Innovations in Ubicomp Products

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Digital Health Devices for Everyone!

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Behavior-related diseases, such as heart disease, stroke, or diabetes, are the leading causes of mortality, causing over 36 million deaths worldwide.[1] Relatively small changes in health behaviors, such as being less sedentary, playing sports, losing weight, or sleeping more, can considerably reduce individual health risks. However, implementing a behavior change is difficult, as many of us know from recalling our last New Year's resolution.

After more than a decade of research, we're now seeing the commercial development of wearable and ambient "smart health devices," which aim to help users initiate and sustain a healthy lifestyle. These devices receive massive attention when presented at events such as the Consumer Electronic Show or announced on crowdfunding websites such as indiegogo.com or kickstarter.com. Surely much of this attention is hype—some devices might never reach the market, while others might fail spectacularly or silently disappear. It has yet to be proven whether such devices will be more than just a toy. Can they really help us sustain a healthy lifestyle?

Figure 1. The Garmin Forerunner 305 sports watch. Training watches combine heart-rate monitoring and GPS tracking.

SMART HEALTH DEVICES

Smart health devices fulfill three properties: they monitor certain health parameters, are connected to an Internet service, and target primarily a lay consumer rather than the medical expert. While traditional home healthcare devices, such as blood pressure monitors, focus on chronically sick or at-risk individuals, these new health devices target people seeking an active and healthy lifestyle.

Fitness Devices

Smart health devices first appeared in the fitness domain with the Nike+ system (nikeplus.nike.com), a foot pod wirelessly connected to an iPod that let the runner monitor the duration and distance of a workout. The data was uploaded to a website that served as a training diary and offered social networking. The system let users monitor their outdoor training, compare times with other runners, and show off good training results.

GPS has since replaced most foot pods. Polar, a company known for sports monitoring, and Garmin, known for GPS devices, developed training watches that combine heart-rate monitoring and GPS tracking (see Figure 1). Other companies quickly followed, and such watches are now used by numerous professional athletes, ambitious amateurs, and pleasure runners.

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Smartphone apps such as Runkeeper (http://runkeeper.com), Endomondo (www.endomondo.com), and Runtastic (www.runtastic.com) are popular alternatives for tracking outdoor activities. They're cheap (if not free) and let users listen to music while working out. The apps usually synchronize with dedicated portals that can import data from sports watches or integrate data from other sensors. However, not everyone wants to carry a phone while working out, and interacting with the phone might be difficult while running.

Figure 2. Activity trackers (from left to right): Jawbone's UP, Nike's Fuelband, Fitbit's Flex, Fitbit's Ultra, Withings' Pulse, and Misfit's Shine.

Activity Trackers

With activity trackers, an accelerometer measures physical activity and calculates the number of steps walked, essentially creating an intelligent pedometer for the average person interested in general health. Users often are highly enthusiastic about activity trackers,[2] which offer objective feedback about the user's level of activity. The trackers easily upload data to Internet services or apps, so users can share and show off results, compete with others, and track achievements and progress. Furthermore, activity trackers are easy to use, unobtrusive, robust, and reliable.

The Fitbit (www.fitbit.com), now available in different shapes, sizes, and abilities, was the first of these devices. Early followers were Jawbone's UP (www.jawbone.com/up) and Nike's Fuelband (www.nike.com/fuelband). Other examples include Withings' Pulse (www.withings.com/pulse), Medisana's ViFit (www.medisana.com/vifit), the Polar Loop (www.polar.com/loop), and Misfit's Shine (www.misfitwearables.com). An activity tracker that also includes certain vital parameters, such as heart rate and skin conductance, is the Basis watch (www.mybasis.com), and new products are appearing regularly.

The trackers can be shaped like a clip to attach to clothes or a bit to put in a pocket, or they can be bracelets or watches worn on a wrist, all of which have pros and cons depending on the user's personal preferences (see Figure 2). The on-device display for presenting the current measurements may be as little as a 5-dot progress bar, or as sophisticated as a graphical display, and vibration may be used for further feedback or to issue a silent alarm.

