain fairly low in patients with CHF. Furthermore, it is unclear what subgroups of patients may benefit from remote health monitoring technologies and what user characteristics and contextual factors determine effective use of these systems.

PURPOSE: The current study was conducted to: 1) examine the predictors of accessing (first-use of) remote health monitoring; and 2) distinguish between users and non-users of remote health monitoring by employing advanced data analytics in a cohort of patients with CHF. The overall goal was to assess patient adherence by determining whether subgroups of patients with CHF would be more inclined to effectively using remote health monitoring systems, and identifying contextual and physiological factors that contribute to such adherence prediction.

METHODS: This pilot study was a single-arm experimental study with a pre- (baseline) and post- (3 months) test design that was conducted between November 2009 and October 2010; data from the baseline measures was used for the proposed data analyses. A total of 16 patients (mean age 65.8 ± 6.1, range 58-83) provided consent; however, only 7 patients accessed the developed remote health monitoring system and transmitted data (e.g. weight, blood pressure, heart rate, symptom distress) to a centralized information system within 7 ± 2 days of hospital discharge for CHF exacerbation per study protocol. The baseline data (about 200 attributes) was used for attribute selection and patient classification. All attributes with a missing value were eliminated from data analysis to avoid the effect of missing data imputation on adherence assessment. The remaining 88 attributes were fed into an attribute selection algorithm followed by a decision table classifier. The classifier was used to distinguish between the two groups of patients (adherent versus non-adherent).

RESULTS: Baseline socio-demographic and clinical characteristics of users and non-users were comparable. The attribute selection algorithm revealed that non-users were less likely to have CHF specialty based care, an automatic internal cardioverter defibrillator, and a history of alcohol use, the three prominent attributes identified by our attribute selection algorithm. The decision table classifier had both precision and recall of 87.5%, and an F-score of 76.2% for predicting access to remote health monitoring.
CONCLUSION: Our preliminary data show that a small set of baseline attributes is sufficient to access adherence of patients with CHF to remote health monitoring technologies. Furthermore, subgroups of patients with CHF may be more inclined to using remote monitoring interventions. While our findings shed light on potential end-users more likely to benefit from remote health monitoring interventions, additional research in a larger sample is warranted to better explicate the impact of user characteristics on actual exposure to the use of these technologies.

Hassan Ghasemzadeh (UCLA, US)
Lorraine Evangelista (UCLA, US)
Majid Sarrafzadeh (UCLA, US)

2.3 Invited Talk: The Evolution of mHealth in the Management of Cardiac Conditions through Self-care and Behaviour Change

Remote patient monitoring (RPM) has shown some evidence in improving health outcomes and avoiding readmissions for heart failure patients. However, many challenges remain in creating consistent, large scale results and address the cost and complexity of implementation of such technologies.

Our work suggests that simple mobile phones can replace costly, purpose-built technologies for RPM. The sophistication and ubiquitousness of smartphones have created opportunities for mHealth applications, but few are evidence-based and far fewer are thought to be able to handle the complexity of chronic conditions such as heart failure.

We report on the design, development and results of RCTs of mHealth applications for the management of hypertension, heart failure, and identifying risk factors. The applications demonstrated that patients can have improved health outcomes while lowering their dependence on formal care providers. Eliciting health behavior change is discussed in detail and how the future of mHealth application should be focused on their ability to scale and to facilitate greater self care.

Joseph Cafazzo (University of Toronto, Center for Global eHealth Innovation, CA)
3.1 Paper: Remote Patient Monitoring: What Impact Can Data Analytics Have on Cost?

While significant effort has been made on designing Remote Monitoring Systems (RMS), limited research has been conducted on the potential cost savings that these systems offer in terms of reduction in readmission costs, as well as the costs associated with human resources involved in the intervention process. This paper is particularly interested in exploring potential cost savings that an analytics engine can provide in presence of intelligent back-end data processing and machine learning algorithms against conventional RMS that operate based on simple thresholding approaches. Using physiological data collected from 486 heart failure patients through a clinical study in collaboration with the UCLA School of Medicine, we conduct a retrospective data analysis to estimate prediction accuracy as well as associated costs of the two remote monitoring approaches. Our results show that analytics-based RMS can reduce false negative rates by 61.4% while maintaining a false positive performance close to that of conventional RMS. Furthermore, the proposed analytics engine achieves 61.5% reduction in the overall readmission costs.

Sunghoon Lee (University of California Los Angeles, US)
Hassan Ghasemzadeh (UCLA, US)
Bobak Mortazavi (UCLA, US)
Mars Lan (UCLA, US)
Nabil Alshurafa (UCLA, US)
Michael Ong (UCLA, US)
Majid Sarrafzadeh (UCLA, US)

3.2 Invited Talk: Materials, Mechanics and Stretchable Designs for Emerging Bio-integrated Systems

Microelectronics technology has driven important advances in health diagnostics and therapeutics. However, there are fundamental incongruences in size, density and mechanical properties between existing classes of rigid electronics employed in most medical devices and soft biological substrates. In this talk, I describe novel materials, mechanics and design strategies for emerging wireless health monitoring systems. These systems incorporate microfabricated conformal sensors (electrodes, temperature sensors, and accelerometers) for sensing and piezoelectric actuators configured in ultrathin, flexible formats for energy harvesting. Quantitative analyses of individual sensor and circuit performances under stress illustrate the ability to mechanically couple with soft tissues in a way that is invisible to the user. Representative examples of these biointegrated systems can be applied for continuous sensing of cardiac, muscle and neural activity in hospital settings, and for low-cost transient data capture for ambulatory care.

Roozbeh Ghaffari (MC10, US)
3.3 Invited Talk: The paradox of healthcare cost: an African perspective

Advances in process power and reductions in cost make computing devices accessible to an ever-increasing number of people in both emerging and developed countries, empowering innovations across the computing continuum—from the smallest handheld devices to the largest cloud-based servers. However, advances in medical technology over the last few decades did not follow the same trend, but instead lead to substantial increase in healthcare cost. This is especially true for imaging technology procedures where specialist skill and knowledge is required to operate these devices and with no incentive to use cost-effective technologies.

With the decentralization of healthcare services in both emerging and developed countries, mobile computing technology is ideal positioned to facilitate access to care, audit the quality as well as reduce the cost. This will require a shift in knowledge and skill to the point of care by the latest affordable communication, computing and data management capabilities. For the best adoption, the shift should focus on empirical medicine (evidence based) and precision medicine where the outcomes do have a high level of prediction.

Current implementations of mobile healthcare technologies in Africa are focusing on business models providing services to:

• Monitor remote healthcare workforces in real time.
• Empowering a decentralized workforce to perform complex tasks, treatment and scheduling.
• Movement and monitoring of medical equipment and healthcare stock.
• Identifying and addressing risks within a community.
• Point of care diagnostics and decision-making.

The stethoscope is regarded as one of the oldest pieces of medical technology, widely used to assess internal organ sound, of which heart and lung sounds provides invaluable information on the patient’s cardiac and pulmonary well-being. Although cardiac auscultation is still regarded as a very important skill for front-line care, there appears to be a significant decline in this skill. The reasons for this are, the availability of imaging technology in developed markets, increasing healthcare cost significantly, and lack of knowledgeable human resources in emerging markets, limiting access to quality care.

The need for cardiac assisted auscultation technology is therefore driven by the high informative nature of auscultation, the difficulties and required skill associated with auscultation, the need for objective evidence, as well as the high cost of the next best alternative.

Two studies recently conducted in rural China (Yunnan Province) with an NGO, China California Heart Watch, showed that respectively 78% and 58% of the referrals for cardiac echo-cardiography (ultrasound) were due to innocent murmurs. Computer assisted cardiac auscultation technology has the ability to reduce these unnecessary referrals by respectively 69% and 63%, while achieving a sensitivity of 83% and 87% (on the same level as an experienced pediatric cardiologist). This could lead to a significant reduction in health care cost, where in the US the direct cost of an echo is above $500. In Africa (and China) the skills to perform these specialized health care services are relatively scarce and too expensive for the general population who mostly require it. Add to that the indirect cost for travel and leave at work, an unnecessary referral for an echo-cardiograph becomes very expensive.

Mobile and cloud based computing technologies at point of care could facilitate the turn-around of the cost paradox that exists within the healthcare sector in the developed market, as well as providing access to quality care in emerging markets.

Thys Cronje (Diacoustic Medical Devices, ZA)
TECHNICAL SESSION #4: Aint Misbehavin’

4.1 Research Abstract: Capturing Illicit Drug Use Where it Happens: an Ecologic Momentary Assessment of the Social, Physical and Activity Environment of Using Versus Craving Illicit Drugs

**Background:** Understanding the environmental influences of using rather than craving (but resisting) illicit drugs can inform interventions to prevent relapse and support cessation.

