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Guest Editor's Introduction

Personalized Pervasive Health

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Over more than two decades, mobile, wearable, and ambient sensor and interaction devices have grown into today's plethora of computing platforms and tools for pervasive health. Pervasive computing is now assimilating into medicine, from disease risk prevention to diagnostics, and from treatment support to chronic-care management. Unlike more traditional medical lab technology, pervasive computing systems can be continuously available, using unobtrusive sensors, actuators, computing, and interactive interfaces to liberalize access to information on basic body functions and processes in everyday life, e.g., physical activity and vital signs. Pervasive computing platforms now natively provide practitioners and researchers with a set of functionalities that allow for the development of applications and systems that are able to make sense of complex situations, e.g., daily routines, mood, and the user's physiology. With this potential at hand, pervasive computing systems will play a central role as enabling technology for healthcare.

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Evidence-based research now suggests that care is optimal when considering the outcome for each and every patient individually; this personalization requires obtaining patient-related outcome measures. Pervasive computing can contribute by obtaining patient feedback but moreover pervasive monitoring can augment individual patient records with data on lifestyle and environmental factors, thus creating new opportunities for personalizing health risk assessment, diagnosis, and treatment (e.g., to minimize side-effects or drug overdosing). The individual-level tailoring can occur with unprecedented temporal resolution and signal scale. Technology-enabled personalization can ensure that healthcare is delivered precisely when and where it is needed.

Companies making smartphones, smartwatches, and activity monitors have reached millions of users with their products and demonstrated that pervasive computing can scale up for consumer fitness and health services. The recent SARS-CoV-2 virus outbreak, however, requires fast insight, and there are efforts underway to exploit pervasive consumer products that are already widely deployed to do so. The data donation initiative (https://corona-datenspende.de) of the

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Robert Koch Institute (German Center for Disease Control) and Singapore's TraceTogether (https://www.healthhub.sg/apps/38/tracetogether-app) were among the first efforts to leverage smartphones and wearables to react to the infection spread at the scale of country-wide studies. Various further endeavors are following suit.

While today we understand at least some potential of pervasive computing for health, there are major open challenges. For one, there are challenges in pervasive technology: through their smartphone, every user can conveniently access activity patterns, location, and other context variables. However, reliably obtaining vital parameters with consumer-grade mobile and wearable devices can still be laborious or infeasible. Furthermore, scientific research is just starting to enable systems that can interpret complex behavior patterns and body-internal processes. Once the basic technical functions required to create behavior-estimating systems are validated, researchers must determine how to use such systems to support medical and healthcare use. While many entrepreneurs and businesses still focus on developing consumer health services and want to avoid medical device certification hurdles, the boundary between consumer- and medical-based devices is blurring. For example, consumer ratings of pervasive health devices often imply accuracy and reliability at advanced levels. Simultaneously, regulations on medical devices and software are constantly updated and are becoming more stringent to ensure medical benefit and to safeguard patients. Thus, consumer-based pervasive health services that attempt to improve health-related behaviors, such as medication adherence (being one of the topics of this special issue), must avoid raising health risk; in the case of medication reminder systems, they must not contribute to drug overdosing.

This special issue includes application examples in pervasive health. The selected papers highlight promising trends, opportunities, and challenges and demonstrate how pervasive computing can be translated into healthcare solutions. The papers also show that novel, rapid evaluation processes that incorporate relevant stakeholders, including patients and medical professionals, are necessary when creating pervasive health systems. Furthermore, the investigations presented in this issue illustrate the ongoing quest to use new technologies to obtain reliable measurement of health-related behaviors and body-internal processes.

In the article "Inferring circadian rhythms of cognitive performance in everyday life," Tag *et al.* build on recent research on monitoring the human circadian rhythm as a mediator of cognitive performance. The authors highlight that alertness and sleep/wake cycles should be incorporated into the design of systems. For this purpose, the article introduces an open-source mobile toolkit to collect information on cognitive state fluctuations, in particular changing alertness. Bagline *et al.* address the long-standing dilemma of medication adherence in their contribution "Leveraging mobile sensing to understand and develop intervention strategies to improve medication adherence." The article highlights the potential of just-in-time adaptive interventions administered through a pervasive computing system that includes various Internet-of-Things devices. The authors discuss the presently insufficient link between behavior theories, human behavior models, and pervasive monitoring.

In the spotlight article "Evaluating personalized pervasive health technology—But how?" Bardram illustrates the evaluation process in pervasive health and reports about a new methodology to assess clinical feasibility. The method attempts to assess feasibility during the design of a pervasive health solution and incorporates usage adoption (a.k.a. adherence), perceived usefulness, and health efficacy. Both Bagline *et al.* and Bardram emphasize that randomized controlled trials, while being a standard of evidence-based medicine, should be complemented with more agile methods that elicit rapid and repeated feedback on feasibility and efficacy.

We hope that the selected articles provide useful insight into the ongoing quest to use personalized pervasive health to support health, and the related basic research challenges that remain before us. We aim to motivate new research, discussion, development, and evaluation of pervasive health systems.

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