1st International Symposium on Human Hydration Monitoring Technologies

at the

14th International Conference on Wearable and Implantable Body Sensor Networks

BSN2017, Eindhoven, The Netherlands

Date & Venue

Friday, 12 May, 2017, 9:00 – 13:00
Auditorium, Philips Building 34, The High Tech Campus, Eindhoven, The Netherlands

Organizers

Matthias Ring, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany
Karl E. Friedl, U.S. Army Research Institute of Environmental Medicine, Natick, MA, USA

Abstract

Humans are bags of mostly water. The amount of total body water (TBW) constitutes about 55-60 % of an adult's body composition. The regulation of water balance is vital to health and performance, since moderate TBW reductions by 4-6 % already produce noticeable symptoms and severe TBW reductions by more than 10 % become life-compromising. The detection of dehydration and management of TBW is particularly crucial for athletes in endurance sports, athletes that dehydrate to meet weight class limits, soldiers and workers with high sweat losses in hot environments, clinical patients with poorer body water regulation, and the elderly people. Technological approaches for dehydration detection have included, for example, bioelectrical impedance, changes in skin properties, and biochemical analyses of aqueous body fluids (urine, sweat, saliva, tears). However, there are still challenges in these technologies and so much the more in wearable technologies for continuous hydration monitoring. This workshop will therefore consider technological, physiological, and data-analytics aspects that have been explored by researchers with first-hand experience in a range of applications from clinical patients to active athletes.

Speakers

Salzitsa **Anastasova**, Ph.D.	The Hamlyn Centre, Imperial College London, United Kingdom
Clement Ogugua **Asogwa**, Ph.D.	College of Engineering and Science, Victoria University, Australia
Carlos **Castelar**, M.Sc.	Philips Chair for Medical Information Technology (MedIT), RWTH Aachen University, Germany
Karl E. **Friedl**, Ph.D.	U.S. Army Research Institute of Environmental Medicine, Natick, MA and University of California at San Francisco
Reed W. **Hoyt**, Ph.D.	Biophysics and Biomedical Modeling Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA, USA
Ahyeon **Koh,** Ph.D.	Department of Biomedical Engineering, Binghamton University-State University of New York (SUNY), USA
Richard C. **Murdock**, Ph.D.	Air Force Research Laboratory, USA
Matthias **Ring**, M.Sc.	Digital Sports Group, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany
Junchao **Wang**, M.S.	Integrated Microsystems Laboratory, McGill University, Canada

Introduction 9:00 – 9:05

Matthias Ring, Karl Friedl

Machine Learning for Quantitative Water Loss Estimation During Physical Exercise 9:05 – 9:30

Matthias Ring

This talk considers the estimation of total body water (TBW) loss during physical exercise. Marathon runners, for example, may lose up to 14 % of their TBW during races in warm environments. This excess of TBW loss is considered close to life-threatening. But also less severe amounts of TBW loss can already impair aerobic endurance, muscular strength, and cognitive performance.

In this light, three machine learning approaches are discussed to quantitatively estimate TBW loss based on bioimpedance measurements, sweat markers, and salivary markers, respectively. All three approaches were developed and evaluated using measurements from 10 male subjects who performed a 2-hour running workout without fluid intake. The experimental evaluation illustrated that the minimal TBW loss estimation error of 0.34 liter could be achieved based on the salivary markers. In the future, such TBW loss estimations might support accurate diagnoses of dehydration and corresponding recommendations on the amount of fluid to rehydrate properly.

A Soft, Wearable Epidermal Microfluidic Systems Capable of Sweat Monitoring 9:30 – 9:55

Ahyeon Koh, Daeshik Kang, John A. Rogers

The ability to monitor health and disease status transdermally via analysis of sweat obviating the need for a blood draw is a medical goal and unmet need. Present sweat monitoring technology remains limited as a largely experimental practice, relying on lab-based systems. Further, these approaches are unsuitable for actively monitoring sweats during dynamic human activities and thus impedes immediate treatments. Herein, I will present the study of epidermal, flexible, conformal microfluidic devices with integrated wireless communication electronics that allow collection and point-of-care analysis of sweat. Constructed devices offer advanced biomechanical capabilities affording strong skin adhesion, in situ sweat collection via perspiration, and thus the determination of local sweat rate and volume as well as biomarker content under dynamic conditions. The microfluidic designs satisfy sufficient stretchability, structure stability, and vapor permeability for epidermal sweat patch applications. The sweat patch enables multiple analysis of the concentration of representative biomarkers in sweat–glucose, lactate, chloride, and pH via quantitative colorimetric analysis and interrogates to smartphone utilizing near-field communication electronics. Two human studies demonstrate assessment of perspiration with the devices: temperature and humidity controlled mild indoor cycling, and real-world outdoor use during a long-distance cycling race. Indeed, the epidermal microfluidics for sweat analysis yield information of sweat loss and rate in situ and demonstrates reliable chemical assessment of perspiration compared to traditional lab-based analysis.

