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EDITORIAL

The Potential of Sensor-Based Monitoring as a Tool for Health Care, Health Promotion, and Research

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Ann Fam Med 2011;296-298. doi:10.1370/afm.1292.

Conflicts of interest: authors report none.

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This issue of the *Annals* features an article on the automated observation of a small number of residents in a care facility.[1] Berke and colleagues use portable devices outfitted with tiny sensors to infer the activity level and social context of the study participants. Perhaps more importantly, the authors validate the sensor-based analysis using traditional instruments, showing that the sensor-based approach provides equivalent diagnostic utility while reducing error and reporting load on participants and increasing the temporal fidelity and richness of the data. As one of the first forays of ubiquitous sensing into the field of human health, this study raises questions on the natural scope of ubiquitous sensing in health, its future applications, and the roadblocks leading to its widespread adoption as a clinical tool.

Ubiquitous sensing is a discipline at the intersection of sensor networks and ubiquitous or pervasive computing. Tiny sensors placed on a mobile entity are used to continuously record aspects of the entity's behavior, both environmental and social context. This technology has been successfully used in zoology and veterinary medicine to study the feeding and social patterns of animals from zebras to whales.[2,3] Automated social contact and activity detection, however, have received less attention in human health. This lack of adoption is puzzling, because the gaps in our understanding about health—particularly the role of the social and physical environment—provide a drive for inquiry, and sensors and communications devices embedded in commonplace devices, such as smart phones, provide a means to acquire insight.[4,5]

Most sensors currently available are designed for consumer electronics devices or automotive equipment to make devices and cars safer or more intuitive to use. Although not designed with health applications in mind, these sensors can be repurposed without adversely affecting their original function. For example, a typical smart phone has accelerometers for detecting screen orientation, a microphone suitable for voice conversations, a camera for capturing images, and a GPS for displaying location.[4,6] These sensors can be repurposed to provide measures of activity (accelerometer) and ambient sound environment (microphone) as described in the article featured here. Additional sensor suites can be leveraged to provide detailed insight into health behavior and risks. For example, the GPS sensor can be used to estimate the amount of time a person spends indoors and outdoors, as well as where that time is spent.

The greatest power of such techniques comes from the capacity to cross-link information drawn from multiple sensor systems and other information sources.[6] For example, GPS data can cross-link with accelerometer-based physical activity estimates and geographic information systems (GIS), potentially providing insight as to how the proximity of recreational facilities affects physical activity levels, or how the relative accessibility of grocery stores and fast-food restaurants influence diet. Local area communication standards, such as Bluetooth, can be leveraged to determine relative proximity of individuals to each other or fixed locations, relevant to the study of infectious disease.[7,8] These data can be crossed with speech recognition software, as described Berke et al, to provide an analysis of whether a conversation occurred during contact, implying a social situation. Such approaches can help determine the role of social networks in the spread of positive (contact, conversation, and physical activity) or negative (contact, conversation, location near known smoking area) habits. Bluetooth can also be used for ambulatory data collection of more traditional signals, such as blood pressure, heart rate, respiration, and blood glucose level.

The impact of these sensor-enabled health techniques could be felt at the individual and the institutional level. In self-care and health promotion, the sensors provide a simple and unobtrusive method for individuals to probe their health and habits. Metaphorically, the sensors can help provide a less-biased mirror for individuals to examine the health effects of their decisions. Specialized physiological sensors, such as heart rate monitors for amateur athletes, pedometers, or glucometers for diabetic patients, are already in widespread use, but we envision a parallel with a more ubiquitous, yet humble, household medical monitoring device: the bathroom scale. Just as the bathroom scale provides an unbiased assessment of weight gain or loss, ubiquitous sensors can provide individuals with feedback on their mobility and dietary habits by recording and permitting later reflection on where they ate (through GPS) and what they ate (through the camera) or on realized activity levels. Paralleling a rapidly growing online trend toward the "quantified self" and "life-logging," some individuals may choose to share this information socially, either in person or through social media sites, much like the readings on a scale in weight-loss clubs. The combination of personal retrospectives and social stigma could prove sufficient to deter a person from fast-food restaurant visits if they knew that the trip would be logged and displayed for both themselves and their peers to see.

Ubiquitous sensors have a particularly strong role to play in integrating health care by providing clinicians a novel and less-biased window into the habits of their patients. This, of course, comes at a cost to individual privacy and therefore must be voluntary lest the medical community become Big Brother. The medical establishment, however, routinely performs continuous monitoring of relevant physiological parameters in institutional settings. Novel wireless sensor platforms using commodity devices support monitoring of higher-level but still medically relevant parameters, such as physical activity level, location, contact frequency, and social context outside institutions. For individuals with chronic conditions, unobtrusive monitoring could result in better patient outcomes by allowing the physician to monitor compliance with pharmaceutical regimens and activity level guidelines; to better understand the range of variation of patient experiences in such factors as blood pressure, respiration rate, and weight; and to be alerted to proximity to known high-risk locations, from frequenting open-air shooting galleries to repeated loitering in a smokers' area. For elderly patients these devices could be utilized to monitor not only pharmaceutical regimen and other measures similar to those above, but also falls and near-falls (leveraging research in accelerometer-based fall identification), physical activity, socialization, or even overall mobility, including car or bus use and distance traveled. Availability of hard, reliable information could allow family practitioners to prioritize questions to make the most of brief patient visits.

Data can be a mixed blessing, however. The primary benefit of these systems—continuous streams of high-fidelity data—can also be a liability, especially given the common disconnect between that which is measured (sound through a microphone) and that which is desired (am I hearing a conversation?). Although a myriad of signal analysis, pattern recognition, clustering, and data-mining algorithms exist to manipulate such information, physicians have neither the time nor the expertise to apply such algorithms. Similarly, computer scientists and engineers are usually unfamiliar with relevant target populations, protocols, and standards of care in specific health disciplines. For these ubiquitous techniques to have a material impact on medical practice—rather than being used for a purely research use—additional rigorous studies, such as the one described by Berke et al, are required.

Validated sensors and algorithms are only the first step in moving ubiquitous sensor systems toward clinical practice. Linked sensor data and causal models could forecast the potential implications of sensed data for a patient's future health and point the way toward more sophisticated data collection. These algorithms and systems must be packaged to allow medical professionals to configure and deploy systems and collect and derive insight from data without requiring a deep understanding of the underlying hardware or software. Fortunately, there are many recent examples of sophisticated digital systems in medicine showing that collaboration between the medical and engineering sciences is both possible and fruitful.

Regardless of the overall adoption of these technologies in clinical practice, sociological, anthropological, and health studies conducted using ubiquitous sensing devices are poised to assemble whole new bodies of evidence germane to family practice, thereby shaping clinical practice guidelines and influencing the practice of even the most technologically averse or isolated physicians.

As shown in the article by Berke and colleagues, ubiquitous sensors can provide relevant medical information with limited impact on the patient.[1] Properly validated, these sensors have the potential to transform both personal and institutional care by providing high-fidelity contextual information to individuals and practitioners. Given the extant knowledge on signal analysis and pattern recognition, the ever-decreasing cost of sensor-wielding smart devices, and the medical need for better information regarding a patient's habits outside the clinical environment, widespread adoption of these systems is feasible and plausible. With sufficient research into validated signal analysis techniques targeted to yield succinct summaries of sensor data required by physicians, these systems can provide important health insight to individuals and physicians with unprecedented fidelity and scope.

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Key words: Health promotion; mobile sensing; technology

Submitted June 6, 2011; submitted, revised, June 6, 2011; accepted June 7, 2011.

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