**Objective:** To provide real-time assessment of drug users’ natural environment using mobile devices.

**Methods:** Selected participants from the AIDS Linked to the IntraVenous Experience (ALIVE) cohort study in Baltimore, MD were recruited into the Exposure Assessment in Current Time (EXACT) study. Those eligible had to follow directions on a personal digital assistant (PDA) or mobile phone and have a history of prior heroin or cocaine use. Individuals were excluded if they had medical conditions that would prevent them from operating the device (e.g., limited vision or hearing). Participants (N=109) were given a PDA or mobile phone and followed for a 30-day period from November 2008 through May 2013.

Ecologic momentary assessment (EMA) utilizes mobile devices to collect data from participants in real-time. EXACT participants received five random prompt surveys each day. Additionally, participants were asked to self-report every time they either craved or used heroin or cocaine (event-contingent responses). Participants were asked if the event occurred within the last 30 minutes to ensure responses were recorded in real-time. For each event, participants answered questions concerning their drug use, current mood, social, physical and activity environment using EMA survey instruments adapted from collaborators[1-3]. Odds ratios (OR) of drug use versus craving were obtained from logistic regression models with generalized estimating equations (GEE) of all event-contingent entries. All models included a control term for the number of records that each participant contributed to the dataset.

**Results:** Study participants were a median of 48.5 years old, 90% African American, 52% male and 59% HIV-infected with limited income and educational attainment. Of 2,798 events, 1,954 (69.8%) were craving and 844 (30.2%) were drug use events. Participants reporting being with someone who was using drugs (OR 1.45; 95% CI, 1.13-1.86), being in an abandoned space (OR 6.65; 95% CI, 1.78-10.00) or walking/wandering (OR 1.68; 95% CI 1.11-2.54) at the time of the event were significantly more likely to use rather than crave drugs. Handling more than $10 (OR 1.70; 95% CI: 1.11-2.59) and using tobacco (OR 2.27; 95% CI: 1.37-3.78) were also significant predictors of drug use. Craving drugs was associated with being with a child (OR 0.26; 95% CI, 0.12-0.59), eating (OR 0.54; 95% CI, 0.34-0.85) or being at the doctor's office (OR 0.31; 95% CI, 0.12-0.80).

**Conclusions:** EXACT participants are ‘out of treatment’ individuals in their natural settings at high risk for drug relapse. Drug use was significantly associated with reports of being in an environment where drugs were readily available or being used. In contrast, reports of craving without actual use were associated with more stable environments, such as public spaces or where children were present. With a more informed understanding of the drug-using environment, personalized, context-sensitive interventions (ecological momentary interventions) can be tailored to prevent relapse and support cessation of illicit drug use.

*Beth S. Linas (Johns Hopkins Bloomberg School of Public Health, US)*
*Andrew Genz (Johns Hopkins Bloomberg School of Public Health, US)*
*Gregory D. Kirk (Johns Hopkins Bloomberg School of Public Health, US)*
4.2 Invited Talk: Using new technologies for understanding and changing behavior

Background: Adverse and suboptimal health behaviors and habits are responsible for approximately 40% of preventable deaths1-4. Our current understanding of human behavior is based on static ‘snapshots’ of human behavior5, rather than ongoing, dynamic cascades of behavior in response to ever-changing biological, social and personal environmental states. To solve the major behavior-driven problems faced globally, new empirically-based theories that can better explain the “just-in-time” dynamics of behavior are required. New technologies now enable users to access, store, transmit, and manipulate information in real time, anywhere, at any time. We can now monitor a host of health related behaviors, states, social interactions, and health indices, as well as a host of other physiological, behavioral and contextual signals in real time. Data from mobile and environmental sensors and systems must now be exploited to understand human behavior in real time by using emerging computational methodologies such as systems modeling. This combination of ongoing, real-time measurement and emerging modeling techniques provide us the tools to describe, predict, and hopefully positively manipulate health behaviors of individuals6.

Purpose: To present examples how big data acquired with new wearable and ubiquitous technologies can be used to acquire patterns of behavior during everyday life and enable modeling of behaviors.

Methods: Two example studies on unobtrusive health monitoring are briefly reported. Study 1: >24h beat-to-beat heart rate data was acquired from >14.000 individuals during daily life, constituting >21.000 monitoring days. Energy expenditure, physical activity, and stress related parameters were calculated, and differences related to age, gender, activity level (self-assessed level of typical physical activity), weekday, and month were analyzed to reveal patterns of physical activity and stress and their association to individual’s characteristics. Study 2: daily self-weighing data from 118 individuals participating in occupational health promotion program (6 wk intervention, 1y follow-up) was analyzed to study if weekday or non-adherence to self-weighing is associated with weight management success.

Results: Patterns of physical activity and stress were found to vary with weekdays and months. Activity level was major determinant for energy expenditure, physical activity, and stress. Adherence to daily self-weighing was associated with weight loss while long-term (>1mth) non-adherence was associated with weight gain. Weight increased during weekends and decreased during week days, and this pattern was strongest in subject’s losing weight during the study.

Conclusion: Data acquired with modern wearable and ubiquitous technologies reveals novel patterns and relationships between different factors which can help us to develop dynamic computational models of behavior. However, there are several steps that need to be taken to harness new technologies and the data that they provide, doing so may help the field to develop new dynamic, personalizable, adaptable, contextualized models of health behavior and behavior change.

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Current methods of healthcare service delivery are generally considered non-sustainable given the increasing demand on the system from an ageing population, increasing prevalence of long-term conditions, and high expectations. In particular, the increasing prevalence of diabetes is an issue facing all health services worldwide. The burden to the health system from associated morbidity is significant. People with diabetes face the prospect of progression to debilitating consequences such as blindness, heart disease, stroke, kidney failure and lower limb amputation. It is a constant challenge for both patients and clinicians to control their condition and prevent or delay disease progression.

Good self-management is considered vital although this requires a very good understanding of complex issues, a positive attitude towards the future in order to undertake secondary prevention activities, and a constantly high level of motivation. Many people with diabetes struggle with their control, and links with and between members of the broader clinical team are largely based on delayed written correspondence. There is a demand for closer connection in the form of shared patient health information, agreed care plans, structured clinician-patient communications and real-time advice. Part of the solution may be to reduce the reliance on more expensive healthcare resources by a more integrated approach enabled by technology.

The National Institute for Health Innovation (University of Auckland, New Zealand) has been working with the Waitemata District Health Board around technology-based tools to support self-management of diabetes. This process has included consultation with primary care and secondary care teams, a Māori Advisory Group, and people with diabetes. Gaps were initially identified, existing tools and systems examined, and new tools proposed. These included: population-based health information; shared patient health information between care team members; structured communications between patients and their care teams; and tools to support and encourage self-management. Particular target groups identified included those struggling with motivation to control their condition, those wanting more dietary information, those commencing insulin therapy, and those with limited access to services and technology. The tools being developed and tested include: 1) a text message motivational support programme, 2) a structured telehealth programme, 3) a smartphone application, and 4) video conferencing for secondary care specialists to support primary care team management. These are being integrated into health IT systems via the national Shared Care Plan platform.

This has been a broad approach to identifying and developing technology-based tools that may assist along the continuum of better integrated care and self-management of diabetes. Through this approach a diversity of needs amongst patients and clinicians alike has been observed. A key component in developing new technology-based tools has been engaging clinicians and patients in pre-test phases to optimally design interventions. Any tools must be user friendly to accommodate for the variations in willingness to engage new technologies, and flexible enough to accommodate variations in individual needs and levels of engagement. Integrating tools into centralised health IT systems is also vital to their adoption. Lessons learned here can be applied to the management of many other long-term conditions.

Robyn Whittaker (National Institute for Health Innovation, University of Auckland, NZ)
5.1 Paper: The Impact of Vibrotactile Biofeedback on the Excessive Walking Sway and the Postural Control in Elderly

Gait and postural control are important aspects of human movement and balance. Normal movement control in human is subject to change with aging. With aging, the nervous system comprising, somatosensory, visual senses, spatial orientation senses, and neuromuscular control degrade. As a result, the body movement control such as the lateral sway while walking is affected which has been shown to be a significant cause of falling among the elderly. Biofeedback has been investigated to assist elderly improve their body movement and postural ability, by supplementing the feedback to the nervous system. In this paper, we propose a wearable low-power sensor system capable of characterizing lateral sway and gait parameters. Then, it can provide corrective feedback to reduce excessive sway in real-time via vibratory feedback modules. Real-time and low-power characteristics along with wearability of our proposed system allow long-term continuous subjects’ sway monitoring while giving direct feedback to enhance walking sway and prevent falling. It can also be used in the clinics as a tool for evaluating the risks of falls, and training users to better maintain their balance. The effectiveness of the biofeedback system was evaluated on 12 older adults as they performed gait and stance tasks with and without biofeedback. Significant improvement \((p\text{-value} < 0.1)\) in sway angle in variance of the sway angle, variance of gait phases, and in postural control while on perturbed surface was detected when the proposed Sway Error Feedback System was used.