All devices count steps, and most also present the distance walked, calories burned, and other derived measures. Some use barometric pressure measures to count stairs climbed, and many support sleep monitoring. Although they're fairly precise for normal walking, the assessment of nonwalking activities—such as cycling or minor arm or leg movements—can vary considerably. This is to some extent an inherent problem of the approach: daily physical activity is more than walking, so step-counting alone isn't sensible. On the other hand, step counts have value as an established measure for physical activity[3] that's easy to understand by the layperson and simple to monitor and improve. For more reliable conclusions, other measures (such as minutes active) are often also available on the devices.

Home Care and Health Monitoring

Traditional home healthcare devices have also found their way into smart health. The most popular example is networked body scales. Withings produces a body fat scale (www.withings.com/bodyanalyzer), which is equipped with a network connection and uploads the measurements to the company's Internet service using a home's WLAN (see Figure 3a). The user can then review the measurements and observe changes over time (see Figure 3b). Fitbit later followed with the Aria scale (www.fitbit.com/aria), which offers virtually the same functionality.

These scales exemplify the advantage of networked devices: after initial installation, there's no additional user interaction required beyond the normal weighing procedure. The real value of the scales becomes apparent after several months of use, when the user can see changes in his or her weight.

Various other devices follow a slightly different approach, requiring a Bluetooth connection to a smartphone as a relay to the Internet service or for storing the measurements. Examples include Medisana's TargetScale (www.medisana.com/en/Health+control/Personal+scales) and the Beurer Bluetooth scale, which interestingly is also sold as "Runtastic Libra" (www.runtastic.com/libra), branded by the aforementioned runner's portal.

Withings and Medisana also offer blood pressure monitors that can plug into an iPhone's connector socket or connect wirelessly (see Figure 4). The iPhone is used as a control panel and as a relay for forwarding the measurements to the companies' Internet portals. Basically, they share the same advantage as the body scales—that is, no additional interaction is required aside from normal device use.

Sleep Monitoring

Most activity trackers also offer sleep monitoring. In this case, the accelerometer is used to implement an actimetry. Devices are worn around the

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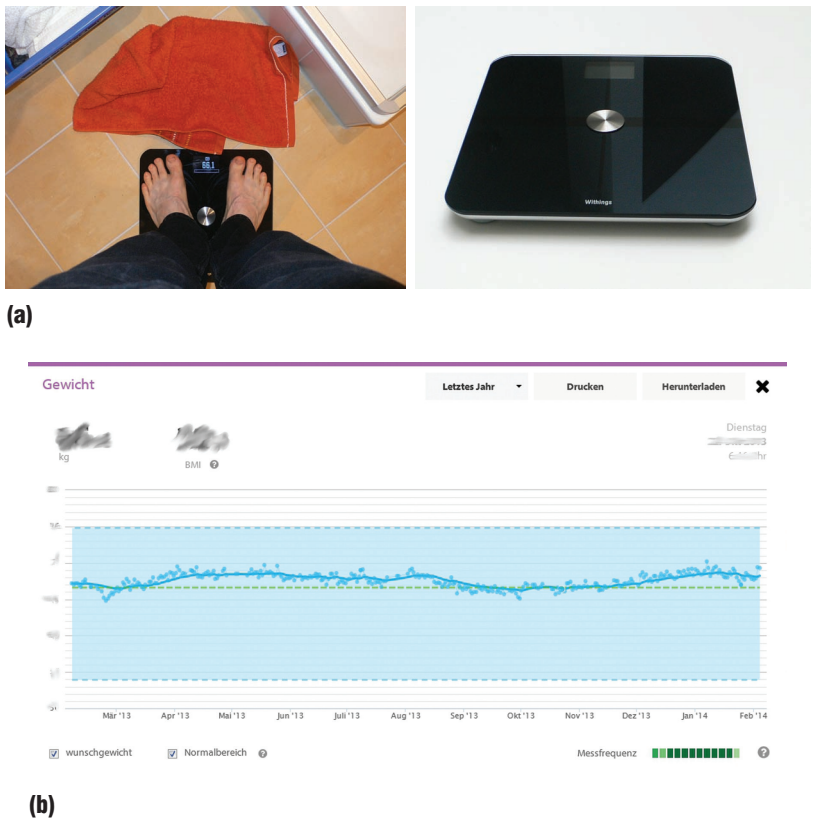

Figure 3. Networked body scale: (a) photos of the Withings Scale and (b) a year's worth of weight measurement with the Withings scale.