Wearable Sensors: Can We Get Enough Information from Sweat? 9:55 – 10:20

Salzitsa Anastasova, Benny Lo, Guang-Zhong Yang

Several different methods of noninvasive detection of analytes in body fluids are being evaluated and validated. Sweat is one candidate fluid that can be quite useful because it contains a many molecules ranging from simple electrically charged ions to more complex proteins that can provide insights to what is happening inside the human body. Sweat analytes may also provide insights to athletic performance.

Our device used a microfluidic, lab-on-a-chip approach to sweat capture and analysis and electrochemical detection. In our study, we embedded chemical sensors into a soft, flexible silicone based microfluidic platform that can easily stick to skin. The flexible sweat sensor acts as a passive pump where the sweat passes constantly through the microfluidic channels and the sensors are able to detect the analytes. Different sections of the sensor react to different levels of certain chemicals found within sweat. The readings are transmitted wirelessly to a smart phone. In a trial involving six volunteers doing indoor cycling, measurements from the sweat sensor were comparable to lab-based standards. Measurements included sweat rate, pH (an indicator of hydration levels), and concentrations of lactate, glucose, potassium and sodium.

Wearable Sweat Sensors — 10:20 – 10:45

Richard C. Murdock

Break — 10:45 – 11:00

A Galvanic Coupling Method for Assessing Human Body Hydration — 11:00 – 11:25

Clement Ogugua Asogwa

Changes in human body hydration leading to excess fluid losses or overload affects the body fluid's ability to provide the necessary support for healthy living. We propose a time-dependent circuit for real-time monitoring of human body hydration using galvanic coupled intrabody communication technology. The circuit model predicts the attenuation of a propagating electrical signal. Current measurement techniques are mostly suitable for laboratory purposes due to complexity and technical requirements. Less technical methods are subjective and cannot be integrated into a wearable device. We model hydration rates by a time constant τ which characterizes the individual specific metabolic function of the body and a surrogate human body anthropometric parameter θ by the muscle-fat ratio. Our results show that hydration can be tracked non-intrusively with theoretical values varying from 1.73 dB/min, for high θ and low τ to 0.05 dB/min for low θ and high τ which is comparable to empirical measurements, which ranged from 0.6 dB/min for 22.7 kg/m^2 down to 0.04 dB/min for 41.2 kg/m^2. Our results show individuals with high BMI would have higher time-dependent biological characteristic, lower metabolic rate, and lower rate of hydration. And a galvanic coupled intrabody signal propagating through the body can provide qualitative hydration and dehydration rates in line with changes in an individual's urine specific gravity and body mass and can detect up to 1.30 dB reduction in attenuation when as little as 100 mL of water is consumed. The real-time changes in galvanic coupled intrabody signal attenuation can be integrated into devices to evaluate body fluid levels and can aid diagnosis and treatment of fluid disorders such as lymphoedema.

Principles and Pitfalls of Fluid Balance Monitoring for Hydration Management — 11:25 – 11:50

Reed W. Hoyt

Hydration management is essential for individuals working in hot, cold, or mountainous environments, where under- or over-hydration can lead to decreased physical and cognitive performance, organ injury, and even death. Fluid balance depends on water influx: (a) ingestion of pre-formed dietary water from food or liquids, (b) metabolic water produced from fat, protein, and carbohydrate oxidation, (c) and water entering through the lungs or skin, and on water efflux: (i) respiratory water loss, (ii) cutaneous evaporative water loss, (iii) fecal water loss, and (iv) urine production. Typically, fecal water loss is negligible, and respiratory water loss is balanced by metabolic water production. Urine output, which is typically ~1 ml/min

(~1.44 L/d), is a key indicator of intravascular volume status in normal individuals. A low urine output leads to a decreased circulating blood volume and decrements in strength and endurance if the fluid loss exceeds ~3% of body mass. Classic methods of logging water intake, urinary output, and changes in body mass, are not practical. Methods suited for use in the field include stable isotopic tracers that track water turnover, energy expenditure, and changes in extracellular space and total body water. However, a need exists for wearable sensor systems capable of monitoring urine output and fluid intake and providing real-time feedback. An ultrasound-based Bladder Volume Monitor (BVM) developed by Kristiansen et al. (2005) will be presented, along with Fluid Intake Monitor (FIM) capable of logging fluid consumed from a flexible canteen. BVM can be used to ensure normal hydration, even in the event of heavy fluid losses from sweating. The FIM can be used to teach good hydration practices and reduce the risk of over-hydration and hyponatremia.