Omid Dehzangi (University of Texas at Dallas, US)
Zheng Zhao (UT Dallas, US)
Mohammad-Mahdi Bidmeshki (UT Dallas, US)
John Biggan (University of Texas at Arlington, US)
Christopher Ray (UT Arlington, US)
Roozbeh Jafari (UT Dallas, US)

5.2 Paper: Wireless Multi Sensor Bracelet with Discreet Feedback

A novel wireless multi sensor bracelet has been developed. The design choices of the bracelet - based on insights obtained with a predecessor sensor bracelet –, as well as the rationale for the choice of sensors, are presented. The hardware and software architecture are described. An example of obtained sensor data is shown. The limited battery life of the performance optimized product software fell short of the one week design target. A power optimization of the software has been made, which meets the battery life design target. It is based on current consumption measurements, and optimized sensor timing. The tradeoffs between high performance - short battery life, and low performance - long battery life are analyzed. The learnings from recent field studies on work-related stress and affective health are discussed.

Martin Ouwerkerk (Philips Research, NL)
Pierre Dandine (INSA de Lyon, FR)
Dennis Bolio (Philips Group Innovation - Research, NL)
Rafal Kocielnik (Eindhoven University of Technology, NL)
Johana Mercurio (SICS Swedish ICT AB, SE)
Henk Huijgen (Philips Group Innovation - Research, NL)
Joyce Westerink (Philips Group Innovation - Research, NL)
5.3 Invited Talk: Tracking Wrist Motion to Monitor Energy Intake

Advances in body-worn sensors and mobile health technology have created new opportunities for empowering people to take a more active role in managing their health. Obesity has been recognized as a target of opportunity that could particularly benefit from this approach. Self-monitoring of dietary intake is critical for weight loss/management, but currently used tools such as food diaries require users to manually estimate and record energy intake, making them subjective, prone to error, and difficult to use for long periods of time. Our group is researching methods that automate the monitoring of dietary intake by tracking wrist motion. This talk will summarize results showing (a) the detection of meals/snacks during continuous all-day tracking; (b) the automatic counting of bites across a wide variety of foods, utensils and subject demographics; (c) the correlation of bites with calories at the meal level; (d) the comparison of our method against a 24 hour recall, and (e) the benefits and potential applications of our approach.

Bruce H. Dobkin (Department of Neurology, University of California, Los Angeles, US)
Andrew Dorsch (Department of Neurology, University of California, Los Angeles, US)
William Kaiser (Departments Electrical Engineering, University of California, Los Angeles, US)

TECHNICAL SESSION #6: Safety & Security

6.1 Paper: PEES: Physiology-based End-to-End Security for mHealth

Ensuring security of private health data over the communication channel from the sensors to the back-end medical cloud is crucial in a mHealth system. This end-to-end (E2E) security is enabled by distributing cryptographic keys between a sensor and the cloud so that the data can be encrypted and its integrity protected. Further, the key can also be used for mutually authenticating the communication. The distribution of keys is one of the biggest overheads in enabling secure communication and needs to be done in a transparent way that minimizes the cognitive load on the users (patients). Traditional approaches for providing E2E security for mHealth systems are based on asymmetric cryptosystems that require extensive security infrastructure. In this paper, we propose a novel protocol, Physiology-based End-to-End Security (PEES), which provides a secure communication channel between the sensors and the back-end medical cloud in a transparent way. PEES uses: (1) physiological signal features to hide a secret key, and (2) synthetically generated physiological signals from generative models parameterized with patient’s physiological information, to unhide the key. Moreover, in PEES authentication comes for free since only sensors on the user’s body has access to physiological features and can therefore gain access to the protected information in the cloud. The analysis of the approach using electrocardiogram (ECG) and photoplethysmogram (PPG) signals and their associated models demonstrate the feasibility of PEES. The protocol is light-weight for sensors and has no pre-deployment or storage requirements and can provide strong and random keys (~90 bits long). We have also started clinical studies to establish its efficacy in practice.

Ayan Banerjee (Arizona State University, USA);
Sandeep Gupta (Arizona State University, USA);
Krishna Kumar Venkatasubramanian (Worcester Polytechnic Institute, USA)
6.2 Paper: Interactions in an Intensive Care Unit: Experiences Pre-Processing Sensor Network Data

Healthcare-associated infections (HAIs) represent a significant burden to healthcare provision; in the United States alone, it is estimated that approximately 2 million patients acquire HAIs each year. As part of a larger effort to understand how HAIs spread, we deployed a wireless sensor network in the Medical Intensive Care Unit of the University of Iowa Hospitals and Clinics. We used data reported by the network to estimate healthcare worker movement, interactions between healthcare workers, and adherence to hand sanitization policies.

Our experiment joins the growing yet still small collection of sensor network deployments in healthcare settings. This work contributes to this body of research by presenting a comprehensive approach to pre-processing the collected sensor data, thereby reducing errors and increasing robustness. We provide two main contributions: (i) a simple and theoretically sound calibration method for sensor signals that eliminates biases in pairwise sensor communication and (ii) filters that increase the reliability of signal strength from stationary sensors. We validate our methods by comparing visits of healthcare workers to rooms, as discovered from the sensor data, to ground truth room occupancy data collected in notes.

Mauricio Monsalve (The University of Iowa, USA)
Sriram Pemmaraju (The University of Iowa, USA)
Philip Polgreen (The University of Iowa, USA)

6.3 Invited Talk: Trustworthy Health and Wellness (THaW)

This talk will present a brief overview of a new NSF-funded project that aims to tackle many of the fundamental research challenges necessary to provide trustworthy information systems for health and wellness, as sensitive information and health-related tasks are increasingly pushed into mobile devices and cloud-based services. The interdisciplinary research team includes expertise from computer science, business, behavioral health, health policy, and healthcare information technology to enable the creation of health & wellness systems that can be trusted by individual citizens to protect their privacy and can be trusted by health professionals to ensure data integrity and security. Although these problems are motivated by a nationally important application domain (health and wellness), the solutions have applications far beyond that domain. For more information on the project, visit thaw.org.

David Kotz (Dartmouth, USA)
DEMONSTRATION & RESEARCH ABSTRACT ORAL PRESENTATION SESSIONS

Presentation Session 1:

1.1 Demonstration Paper: A Secure mHealth Application for EMS: Design and Implementation

Healthcare organizations are looking to implement mobile health applications that significantly improve healthcare delivery, yet adhere to existing health information privacy and security rules and regulations. However, these same organizations are struggling to find comprehensive frameworks, guidelines, and examples on how to successfully accomplish these interrelated goals. This paper presents a set of guiding principles specific to designing and building practitioner oriented mHealth applications. The system design is described, including the security features that were implemented, and results from performance testing in a live field test environment on 20 ambulances and 7 hospitals.

Abdullah Murad (Claremont Graduate University, US)
Benjamin Schooley (University of South Carolina-Columbia, US)
Yousef Abed (Claremont Graduate University, US)

1.2 Demonstration Paper: Accurate Energy Expenditure Estimation using Smartphone Sensors

Accurate and online Energy Expenditure Estimation (EEE) utilizing small wearable sensors is a difficult task with most existing schemes. In this work, we focus on accurate EEE for tracking ambulatory activities of a common smartphone user. We used existing smartphone sensors (accelerometer and barometer sensor), sampled at low frequency, to accurately detect EEE. Using Artificial Neural Networks, a machine learning technique, a generic regression model for EEE is built that yields upto 83% correlation with actual Energy Expenditure (EE). Using barometer data, in addition to accelerometry is found to significantly improve EEE performance (upto 10%). We compare our results against state-of-the-art Calorimetry Equations (CE) and consumer electronics devices (Fitbit and Nike+ Fuel Band).

Amit Pande (UC Davis, CA, US)
Yunze Zeng (UC Davis, CA, US)
Aveek Das (UC Davis, US)
Prasant Mohapatra (UC Davis, CA, US)
Sheridan Miyamoto (Betty Irene Moore School of Nursing, US)
Edmund Seto (UC Berkeley, US)
Erik Hennicson (UC Davis School of Medicine, US)
Jay Han (UC Davis School of Medicine, US)
1.3 Demonstration Paper: Monitoring Mobility Disorders at Home using 3D Visual Sensors and Mobile Sensors

In this paper, we present PoCM2 (Point-of-Care Mobility Monitoring), a generic and extensible at-home mobility evaluation and monitoring system. PoCM2 uses both 3D visual sensors (such as Microsoft Kinect) and mobile sensors (i.e., internal and external sensors embedded with/connected to a mobile device such as a smartphone) for complementary data acquisition, as well as a series of analytics that allow evaluation of both archived and real-time mobility data. We demonstrate the performance of PoCM2 with specific application developed for freeze detection and quantification from Parkinson’s Disease mobility data, as an approach to estimate the medication level of the PD patients and potentially recommend adjustments.

