Editorial

Special Issue on PHM for Human Health & Performance

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PREDICTIVE HEALTH MANAGEMENT (PHM), originally applied in the Aerospace Industry, tries to predict when what part would fail for what reason(s) in order to make preventive maintenance more efficient and cost-effective. Over the past several years, PHM has been infused increasingly into the human healthcare, precision medicine, and human performance sectors. As such, a diverse and trans-disciplinary group of expert authors presents in this *Special Issue on PHM for Human Health & Performance* its perspectives on PHM in the context of prognostics and health management for human health and performance, both on Earth and in space, in nine excellent contributions that cover a wide range of current research and application topics related to this emerging field. In particular, these contributions highlight various technological and analytical aspects that in combination contribute and make a reality an autonomous healthcare paradigm. These aspects include, but are not limited to: wearable smart sensors, rehabilitation devices and robotics, image classification, signal processing, data mining, data understanding, machine learning, prediction and diagnosis, electronic health records and databases, and overarching PHM-based healthcare frameworks, etc.

Arguably no other process is more dependent on autonomy and an associated PHM methodology driving it than the human exploration of the last frontier: space. As humans are on the verge of expanding space travel to beyond the Moon towards Mars, with the intent of establishing permanent settlements preceded by orbiting and ground-based space habitats (e.g., NASA's gateway program), there is a need for applying PHM techniques to ensure crew health and performance, as a quick return to Earth for medical treatment is not an option. As such, current paradigms, such as tele-health and telemedicine, have to give way to autonomous healthcare in the absence of Earth-based support. The paper by *Popov, Fink, Hess, & Tarbell: "A Paradigm Shift from Telemedicine to Autonomous Human Health & Performance for Long-Duration Space Missions"* sets the stage for this transition and sheds light on what the various requirements and associated PHM techniques are that will establish and support an autonomous healthcare paradigm, ranging from sensing, data understanding, anomaly detection, to prognostics to ensure and sustain crew health and performance. The authors make a case for validation of this paradigm on the International Space Station (ISS), which, now more than ever, appears to be a real possibility as NASA will open the ISS to new commercial opportunities and private astronauts (Release 19-044 on 06/07/19).

Congruent with the overarching theme of this Special Issue, the paper by *Vaisali, Parvathy, Hima Vyshnavi, & Krishnan Namboori: "Tumor Hypoxia Diagnosis using Deep CNN Learning strategy - A theranostic pharmacogenomic approach"* demonstrates the use of convolutional neural networks in detecting tumor hypoxia formation in simple pathological images to determine the (continued) efficiency of anticancer drugs affected by it during the process of treatment.

Worldwide healthcare costs are on the rise, taxing economies at large and the insured in particular. At the dawn of precision medicine, the goal has to be to increase treatment efficiency and outcomes to reduce or avoid subsequent healthcare costs downstream. In this context, the paper by *Zhang: "Patient-Specific Readmission Prediction and Intervention for Health Care"* introduces a PHM-based general decision support system to reduce the 30-day hospital readmission rate - an important metric in this field - as hospital readmission is often associated with both unfavorable patient outcomes and large resource costs.

Atherosclerosis refers to arterial plaque deposition that can eventually lead to cardiovascular diseases such as heart attack, stroke, or peripheral vascular disease, depending on the exact location of the blockage in the human arterial network. In their paper *"A Particle Filter Based Framework for the Prognosis of Atherosclerosis via Lumped Cardiovascular Modeling," Jain, Guha, & Patra* introduce a particle filter based mathematical framework to predict the time of onset of any of these pathological conditions through radial artery blood pressure measurements in the context of their cardiovascular model.

The paper by *Natarajan, & Laftchiev: "A Transfer Active Learning Framework to Predict Thermal Comfort"* details an active learning framework for thermal comfort prediction. Personal thermal comfort - the feeling individuals have about how comfortable they are temperature wise - is a key component of human performance in the work place and hospitalized/bed-bound or bedridden patient comfort. The introduced framework leverages both domain knowledge from prior users and active learning for new users, thereby reducing the need for large labeled datasets.

On the wearable sensor side, *Yang, Nicolini, Kuang, Lu, & Djurdjanovic* introduce in their paper *"Long-Term Modeling and Monitoring of Neuromusculoskeletal System Performance Using Tattoo-Like EMG Sensors"* stretchable, long-term wearable, tattoo-like dry surface electrodes for electromyography (EMG). They then relate signatures extracted from EMG-electrode-recorded signals to long-term fatiguing and recovery processes in the human neuromusculoskeletal system via an autoregressive moving average model. This application harbors tremendous potential for astronauts, athletes, warfighters, and, in general, persons working in physically taxing professions.