Electrical Impedance Tomography for Bladder Volumetry — 11:50 – 12:15

Carlos Castelar

Paraplegic patients, depending on the degree of neural damage, often suffer from an impaired bladder volume sensation, sometimes also associated with a complete lack of urinary function. A common treatment for these patients is the emptying of the bladder by self-catheterization, usually following a fixed self-catheterization schedule at regular time intervals. However, this procedure is not optimal. If the catheterization is performed too late, it may lead to general discomfort or even high blood pressure or kidney damage. If the bladder is emptied too early, it unnecessarily degrades the quality of life of the patient and increases the risk of urinary tract infection. A demand-driven emptying scheme would be preferred and could be made possible by a non-invasive and continuous bladder volume monitoring device.

Our investigation deals with the evaluation of Electrical Impedance Tomography (EIT) as a potential solution. It includes FEM-simulation studies, in-vitro measurements and clinical trials. A good linearity between bladder volume and measured impedance has been shown. Recent work has focused on optimizing electrode positioning as well as current injection and voltage measurement patterns and the development of volume estimation algorithms. Furthermore, the influence of body position, movement artefacts and the a priori unknown urine conductivity have been analyzed. EIT bladder volumetry already shows good promise and the potential to be improved with respect to measurement repeatability and artefact suppression.

RF Technology for Non-Invasive and Real-Time Hydration Monitoring — 12:15 – 12:40

Junchao Wang

In the medical field and hospital settings, there are many hydration assessment techniques such as isotope dilution, neutron activation analysis, blood plasma and urine osmolality analysis, urine specific gravity, urine conductivity, urine color, hematocrit, hemoglobin, rating of thirst, body mass change, bioelectrical impedance etc. However, those techniques are often invasive, require cumbersome testing equipment, long testing hours, as well as expertise. The only method mentioned above that shows potential to be transformed into a wearable solution is bioelectrical impedance. Attempts have been made to develop wearable electronics for hydration detection based on bioelectrical impedance. However, the electric current passing through body parts require close and good electrical contact to human skin, which largely impairs its accuracy during scenarios like intense exercise and physical work. Also, the correlation between local skin hydration and global body hydration status can vary from person to person. Thus, alternative methods need to be explored for assessing hydration status conveniently.

The interactions between electromagnetic (EM) waves and biological tissue have been investigated extensively since last century. The theoretical aspects of dielectric phenomena in biological materials across various ranges of electromagnetic waves have also been widely reviewed. When interacting with biological tissue, the mode of interaction between EM waves and water molecules is different from between EM and solute ions. At lower frequency (below 1GHz), the electrical conduction is dependent on the quantity of water solute, and the ionic conduction results in energy absorption, which can lead to amplitude attenuation of EM waves. At higher frequency (above 3 GHz), the rotation of water molecules in response to alternating EM field starts to contribute to the energy absorption. Thus, based on the absorption of EM energy, the quantity of water can be determined in biological tissues.

In this talk, the basic principle of RF and biological tissue interaction, and how it may help generate signals for characterizing body hydration, the nature of relevant signals, and what potential biological experiments could be designed to acquire trustworthy data, as well as the potential role of machine learning in assessing hydration level of human being will be discussed.

Blue Skies Concepts & Technologies for Personal Hydration Monitoring Applications — 12:40 – 13:05

Karl E. Friedl

Strategies to monitor human hydration status include assessment of hydration-dependent symptoms, compensatory physiological changes, or direct measures of fluid content or concentration. The best approach depends in part on the specific application. Implanted hydrogel sensors responding to extracellular fluid osmolality may signal the need to increase fluid intake in elderly patients at risk for dehydration or indicate fluid accumulation in a patient with congestive heart failure patient. Terahertz imaging may signal localized tissue hydration and viability in wound healing. Assessment of specialized fluid compartments such as intraocular fluid and localized changes in skin hydration may not provide a sensitive reflection of other fluid compartment changes. Surrogate markers such as nail bed capillary refilling, postural hypotension, and heart rate variability may be relatively insensitive or nonspecific indicators of water deficit especially without other contextual information. Direct spectroscopy-based measures of intravascular composition (i.e., plasma volume from hematocrit/hemoglobin) may prove to be quite sensitive to hydration changes. The practical continuous measurement of concentration of a variety of analytes in secreted body fluids (sweat, tears, saliva, urine) or in extracted fluid (e.g., laser poration, reverse iontophoresis) has been challenging but micro-scale technologies may provide new opportunities (e.g., unobtrusive mouth appliances for continuous salivary assessments).

Joint Discussion — 13:05 – 13:15

All