Farnoush Banaei-Kashani (University of Southern California, US)
Gerard Medioni (University of Southern California, US)
Khanh Nguyen (University of Southern California, US)
Luciano Nocera (University of Southern California, US)
Cyrus Shahabi (University of Southern California, US)
Ruizhe Wang (University of Southern California, US)
Cesar Blanco (University of Southern California, US)
Yi-An Chen (University of Southern California, US)
Yu-Chen Chang (University of Southern California, US)
Beth Fisher (University of Southern California, US)
Sara Mulroy (University of Southern California, US)
Philip Requejo (University of Southern California, US)
Carolee Winstein (University of Southern California, US)

1.4 Demonstration Paper: Cloud-Based Integrative Solution for Personalized Pain Management

Pain is a leading cause of discomfort and loss of efficiency, with a total of 100 million people in the United States of America suffering from acute and chronic pain conditions. In many types of pain conditions, it is not possible to completely alleviate the symptoms; hence there is a need to develop techniques to manage pain effectively. Some of the clinically used pain management tools are paper based, which is cumbersome. Hence we propose a cloud based universal pain management system. Our system is designed to collect data from users about the location and type of pain experienced by them and gives clinical interventions if the pain levels are greater than a personalized threshold for an extended duration. Pilot results have demonstrated that the usability levels of a portion of our system (SMS). Following IRB approval, we hope to recruit a total of 60 patients with four different causes of pain from Emory pain clinic to show usability of the complete system.

Janani Venugopal (Georgia Institute of Technology, US)
Chihwen Cheng (Georgia Institute of Technology, US)
May Dongmei Wang (Georgia Tech and Emory University, US)
1.5 Demonstration Paper: bHealthy: A Physiological Feedback-based Mobile Wellness Application Suite

We demonstrate bHealthy, a physiological feedback-based mobile wellness application suite. bHealthy monitors physiological signals using electrocardiogram, electroencephalogram, and accelerometer sensors; uses a suite of assessment applications to detect mental state of the user; suggests apps to enhance wellbeing; and tracks the performance of the user in the suggested apps. bHealthy also provides wellness reports based on the user's activity in apps over a period of time.

Joseph Milazzo (Arizona State University, US)
Priyanka Bagade (Arizona State University, US)
Ayan Banerjee (Arizona State University, US)
Sandeep Gupta (Arizona State University, US)

1.6 Demonstration Paper: Mobile Electronic Triaging for Emergency Response Improvement Through Crowdsourced and Sensor-Detected Information

Emergency resources are often insufficient to satisfy fully the demands for professional help and supplies after a public disaster. Furthermore, in a mass casualty situation, the emphasis shifts from ensuring the best possible outcome for each individual patient to ensuring the best possible outcome for the greatest number of patients. Historically, various manual and electronic medical triage systems have been used both under civil and military conditions to determine the order and priority of emergency treatment, transport, and best possible destination for the patients [3][4][5]. Unfortunately, none of those solutions has proven flexible, accurate, scalable or unobtrusive enough to meet the public's expectations [1]. We demonstrate a system for realtime patient assessment which uses mobile electronic triaging accomplished via crowdsourced and sensor-detected information. With the use of our system, emergency management professionals receive most of the information they need for preparing themselves to perform a timely and accurate treatment of their patients even before dispatching a response team to the event. During our demonstration, we will show how our system behaves with different combinations of information inputs and compare its resulting outputs with evaluations done by medical experts. The public will be given the chance to participate in real-time demos by posing as victims and providing self-reported information about their health.

Liliya Besaleva (University of Virginia, US)
Alfred Weaver (University Virginia, US)

1.7 Demonstration Paper: Personalized Physical Activity Monitoring on the Move

Accurate Energy Expenditure (EE) estimation is key in understanding how behavior and daily Physical Activity (PA) patterns affect health. Mobile phones and wearable sensors (e.g. accelerometers (ACC) and heart rate (HR) monitors) have been widely used to monitor PA. In this paper we present a real-time implementation of activity-specific EE estimation algorithms, using an Health Patch and an iPhone. Our approach to continuous monitoring of PA targets personalized behavior and health status assessment, by automatically accounting for a person's cardiorespiratory fitness level (CRF), which is the main cause of inter-individual variation in HR during moderate to vigorous activities. The proposed system opens new opportunities for personalized health assessment in daily life, using ubiquitous devices.

Marco Altini (Holst Centre/imec-nl, NL)
Julien Penders (imec / Holst Centre, NL)
Ruud Vullers (imec-Netherlands, NL)
Oliver Amft (TU Eindhoven, NL)
1.8 Demonstration Paper: A Mobile Point of Care Reader for Immediate Diagnostics and Analysis

In this paper, we describe a mobile point of care system designed to improve the healthcare workflow. We have created a rapid diagnostic test reader that can interpret the results from lateral flow point of care tests. Our approach exploits the use of mobile technology and cloud based services to closely integrate the clinic with the community.

Phillip Olla (Mobile Diagnostic Services, US)
Tatu Prykari (iSTOC, FI)
Hannu Kauniskangas (iSTOC, FI)

1.9 Demonstration Paper: An Automated Video Recommendation System to Enhance Engagement Levels in Moderate-Dementia Care Patients

We present a non-intrusive system (called ‘SENSEI’) that can measure engagement levels in moderate-dementia care (MDC) patients. The measurement software communicates with the YouTube recommendation system via a web-based program (developed using YouTube API) to alter or continue the video clip. The system fuses information from a webcam (face recognition, body posture, and voice intonation features) and optional body-worn sensors to determine the arousal and valence levels of subjects watching these videos. The proposed assistive technology is aimed at augmenting MDC patient’s interest levels that are strong indicators of quality-of-life enhancements.

Priya Ganapathy (UtopiaCompression Corporation, US)
Tejaswi Tamminedi (UtopiaCompression Corporation, US)
Evan Dong (UtopiaCompression Corporation, US)
Shalini Keshavamurthy (UtopiaCompression Corporation, US)
Jacob Yadegar (UtopiaCompression Corporation, US)
Aravind Kailas (University of North Carolina at Charlotte, US)
Parminder Juneja (University of North Carolina Charlotte, US)
Boyd Davis (University of North Carolina Charlotte, US)
Dena Shenk (University of North Carolina Charlotte, US)

Presentation Session 2:

2.1 Demonstration Paper: A Low Power and Convenient Bio-impedance Monitor, and Its Application to Respiration Monitoring

A low power and convenient bio-impedance monitor, which relies on a proprietary ASIC to achieve low power performance, is shown. It can be used in several bio-impedance applications, especially in continuous and wearable applications thanks to its compact form factor and long battery life time. In this paper, we demonstrate its performance for respiration monitoring. The result is compared with that of the reference system, showing a high correlation factor of 0.91.

Seulki Lee (Holst Centre / imec, NL)
Carlos Agell (Holst Centre / imec, NL)
Salvatore Polito (IMEC / Holst Centre, NL)
Ruud Vullers (imec-Netherlands, NL)
Julien Penders (imec / Holst Centre, NL)
2.2 Demonstration Paper: A Glanceable Mobile Avatar for Behavior Change

We present a mobile avatar system designed to provide a constant user-avatar interface for health behavior change therapy. The presented Android application replaces the user’s phone background with an animated avatar. The avatar’s level of physical activity is made to match the physical activity level of the user. This activity level is inferred using a decision-tree-based frequency analysis of the built-in phone accelerometers. User physical activity data collected is also sent via a mobile analytics platform (Countly) to be stored in a server. Also included in our demo is a simple website which pulls information from this server and places a user’s avatar among other people’s avatars. In this display a user can see how their avatar’s physical activity compares to others’, and observe their real-life physical activity behavior directly impacting the performance of their avatar in the virtual world.

Tylar Murray (University of South Florida, US)
Luis Jaimes (University of South Florida, US)
Eric Hekler (Arizona State University, US)
Donna Spruijt-Metz (University of Southern California, US)
Andrew Raij (University of South Florida, US)

2.3 Demonstration Paper: Connecting Medical Devices Through ASTM-2761-09 - Schedule Conflict Detection Prototype

The Integrated Clinical Environment (ICE) ASTM-2761 Standard specifies an architecture for real-time medical device interoperability, and a set of Clinical Concepts of Operations (CConOps). Based on an analysis of the CConOps, all showing improved patient safety, we developed an ICE prototype reflecting the ICE Synchronization with Safety Interlock Scenario, but with no risk to human participants, using wireless Medical Devices of different vendors.