As the general population (especially in the industrialized world) grows older, there is an increasing need for and shortage of rehabilitation clinicians, especially for elder and disabled patients. Recognizing this divergence, *Johnson, Sobrepera, Kina, & Mendonca* in their contribution *"Design of an Affordable Socially Assistive Robot for Remote Health and Function Monitoring and Prognostication"* investigate the acceptance of such socially assistive robotics from the perspective of clinicians working in various elder-focused healthcare settings. This work lays the foundation not only for remote healthcare, but also for autonomous healthcare in extraterrestrial space habitats and planetary settlements.

Stress at the work place and in life in general is a key component affecting human health (especially mental health) and performance. As such, it is of vital importance to monitor stress levels, ideally in (near) real time. In their study *"Dynamic Behavior of Cortisol and Cortisol Metabolites in Human Eccrine Sweat," Runyon, Jia, Goldstein, Skeath, Abrell, Chorover, & Sternberg* investigate exercise stress-induced temporal changes in cortisol, cortisone and downstream inactive cortisol metabolites in human eccrine sweat, using a novel liquid chromatography-tandem mass spectrometry method. They show that these biomarkers are directly correlated with stress interventions (e.g., physical exercise) and stress responses such as increases in heart rate. As such, this work lays a foundation for the development of wearable sensors/devices that can assess human health, stress, wellbeing, and performance in (near) real time.

Facing the explosion of healthcare costs worldwide, home-based therapy, i.e., outside a clinical or healthcare professional setting, is gaining attention. In this context, and also in the context of self-therapy necessary during long duration space flight and human settlement on other planetary bodies, *Ramalingam, Chinnavan, Jasmi, Xin, Santhiresegar, & Ragupathy* in their contribution: *"Alarm device for self-tracking of progression during wrist rehabilitation"* propose a microcontroller-based alarm device for wrist self-rehabilitation. In a self-educating (i.e., patient-educating), self-motivating, and progress-monitoring fashion, this device assists patients in improving their range of motion after wrist injuries resulting from, e.g., accidents, sports, stroke, and prolonged hand immobilization. It is these kinds of devices that will be necessary not only to reduce healthcare costs in general, while still providing quality healthcare, but to enable and sustain an autonomous healthcare paradigm required for the human exploration of the last frontier: space.

As the Guest Editor, I am confident that this Special Issue containing research papers on PHM for Human Health & Performance with both an academic and industrial (i.e., predominantly healthcare) focus will push further human health and performance related research and help transition more advanced PHM technologies into industrial applications. I would also like to express my gratitude to the authors for their contributions and express my sincere appreciation to the reviewers for their time and expertise in providing valuable feedback.

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Prof. Dr. Wolfgang Fink is the inaugural Edward & Maria Keonjian Endowed Chair with multiple joint appointments in the College of Engineering at the University of Arizona. He was a Visiting Associate in Physics at the California Institute of Technology (2001–2016), a Visiting Research Associate Professor of Ophthalmology and Neurological Surgery at the University of Southern California (2005–2014), and a Senior Researcher at NASA's Jet Propulsion Laboratory (2001–2009). Dr. Fink is the founder and director of the Visual and Autonomous Exploration Systems Research Laboratory both at Caltech (http://autonomy.caltech.edu) and at the University of Arizona (http://autonomy.arizona.edu). He obtained a B.S. and M.S. degree in Physics and Physical Chemistry from the University of Göttingen, Germany in 1990 and 1993, respectively, and a Ph.D. in Theoretical Physics from the University of Tübingen, Germany in 1997. Dr. Fink's interest in human-machine interfaces, autonomous/reasoning systems, and evolutionary optimization has focused his research programs on artificial vision, autonomous robotic space exploration, biomedical sensor/system development, cognitive/reasoning systems, and computer-optimized design. Dr. Fink is an AIMBE Fellow, PHM Fellow, UA da Vinci Fellow, UA ACABI Fellow, and Senior Member IEEE. He has over 250 publications (including journal, book, and conference contributions), 6 NASA Patent Awards, as well as 20 US and foreign patents awarded to date in the areas of autonomous systems, biomedical devices, neural stimulation, MEMS fabrication, data fusion and analysis, and multi-dimensional optimization.