Figure 4. The Withings blood pressure monitor (www.withings.com/en/bloodpressuremonitor).

wrist, possibly in a cuff, while sleeping. They're usually switched into sleep mode in the evening and switched back to day mode in the morning. The measurements are reportedly similar to those of higher-end actimetry devices[4] but suffer from the same limitations—for example, no movement doesn't necessarily mean deep sleep. Also, users frequently reported forgetting to switch the device between the different modes, resulting in flawed measurements.

The Zeo device took a different approach. It used a headband to measure EEG and eye and muscle movement (see Figure 5). The data was analyzed on a bedside panel to identify deep sleep, light sleep, REM sleep, and awakening, and the data could be transferred to an Internet service. (However, the company went out of business in early 2013.)

Two new devices, announced for early 2014, use ballistocardiography—that is, the body's micro movements during sleep to identify the user's heart rate and breathing rate. The Withings Aura will come as a pad to be put under the mattress (www.withings.com/aura), and Beddit will be a strip that goes under the sheets (www.beddit.com). It will be interesting to see how well these devices perform.

THE ROLE OF SMARTPHONES

The smartphone is undoubtedly an important part of a mobile health ecosystem. It hosts a plethora of health-related apps, acts as a relay station or gateway for some devices, and offers a convenient way to review measurements. With the multiplicity of sensors such as GPS, accelerometers, or a compass, it seems obvious to use the smartphone as a sensing device. In fact, many apps are available to track all types of outdoor sports or to use the phone as a pedometer.

However, such apps suffer inherently from the fact that a smartphone is designed to be used interactively in the palm of the hand, not to stick on the body—a smartphone is too large to be "worn" the whole day. You might place it on a desk when at the office or carry it around in a handbag instead of wearing

it on your body. This leads to systematically incomplete data. More promising are approaches like the "Moves" app that uses a more high-level, life-logging-like view to identify periods of certain activities (www.moves-app.com). Still, problems such as battery runtime persist and must be resolved.

CHALLENGES AND OPPORTUNITIES

Clearly, there are many technical as well as nontechnical challenges to be solved. How can we build systems that are easy to use and match the users' needs? How can we ensure privacy and security? How can we motivate people? These discussions are ongoing on many levels already, and we only mention them here for the sake of completeness.

There is one point, however, that should be discussed in more depth. So far, most of these new health devices are considerably less precise than the respective gold standard. Although we can hope for better sensors in the future, there's often an inherent restriction due to the need for small, cheap, easy-to-use, and comfortable devices. However, the conclusion that these devices aren't useful in medical contexts is too simplistic, because this ignores these devices' main advantage—available data that often covers a long period of time, taken under real-life circumstances. Data of lower precision but higher availability is better than high-precision but non-existing data.

So the appropriate question is, given that there's some data available, how can we squeeze out as much knowledge as possible for the user? This calls not only for better data analysis but also for different perspectives in medicine and public health—from the view of the individual. In the end, the user isn't interested in the number of steps per day; rather, the user wants to know if he or she was sufficiently physically active.

Figure 5. A sleep monitor: (a) the headband of the Zeo sleep monitor and (b) the monitor in use.

Aggregating step counts to active minutes per day is a good starting point. It might become considerably better if we manage to aggregate and interpret data from multiple sources: monitoring daily physical activity, workouts, sleep, weight, and blood pressure in parallel are already possible and offer tremendous opportunities for effective and personalized interventions. Also, it would be great to see systems that help in finding an appropriate work-life balance, coping with and reducing stress, or sustaining a good posture and reducing back-pain—to name just a few examples.

Truly wearable computing will surely give another push to smart health devices. Smart watches like the Samsung Galaxy Gear or augmented reality glasses like Google Glass might have many of a smartphone's advantages without sharing the same drawbacks. We've already observed a merging of so far distinct worlds: LG has announced an activity tracker at CES 2014 that's fairly similar to the Nike Fuelband but also connected to a mobile phone and can display a caller's phone number. Smart textiles will also play a role. The Sensoria smart sock (www.sensoriafitness.com) went through a successful Indiegogo campaign in 2013 and won't just act as an activity tracker but will also analyze stride and foot landing.

We'll see how, in the future, pervasive technology can offer support to millions of people who want to maintain and implement a healthy lifestyle. We'll have to see how pervasive technology can help over time to keep the individual interested and invested.

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