Vincent Stanford (National Institute of Standards and Technology US)
Lukas Diduch (National Institute of Standards and Technology, US)
Antoine Fillinger (National Institutes of Standards & Technology, US)
Kamran Sayrafian (National Institute of Standards and Technology, US)

2.4 Demonstration Paper: A 16-channel Bluetooth Enabled Wearable EEG Platform with Dry-contact Electrodes for Brain Computer Interface

A mobile, easy to use, wireless dry contact EEG acquisition system is presented in this work. This system can potentially facilitate continuous in-home monitoring of electroencephalography (EEG) to diagnose ailments such as epilepsy. The system has also been validated with brain computer interface (BCI) paradigms that would enable physically disabled users to communicate.

Viswam Nathan (University of Texas at Dallas, US)
Jian Wu (UT Dallas, US)
Chengzhi Zhong (UT Dallas, US)
Yuan Zou (UT Dallas, US)
Omid Dehzangi (UT Dallas, US)
Mary Reagor (UT Dallas, US)
Roozbeh Jafari (UT Dallas, US)
2.5 Demonstration Paper: Adventurous Dreaming Highflying Dragon - A Full Body Game for Children with Attention Deficit Hyperactivity Disorder (ADHD)

Adventurous Dreaming Highflying Dragon is a full body-driven, game prototype for children ages 6-8 with a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). It incorporates research evidence showing that physical activity can help improve ADHD-related symptoms. Physical activity is integrated with cognitively challenging tasks that may improve brain activity by encouraging goal planning and dedication. The current prototype includes three mini-games, each of which teaches skills with generalization potential. Players role-play a young dragon and repeat virtual tasks to gain mastery over real-life skills. Each activity includes game mechanics targeting ADHD diagnosis categories: specific hyperactivity, impulsivity and inattention.

Yasaman Hashemian (School of Cinematic Art University of Southern California, US)
Marientina Gotsis (School of Cinematic Art University of Southern California, US)

2.6 Late Breaking Research Abstract: Enhanced Multiple Sclerosis Gait Assessment Using Inertial Sensors

**Background:** Multiple Sclerosis (MS) is a chronic autoimmune disorder of the central nervous system (CNS) resulting in neurologic impairment and functional disability over time. Loss of functional ambulation occurs in almost all MS patients over the course of their disease. Walking performance is, therefore, an important outcome to assess severity of disease, disease progression, and therapeutic efficacy. The 6-minute walk (6MW) is gaining popularity as an outcome measure in MS research, reported as distance walked in 6-minutes (i.e., gait speed). While an improvement over prior walk measures, the 6MW still lacks 1) high precision to capture various and subtle gait features that may be clinically meaningful; 2) real-world application to provide continuous monitoring in a patient’s natural environment.

**Purpose:** To better assess gait performance in MS, we adopt a tool that provides higher precision measurements and a remote monitoring capability – wireless, body-worn inertial sensors. To identify gait features that are most relevant in MS gait performance assessment using such sensors, we collect inertial gait data on MS patients and healthy controls, extract gait features from the time series data, and apply statistical methods to assess feature importance.

**Methods:** 28 study subjects (8 mild MS, 10 moderate MS, and 10 health control) wearing inertial sensors (3 axes of accelerometers and gyroscopes on each sensor node for 6 degrees-of-freedom sensing) on the lower limbs were asked to undergo an in-clinic 6MW. Followed by a medical assistant with a measurement wheel, the distance walked was recorded in 1-minute epochs. Subjects were asked to walk as far as and as fast as possible (without running) up and down a 75-foot hallway. The inertial sensor data was wirelessly transmitted to a laptop for post-processing. With the inertial data sampled at 128Hz with 12-bit resolution, high precision gait features were extracted including: double stance time (DST), single stance time (SST), swing time (SWT), gait cycle span (CYC), ratio of combinations of these four features (i.e. DST/CYC, SST/CYC, SWT/CYC, DST/SST, DST/SWT, and SWT/SST), gait complexity measured by elliptical Fourier analysis, and gait asymmetry measured by dynamic time warping. These features were then evaluated by Cohen-D metric for their effect size (ES) between the MS group and the healthy control group.

**Results:** Among the features extracted, DST/CYC, SST/CYC, DST/SST, and SWT/SST all present an ES larger than 0.9, compared to an ES of only 0.77 for gait speed – the current clinically-used gait feature.

**Conclusions:** Wireless, body-worn inertial sensors capture gait features that have greater significance for MS gait performance assessment than the current primary clinically-used feature (i.e., gait speed), providing higher-precision in-clinic assessments and the potential for continuous monitoring of MS gait performance. Ongoing work will further examine how these gait features may improve sensitivity to measure subtle but meaningful group differences in severity, to track disease progression, and to assess the efficacy of therapeutic interventions.

Shanshan Chen (University of Virginia, US)
Jiaqi Gong (University of Virginia, US)
John Lach (University of Virginia, US)
Myla Goldman (University of Virginia, US)
2.7 Late Breaking Research Abstract: HealthHub Suite: An Integrated Platform for Seamless and Continuous Health and Wellness Monitoring

**Background:** Remote and continuous monitoring of health and wellbeing has gained more attention due to the great potential on revolutionizing the healthcare industry and improving the efficiency and the effectiveness of the healthcare system. As an example, according to the CDC, 75% of the healthcare budget in the US is consumed on the treatment of chronic diseases. An easy-to-use and unobtrusive wearable system for monitoring physiological signals can help in early diagnosis of such problems and providing successful treatments with minimal side effects and lower costs. People's awareness of their wellbeing through continuous monitoring could also encourage them to be more proactive about their health and take preventive actions to reduce their risk of developing various diseases.

**Purpose:** Our primary aim is to build a seamless and integrated monitoring system which provides easy mechanism for the collection of physiological signals with least user burden. The system should be suitable for everyday use by individuals. It should further provide an inexpensive and easy-to-use solution for the health-science researchers in longitudinal studies.

**Methods:** To provide a system that can be integrated into people's everyday life and monitors physiological signals and health related parameters, we introduce HealthHub Suite which includes an iOS App running on apple's iPhone and iPad, and several hardware platforms which collect and process physiological signals and communicate wirelessly to the App. The App can be easily ported for any other platform supporting emerging wireless technologies such as Bluetooth low energy (BLE). The App has the capability to store and export data collected over time for further analysis. Current system includes the following devices to monitor physiological and health related parameters: Hand and foot based body composition monitors (BCM): These devices provide two methods for the user to measure the body mass index of the user. The foot based BCM includes a weighing scale while the hand based BCM requires the weight information to be entered in the App. Wrist device: This device which is easy to wear like a watch has the ability to monitor the heart rate as it fits on the wrist. It has an interface to connect a finger Pulse-Ox sensor to get more accurate readings and also computes and monitors the heart rate and SpO2 levels. It also supports the streaming function in which the App can show the waveform and record it for future reference. The wrist device is also equipped with a 9-axis inertial sensor which gives the device the capabilities of a pedometer. These three functionalities can be combined together and used simultaneously. ECG monitor: This device is used to collect ECG signal from chest. It is equipped with a strap which facilitates the mounting of the device on the chest and connecting the signal cords. The device has the capability to monitor the heart rate and stream the ECG signal to be displayed or recorded by the App. Thermometer: The ear thermometer device measures the temperature of user’s ear and communicates it with the App to display and make a history for future reference.

**Conclusion:** Our HealthHub system is an integrated platform for healthcare and wellness monitoring applications. We plan to expand the platform to include more physiological and health related parameters such as blood pressure and fine grain activity monitor and logger and smart algorithms for motion artifact removal. Our system has been tested on 5 participants. HRM devices have an error of ±3.5% on reporting the heart beat during one minute measurement periods. The pedometer had 7.2% average error in counting normal walking steps and in place running while placed on wrist or pocket for 100 steps. The platform can be extended to store data on the cloud, taking into account the security and privacy concerns.

Mohammad-Mahdi Bidmeshki (University of Texas at Dallas, US)
Jacob Clements (UT Dallas, US)
Viswam Nathan (UT Dallas, US)
Jian Wu (UT Dallas, US)
Praveen Aroul (Texas Instruments Inc, US)
Wen Li (Texas Instruments Inc, US)
Lijoy Philipose (Texas Instruments Inc, US)
Daniel Torres (Texas Instruments Inc, US)
Karthikeyan Soundarapandian (Texas Instruments, US)
Roozbeh Jafari (UT Dallas, US)
2.8 Late Breaking Research Abstract: Health Benefits and Voluntary Self-Monitoring: Post-Hoc Analysis of Intervention-less Weight Scale Usage

**Background:** The concomitant health benefits of weight loss and increased physical activity have spurred numerous clinical studies into behavioral treatment programs. Lifestyle intervention programs are associated with significant weight loss; however, they are expensive and time consuming, and have limited feasibility for wide application. Less intensive self-monitoring approaches also result in positive health outcomes, but still involve some interventional or interactive components and rely on subjective and sparse reporting of experiment variables. The advent of consumer self-quantification devices such as wireless weight scales and activity trackers has led to widespread adoption of voluntary self-monitoring, enabling intervention-less experiments on behavioral modification. A key remaining question is whether the same health benefits observed in clinical trials are retained in individuals that voluntarily monitor their activity and weight with no external prompting or explicit intervention.

