What is a Body Sensor Network?

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Body sensor networks (BSNs) comprise wearable or implanted sensors that collect, process, and communicate physiological information from the body. With healthcare costs soaring, we need a more efficient and cost effective approach to medical diagnosis, treatment, and care. BSNs could revolutionize healthcare by offering miniaturized, unobtrusive, nearly continuous monitors to provide unprecedented levels of medical observation while simultaneously reducing the need for visits to the doctor. BSNs provide feedback to users that can illuminate potential health concerns earlier, encourage healthier lifestyles, and improve personal wellbeing. There is also the potential for using the collected data to provide real-time assessments of an individual's condition and need that could trigger a real-time assistance mechanism, such as a balance assistive device or a wearable defibrillator. If adopted widely, this technology could also upgrade well patient monitoring, enable at home aging and care, report on medication effectiveness, and cut the costs of healthcare across the board [Hanson09].

Anatomy of a Body Sensor Network

A BSN consists of one or more sensor nodes that form a communication network. Usually, one of the nodes acts as a base station, which aggregates information from the body-distributed sensor nodes and ultimately conveys it across existing networks to other stakeholders like the wearer's caretakers and physicians. Smart phones are already supporting many useful health related apps, and future generation smart phones are the obvious choice to serve double duty as a BSN base station. The base station thus plays a different role from the other nodes in the system, and it has more resources in terms of bigger size, available energy, longer range radios, and more memory and computing power. The sensor nodes themselves each contain a set of sensors for particular physiological data, processing hardware for computation, and a wireless radio for communication (some BSN nodes may replace the radio with a transceiver that communicates across the body, using the surface of the skin as a communication channel [Barth08]). Based on the application requirements, the sensed data may be streamed wirelessly or stored locally (typically in a flash memory) for later transmission or download.

BSNs versus Wireless Sensor Networks

While BSNs hold these basic components in common with generic wireless sensor networks (WSNs), which have provided a popular research topic for years, there are several important distinguishing features for BSNs. First, the body itself prevents the reuse of the same node across many roles due to the particularities of measuring physiological data. For example, an electrocardiogram (ECG) sensor that measures the electrical activity of the heart works well in the torso area, but it cannot work on the wrist; a gait sensor probably uses accelerometers and gyroscopes and is best located on the legs; the sensor on the head that measures brain activity (electroencephalogram (EEG)) probably cannot also measure respiration rate. Second, the proximity of the base station and the unique nature of each node's sensing modality makes node to node communication largely unnecessary. Instead of the ad hoc network arrangements common in WSNs, BSNs tend to use a star-hub topology with each sensor node communicating only with the base station (as the hub). Third, the number of nodes in a BSN (< 10 for most systems) is smaller than in common WSNs (> 1000s for large-scale environmental monitoring, for example), but the per node data rates are typically much higher, with ECG or EEG data being inherently more dynamic than environmental temperature data. Finally, the wearable nature of the BSN nodes places unique constraints on their specification and design to make them acceptable for widespread use but also provides more regular node access for maintenance and re-charging.

Wearability

Specifically, BSN nodes will not be adopted if they are too inconvenient, uncomfortable, or unsightly. The level of tolerable clunkiness for a BSN node is proportional to its importance to the user; I would wear a life saving heart pacer, for example, no matter how obtrusive it is. On the other hand, if my doctor just wants to get feedback on the effects of my new heart medication, I probably won't put up with wearing a pager attached to my chest. To encourage widespread use of BSNs, system designers must shrink the size of the nodes to the sub cubic centimeter level and give them conformal, wearable shapes that disappear to the point that they are forgettable by the wearer. Such small form factors place a severe limit on the amount of energy that the node can store locally (e.g., small batteries). This creates a challenge to provide the necessary functionality for the desired application within a tight energy budget. Some BSN nodes could use batteries that are recharged regularly, for example if the user removes them at night. Other nodes might need to be used continuously for longer periods, although as noted above, unlike some WSNs, they are unlikely to be worn for much more than a week or so before removal for some activities (e.g., bathing, sleeping). In an effort to further reduce the node size and to extend their usable lifetime, some BSN researchers are pursuing custom solutions that supplement or replace the battery by harvesting energy from the body environment (e.g., body heat, vibration, solar) [Calhoun11]. Eliminating the battery through energy harvesting would shrink the node, make it cheaper, and potentially improve the possibility of integrating it into items people already wear like clothing, shoes, or jewelry.

Other Technical Challenges

While the BSN field has made good progress developing systems to sense data and get it where it needs to go, additional research is necessary to convert that data into information relevant to the target application. This requires advancements not only in signal processing and data mining but also in interdisciplinary collaborations that involve application domain expertise. In the long run, these technologies must be demonstrated to improve patient outcomes, enhance quality of life, and reduce healthcare costs – and the demonstrations must be through real deployments on real people.

Other technical challenges facing BSNs include security, privacy, and safety – all of which are essential given the target medical applications and are made challenging given the severe resource constraints and dynamic nature of the system and environment. Highly important research thrusts also include incorporating additional sensing modalities, providing real-time guarantees (especially for applications involving actuation), achieving ultra low power sensing/processing/communication/networking, and realizing usability across a diverse group of users.

BSNs in Action

BSNs can provide a huge array of applications, both currently implemented and envisioned for the future. Sensing modalities include ECG, EEG, EMG, blood pressure, pulse oximetry, motion, etc., enabling applications ranging from outpatient physiological monitoring [Wong09] and neurology disorder classification [Xu11] to fall risk assessment [Lockhart10] and detection [Li11] and closed loop insulin pump regulation [Clarke09].

Conclusion

In conclusion, BSNs enable a diverse and powerful new direction in medical care. While technical and societal challenges remain, promising initial forays in BSN development show the potentially revolutionary possibilities for this technology. We are confident that BSNs are coming soon to a body near you.

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