**Purpose:** The primary objective of this study was to determine whether users of an intervention-less consumer scale exhibited weight loss trends similar to what has been observed in smaller scale self-monitoring clinical studies.

**Methods:** We performed a post hoc analysis on 10,000 users of the Fitbit Aria™, a consumer Wi-Fi scale released in May 2012 that automatically uploads a user’s weight to cloud-based storage. Users were subsampled to ensure an equal fraction of males and females. The median age in our sample was 40 years old, and the 1st, 2nd, and 3rd quartiles of baseline weight were (177, 200, 229 lbs) and (134, 154, 185 lbs) for males and females, respectively. 6,742 users also owned a Fitbit accelerometer-based activity tracker. We statistically corrected for seasonal variation in user weight by sampling an equal number of users with start dates in each month of the year. Weight loss was examined on an absolute and relative basis and compared against engagement as measured by measurement frequency and the ownership (or lack thereof) of an activity tracker.

**Results:** Subjects in the intervention-less program lost an average of 3.00 +/- 0.19 lb (1.46 +/- 0.09%) in the first 60 days of usage. Subjects that weighed themselves daily lost an average of 6.69 +/- 1.03 lb (3.26 +/- 0.48%). In contrast, subjects that weighed themselves once a week lost 1.44 +/- 0.35 lb (0.64 +/- 0.16%). Subjects that used a Fitbit activity tracker in addition to the Aria scale lost more weight than subjects that just used a scale (3.51 +/- 0.25 lb versus 2.61 +/- 0.29 lb, p < 0.00077).

**Conclusions:** This study shows that the use of intervention-less, consumer weight scales leads to significant weight loss on the order of 3.00 lb over 60 days of usage and accounting for seasonal variation. Frequent weighing is highly correlated with weight loss, with daily weighers losing roughly 4.5 times more than weekly weighers. As a secondary effect, the usage of an activity tracker correlated to more weight loss than for subjects who did not use one.

*Jacob Arnold (Fitbit, US)*
*Jung Hong (Fitbit, US)*
*Shelten Yuen (Fitbit, US)*
2.9 Late Breaking Research Abstract: Does the Use of Electronic Interactive Social Networking Increase the Compliance Rate in Adolescent First Time Oral Contraceptive Users?

**Background:** Oral contraceptive pills (OCPs) are prescribed to adolescent girls for a variety of reasons. If taken as prescribed, OCPs provide relief for many gynecologic conditions and prevent unintended pregnancy.

Research studies have highlighted high discontinuation rates in OCP users during the first few months. The current OCP continuation rates over six months in adolescent women range from 12-58 percent. A study published by Cramer in 1995 concludes that “health care professionals should make every effort to maintain contact with women for whom prescribed medication must be refilled regularly”.

**Purpose:** The objective of this study is to evaluate the effectiveness of an interactive social networking intervention on the compliance rate of first-time adolescent oral contraceptive pill users.

**Methods:** Twenty participants between the ages of 13-21 were enrolled to take part in this prospective study conducted at an ambulatory care center. All participants possessed a cell phone with text messaging and photo capabilities. All were prescribed OCPs for the first time for various indications. Non-possession of a cell phone with texting and media capturing capabilities, previous OCP users and patients whom were actively pregnant were excluded from the study. All eligible individuals agreed to participate in this study.

Participants received traditional verbal contraceptive counseling chose a 21-day active pill or a three month extended cycle pill regimen. Participants chose to take their pill in the morning or in the evening. Pre and post intervention questionnaires were obtained documenting the participants perceived compliance rate. Participants were instructed to set a daily alarm on their phone to serve as a reminder and were registered for an online patient portal. A method for a three month follow up either in person, via telephone, or via the online patient portal was chosen. Daily text message reminders were sent Monday through Friday at either 0700 or 1645. The participants were prompted in the daily text messages to send a reply photo of their OCP pack.

**Results:** To date, out of 20 enrolled participants, four have completed a three month intervention. Participants returned prompts for pictures at a rate of 66%. At five weeks, two patients stopped returning messages. One patient followed up in the way that was originally requested at three months. Two patients reported missing less than five pills over the three month interval while one patient reported no missed pills. Problems with pill misuse were discovered in three out of four patients due to pictorial data. All patients utilized text messaging liberally.

**Conclusions:** In this novel method to assess compliance in first time OCP users, early data suggest that pill misuse in the first few weeks may be under reported. Additionally, the traditional three month follow up evaluation may need to be reconsidered in lieu of a shorter interval follow up utilizing social media methods.

*Elizabeth Ojeda (Texas Tech University Health Sciences Center, US)*
*Leslie Chupp (Texas Tech University Health Sciences Center, US)*
*Betsy Jones (Texas Tech University Health Sciences Center, US)*
2.10 Late Breaking Research Abstract: A Wearable and Low-Power Bio-Impedance Monitor as a Screening Tool for Sleep Apnea

**Background:** Sleep apnea (SA) is a sleeping disorder characterized by pauses in breathing or episodes of shallow breathing. SA requires adequate treatment since it drastically increases the risk for cardiovascular disease, hypertension, stroke, diabetes, clinical depression and obesity. However, up to now, SA can only be diagnosed in a polysomnography (PSG) sleep experiment which is inconvenient and expensive. Since only patients with symptoms undergo PSG testing, there is still a large population that remains undiagnosed, making SA an underlying chronic condition silently worsening clinical conditions. Also, these undiagnosed patients put a large burden on healthcare costs.

**Objective:** The goal of this study was to evaluate a wearable screening tool for sleep apnea with simultaneous monitoring of cardiovascular rhythm, in order to improve the efficiency of PSG experiments and capture more undiagnosed patients.

**Methods:** A compact-sized, low-power bio-impedance monitor was used for continuous respiration monitoring during sleep. Four electrodes measured thoracic impedance with an excitation frequency of 50 kHz and a sampling rate of 10 Hz. Five consecutive patients presenting at the sleep clinic were provided with the wearable device and standard PSG equipment. Their respiratory patterns with simultaneously ECG were measured overnight. Data recorded by the wearable device and PSG were compared on the count of distinguishable episodes of apnea. Episodes of apnea were based on at least a 10-second interval between two breaths.

**Results:** Patients were referred to the sleep clinic based on suspicion of SA. Mean BMI was 33±4 and patients were all male. In total over 40 hours of data was collected. At random intervals samples were taken from both signals and the number of distinguishable apnea events were analysed. A Pearson correlation test between both measurement methods resulted in a significant correlation coefficient of 0.965 (p=0.02). Based on both systems, all patients could be classified as severe SA. ECG signal quality and integrity from the bioimpedance monitoring device was superior compared to the standardized system and no episodes of rhythm disorders could be identified.

**Conclusions:** The wearable bio-impedance monitor was able to measure respiratory events, which correlated significantly with the PSG system. These clinical experiments indicate the viability of such a sensor platform as a screening tool for SA. Additional research will further improve the bioimpedance accuracy and employ other integrated biometric signals to expand sensory capacity while focusing on miniaturization and integration.

*Christophe JP Smeets (Hasselt University, BE)*
*Seulki Lee (Holst Centre / imec, NL)*
*Pieter Vandervoort (Ziekenhuis Oost-Limburg, BE)*
*Julien Penders (imec / Holst Centre, NE)*
*Lars Grieten (Hasselt University, BE)*
1.1 Research Abstract: Use of Mobile Phones for Video Directly Observed Therapy among Tuberculosis Patients in High and Low Income Countries

Nearly 9 million cases of tuberculosis (TB) occur worldwide resulting in 1.4 million deaths annually. While curable, poor adherence to the long (>6 month) antibiotic regimens perpetuates illness, disease transmission, and acquired drug-resistance. Thus, “directly observed therapy” (DOT)—patients watched taking each medication dose—is encouraged where feasible to monitor treatment compliance. However, DOT is costly, labor-intensive and sometimes impractical. In low-resource settings, travel burden is often placed on the patient. We developed and pilot-tested a system to overcome these barriers called “Video DOT” (VDOT) whereby patients use mobile phones to record and send videos of themselves taking medications, which are then viewed remotely by DOT workers. This study determined feasibility and acceptability of VDOT, and estimated the level of treatment adherence observed using VDOT.

Richard S. Garfein (Division of Global Public Health, School of Medicine, University of California, San Diego, US)
Kelly Collins (Division of Global Public Health, School of Medicine, University of California, San Diego, US)
Fatima Muñoz (Division of Global Public Health, School of Medicine, University of California, San Diego, US)
Kathleen Moser (San Diego County Health and Human Services Agency, US)
Paris Cerecer-Callu (Jurisdicción Sanitaria II, Tijuana, Baja California, MX)
Mark Sullivan (California Institute of Telecommunications and Information Technology, UC San Diego, US)
Allison Flick (California Institute of Telecommunications and Information Technology, UC San Diego, US),
Phillip Rios (California Institute of Telecommunications and Information Technology, UC San Diego, US)
Maria Luisa Zúñiga (Division of Global Public Health, School of Medicine, University of California, San Diego, US)
Jose Luis Burgos (Division of Global Public Health, School of Medicine, University of California, San Diego, US)
Timothy Rodwell (Division of Global Public Health, School of Medicine, University of California, San Diego, US)
Maria Gudelia Rangel (El Colegio de la Frontera Norte, MX)
Kevin Patrick (California Institute of Telecommunications and Information Technology, UC San Diego, US)

1.2 Research Abstract: Addressing Medication Nonadherence in Patients with Diabetes Using Mobile Phone-Based Tailored Messages

Adherence to prescribed medications remains suboptimal, particularly in patients with diabetes. Nonadherence contributes to excess healthcare costs and avoidable complications. Interventions to improve medication use have proven insufficient, in terms of effect size, duration of behavior change, and the extent of adherence-related factors addressed. Tailored messages and text messaging have shown to improve medication adherence, but the extent of their effects is still poorly understood, particularly when tailored messages are delivered via text messaging.

Justin Gatwood (University of Michigan College of Pharmacy, US)
Rajesh Balkrishnan (University of Michigan College of Pharmacy, US)
Steve Erickson (University of Michigan College of Pharmacy, US)
Lawrence Ad (University of Michigan School of Medicine, US)
John Piette (University of Michigan School of Medicine, US)
Karen Farris (University of Michigan College of Pharmacy, US)
1.3 Research Abstract: Testing the structure of SMS messages for use in an artificial intelligence (AI)-driven SMS antihypertensive adherence support tool

Up to half of all patients do not take medications as prescribed, contributing to nearly 100,000 premature deaths yearly and $290 billion in healthcare costs. While forgetfulness is one major challenge, medication non-adherence can be intentional due to concerns about medications or beliefs about the condition. Many patients report multiple reasons for non-adherence, and those reasons can change over time. Mobile Health (mHealth) interventions such as text messaging or SMS can deliver frequent patient contact to improve adherence, and randomized trials suggest that SMS interventions can improve medication adherence. To be more effective, mHealth services need to adapt to each patient’s unique needs over the long-term.

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1.4 Demonstration Paper: AsthmaGuru: A Framework to Improve Adherence to Asthma Medication

Asthma is a widespread chronic disease. Poor management of Asthma results in a large number of hospitalizations each year, the majority of which are avoidable through strict adherence to medication. AsthmaGuru is a system which aims to provide personalized guidance to users on their health state, with an aim to improve their compliance to medication. To achieve this aim, AsthmaGuru aggregates three forms of data: (a) automated and unobtrusive measurement of medication adherence using a low-power portable electronic attachment to an inhaler, (b) lung function measurement based on portable spirometry and (c) local air quality metrics. We leverage a custom low-power hardware platform for augmenting the inhalers and spirometry and develop a custom Android API for delay-tolerant data collection.
2.1 Late Breaking Research Abstract: Mobile Technology to Measure Activities Related to Cognitive Health in Older Adults

**Background:** Evidence linking cognitively enriching physical activity to risk for dementia has been largely restricted to exercise, a behavior that is difficult to sustain in aging adults. This is particularly so among urban-dwelling older adults who may live in unsafe and under-resourced neighborhoods. Such limitations have left an important gap in understanding how to increase levels of physical activity in daily life and how much is sufficient to engender use-induced brain plasticity in networks implicated in dementia. A better understanding of the benefits of physical activity will require improved metrics to define patterns of activity in daily life.

**Purpose:** To explore the use of integrated GPS and accelerometer data, develop novel physical activity metrics, and test the association between those metrics and cognitive health measures.

**Methods:** Participants were enrolled in the Brain Health Study (BHS), a sub-study within the Baltimore Experience Corps trial, a randomized, controlled trial funded by the National Institute on Aging to evaluate the health benefits for older adults participating in Experience Corps Baltimore vs. a control group offered other low-service volunteer opportunities. Eligibility criteria of inclusion in the BHS included age ≥ 60 years, ≥24 on the Mini-Mental State Exam and ability to read at a minimum 6th grade level. Twenty participants were randomly selected to wear an accelerometer (Actical) and a GPS device (pTrac Pro) for up to five days.

Physical activity metrics based on total activity measured by the accelerometer and location measured by the GPS devices were developed, including total activity at home, total activity away from home, and total activity within defined activity spaces (e.g. church, shopping malls). Activity metrics were correlated with measures of cognitive health including memory (measured using the Rey Auditory Verbal Learning Test) and processing speed (measured using the pattern comparison test).

**Results:** The mean age of participants was 67 years, 95% were African-American, and 55% had a high school education or less. On average participants spent 77.0% (1098 min/day) of their days at home and 14.2% (203 min/day) in activity spaces. After adjusting for time spent in each location, activity spaces accounted for 46% of total daily activity (234.5 counts/min/day), and home accounted for only 13.3% (67 counts/minute/day) of total daily activity. The correlation between physical activity metrics and cognitive health improved with more specific characterization of location; memory: total activity (r = .28; p=.23); activity away from home (r=.32; p=.16); activity in activity spaces (r=.38; p=.10); processing speed: total activity (r =.18; p=.44); activity away from home (r=.24; p=.31); activity in activity spaces (r=.48; p=.03).

**Conclusion:** By integrating accelerometers with GPS, we were able to develop mobility profiles that captured amount of physical activity by location. We further showed that activity within predefined activity spaces such as churches and shopping malls was most strongly correlated with cognition. These results provide novel metrics with which to better measure how physical activity may promote cognitive health and how to design a new generation of cognitive interventions that embed activities within accessible, everyday contexts.

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2.2 Late Breaking Research Abstract: Low-cost, Wireless-Networked Screening for Oral Cancer by Basic Healthcare Workers

**Background:** The estimated annual worldwide number of incident oral cancers is about 275,000. South and Southeast Asia, India, France, and Brazil have particularly high rates. This is the fifth year in a row in which there has been an increase in the rate of oral cancers; in 2007 there was a surge of over 11%. This increase is seen mainly in young subjects, and is often attributed to the dramatic increase in HPV-related pathologies. Currently approximately 3/4 of all oral cancers are detected in advanced stage of disease so that prognosis and treatment outcomes are poor—typically 5-year survival rate in metastatic oral cancer is less than 20%. However, if detected and treated early, 5-year survival exceeds 80%. Currently there exists no simple, low-cost, non-surgical means of screening for oral pre-cancer and cancer.

**Purpose:** To develop a low-cost, portable wireless networked device that can be used by basic mobile healthcare workers in high risk countries, for early detection of oral cancer with direct translation to cervical, skin and all other epithelial cancers. In addition, this work has potential application to early detection of cancer in the developed world given the ongoing changes in the epidemiology of Human papilloma virus-related head and neck cancer, potential malignant oral lesions and recurrent cancer.

**Methods:** In this project we have completely re-engineer existing technology to provide an inexpensive very small, robust portable diagnostic system for oral cancer based on Optical Coherence Tomography (OCT) and a simple diagnostic algorithm that indicates further diagnostic and treatment needs for each detected lesion. Over the past year the prototype device has been developed and tested ex vivo and in vivo by our group at the University of California at Irvine (UCI), in close consultation with Dr M. A. Kuriakose’s group at Mazumdar Shaw Cancer Center (MSCC) in Bangalore, where the system is undergoing validation in the field. The device will return to UCI for revisions before returning to India for final testing. Data acquired with the OCT system by basic level field healthcare workers is uploaded to their cells phones, and then transmitted via wireless Drobo system to MSCC for potential clinical/histopathological follow-up and to UCI, where we are in the process of validating and fine-tuning an automated diagnostic algorithm.

**Results:** Using a multitude of cost-size-weight reducing innovations a compact, inexpensive, robust, wireless-enabled OCT system was built that passed initial testing at UCI. Device performance was tested and diagnostic quality intra-oral images were successfully obtained. A support network in India was developed addressing training, logistics of screening outreach as well as data acquisition and wireless data transmission from the field to experts at MSCC and UCI.

**Conclusion:** Portable OCT coupled wireless device has the potential to advance early detection, leading to diagnosis for oral, and mucosal

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2.3 Late Breaking Research Abstract: Cloud-based Mobile Rehabilitation Platform

**Background:** Traditional methods used by professionals in occupational and physiotherapies to assist people with injuries or physical disabilities recover their range of motion can be successfully enhanced by modern day engineering solutions. A real-time monitoring system which intelligently allows the patient to continue treatment from home is necessarily required. As such a monitoring platform must be easy to use, reliable and cheap while preserving its multi-functionality including long-distance real-time communication.

**Purpose:** In this work, we present a cloud-based mobile rehabilitation platform that offers remote services for patients who can undergo rehabilitation with minimal therapist supervision. The platform is paired with cheap and safe wearable inertial sensors based on Bluetooth Low Energy (BLE) technology used to gather motion data generated during exercises. The precision of data capturing and interpretation of our system surpasses the limitation of human invigilation. Further, we employ cloud-computing model for data interpretation as well as a real-time remote access to exercise data. It allows physicians and medical professionals to analyze and interpret the captured medical information in terms of correctness and accuracy of measurements wherever they are with devices such as an iPhone, iPad or the web regardless of their proximity to the patients. Due to significant memory capacity and high bandwidth of the cloud, we can provide a quick response to the users.

**Method:** The proposed system extracts body balance, rotation, acceleration and angle measurements. Further, our platform is designed to detect the pattern of complex movements along with instant and off-line feedbacks for the patients. It means health experts are able to either provide real-time feedback, or analyze the data when convenient for them. The degree of the alignment, correlation or coincidence between reference (supervised by an expert) and patient's motion patterns are quantified by applying a correlation-based data processing. Both patients and doctors are informed by vibrations, sounds and visuals when patient movements stray outside the desired range, e.g., when data goes beyond a threshold value. The developed graphical interface visualizes the valuable measurements such as joint angles which are recommended by physiotherapists. The acquisition sensor nodes are fully radio type approved for US, Europe, Japan and Canada. Due to inherent deficiency or aging problems in cyber-biological systems, we have also calibrated the accelerometer sensors using six stationary positions and increased the accuracy of the system.

**Results:** The results obtained in a hospital on 20 patients (children) confirm lifting the patient’s motivation up towards treatment and accurately tracking of the patient's real condition and improvement. Since the main objective is to achieve a prescribed level of physical functioning, the patients could easily refine their kinesthetic movements and react accordingly through remote doctors' feedbacks. The platform also allows the physicians share information together to objectively, precisely, find out how well someone is progressing. After sensor calibration, the platform provides high accurate functionalities, e.g., in yielding the angles; the errors are within the 0.5 degree which is negligible in the rehabilitation purpose.

**Conclusion:** This system could help deliver more efficient and cost-effective healthcare while it does not require controlled and supervised settings and it encourages patients to use it. The prominent benefits of such systems are those of cost, convenience, patient comfort and quality of service. These profits are associated with integrating wearable inertial sensors, Bluetooth Low Energy (BLE) technology and cloud computing models.

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2.4 Late Breaking Research Abstract: Customizable Mobile Applications for Improving Quality of Life of Autistic Teenagers

**Background:** Currently, one out of eighty-eight children in US suffers from autism spectrum disorder (ASD). Children with ASDs suffer from several deficits e.g. poor communication and social skills. Some of them also show reduced attention to others’ faces, and hence have major difficulties in recognizing and responding to emotional and mental states in others’ facial expressions. Such difficulties if persist when they become teenagers hamper their abilities to acquire job skills or live more independent lives.

**Purpose:** The emergence of powerful smartphones, tablets e.g. IPAD and Google Nexus 7 allow developers to produce many useful applications to help autistic children to develop their language or social skills. However, many existing applications target younger children and are not quite suitable for teenagers. In our project, we aim to develop mobile applications targeting autistic teenagers which are customizable to help them acquire some skills that can improve their quality of life. Specifically, we focus on three particular applications: (a) Emotional Recognition Training (ERT) Tool, (b) Conversational Simulator (CS), and (c) ATM Simulator. The ERT application aims to improve autistic children's emotional recognition skills while CS helps to improve their conversational skills. The ATM simulator is being used at Centennial School (a special education school) to teach autistic students how to use ATM machines to deposit/withdraw money. The ERT application will be made accessible to others once we complete our user studies with a special education school and an autism center. The other two applications, already released as free applications, can be downloaded from graceland.herokuapp.com.

**Methods:** Previous research studies have shown that children with ASDs are attracted to systems such as vehicles, spinning objects or computers because such children have intact or even enhanced abilities in “systemizing” which is the drive to analyze or build a system for predicting its behavior and/or controlling it. Such special interests can be harnessed in computer-based teaching tools to keep them engaged while using such tools for longer duration and also frequently. Thus, our applications include animation, visual, and audio features to make them attractive to teenagers with ASDs. In addition, many existing tools e.g. Let's Face It [3] provide videos/images involving actors or environments whom the students are not familiar with. However, some autistic teenagers learn better if they are shown images, or video clips of facial expressions from people with whom they are familiar with. Thus, in order to be effective, our emotional recognition tool is customizable, and contains adaptive contents which can be modified by caregivers, teachers or parents. Moreover, we intend to add appropriate audio and context information to help students with ASDs to generalize what they learnt from such a training tool. Furthermore, our applications run on mobile devices and hence makes they can be used anytime anywhere.

We typically use an iterative design/evaluate process for our application development. First, we gather design requirements by interviewing special education teachers/caregivers. Then, we recruit students from these schools to try our applications so as to gather some feedback. Next, we enhanced our applications to incorporate their feedbacks. For example, we added in a feature to select high/medium/low accuracy in our conversational simulator tool after we encounter a teenager with ASD that stammers. We provided a Mandarin-speaking version after we found more than 85% of the teenagers/children with ASDs at an oversea autism center speak Mandarin. We are currently conducting a small 3-month long user study (6 students) at two places. Students with emotional recognition deficits are identified by their teachers and will undergo training for 30minutes/week using the learning module in our emotional recognition tool and will be tested using the test module.

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2.5 Late Breaking Research Abstract: Remote Blind Calibration of Multi-Sensory Systems in Medical Applications

**Background:** This paper considers the problem of remote self-calibration of multi-sensory systems for health care cyber-biological systems, such as closed-loop glucose control. In particular, the current push for closed-loop insulin control (CLIC) systems must guarantee the continuous supply of insulin to the patient without causing the possibly dangerous state of hypoglycemia. Given the lack of the insulin sensing devices and the low reliability of continuous glucose monitoring systems (CGMs) is not possible to achieve without the multi-sensor platform.

**Purpose:** A real time remote blind sensor recalibration method with high accuracy coupled with reasonable complexity is a must for multi-sensor medical devices. Calibration methods increase tolerances in imperfect manufacturing products while maintaining affordability. They also reduce the test time; improve reliability, increase customer satisfaction and decrease customer returns while having lower warranty costs specifically for medical purposes.

**Method:** Three methods are presented and evaluated in terms of accuracy and execution time. In our system, the sensors are connected to a device such as PC or iPhone, and communicate wirelessly via Bluetooth Low Energy (BLE) to send their real-time data. Then, the calibration method performs on the logged data to be used for further measurements. While all the proposed approaches are generic and applicable to different medical multi-sensory systems, the experimental results are evaluated on digital temperature sensors in consequence of their simple and reliable setup. It is worth noting that due to different possible locations of the sensor nodes that have to be periodically calibrated, the remote calibration of the sensors is an interesting application of these techniques especially in medical fields. The used wireless modules have also radio type approvals (FCC, R&TTE, MIC, IC) and are compliant with safety and medical standards. The initial phase in recalibration process performs a screening of all the sensors in the system in order to exclude faulty or decalibrated sensors [1]. The primary idea is to consider the average of sensors readouts as a reference to be fitted using least squares method while excluding the decalibrated sensors. This solution has a low complexity, which makes it suitable for real-time blind calibration. However, the quality of recalibration suffers, and has to be improved especially in the critical areas such as health monitoring devices. In the second technique, the average of sensors readouts of the best-correlated subset is used as the reference of our curve fitting. This procedure is performed offline and only once to compute the best correlations. Finally, the Minimum Mean Square Error (MMSE) estimator delivers the superior precision compared to the other methods while takes 1.8ms to estimate the reference.

**Results:** The second approach improves the accuracy (sum of mean square errors) by 23.44% comparing to the simple average method. The run time of both methods is 0.7ms for single and multiple decalibrated sensors. The MMSE estimator dominates the second method in terms of precision by 48.57%. The experimental results are evaluated on 7000 real samples of eight digital temperature sensors. Indeed, a dual-slope temperature ramp was generated, where the temperatures are changed in 4° steps between 10°C and 30°C with the starting point of 10°C. Based on the uniform distributions of the original data, the sensor errors which uniformly distributed in the interval [-20 20] have been injected to simulate the decalibrated behaviors of the sensors.

**Conclusion:** The proposed algorithms can be applied to maintain the correct operability of other sensors such as CMS, which current frequent recalibrations from blood reference are a tedious task. As can be figured out from the results, the run time of the methods are negligible compared to the delay of sensors. Hence, the methods can be performed online without impacting the performance of the overall system.

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