Measuring Smart Sensor Value:
a human health monitoring example

Overview

This is the first in a series of reports on measuring smart sensing value. This report focuses on measuring added value for human health monitoring.

Health monitoring operations identify threats and opportunities from cluttered data. Monitoring value depends directly on reducing clutter. Clutter in data hides threats, buries prospects, wastes time, clogs channels, saps energy, crams storage, and costs money[1-3]. With clutter removed, anomalies stand out, decisions are clear, and costs are cut. Most monitoring operations would benefit from affordable clutter reduction. Smart sensing can reduce cluttered sensor data to useful information before it is transmitted, analyzed, or used to make important decisions. This report explains how Smart sensing value can be measured, by introducing a few, simple examples. A detailed analysis of clutter reduction savings is provided elsewhere [4].

Value metrics for human health monitoring, along with other applications, include the following:

- Remote sensor transmission rates: reducing transmission rates can extend battery life, cut transmission costs, and free up clogged communication channels for other use.
- Remote sensor power use: sensors often run on batteries that are sometimes impossible but often difficult to charge or replace. Energy use can most easily be reduced by reduced transmission but also by reducing signal processing operations.
- False alarm rates: cutting false alarms saves money, reduces staffing, limits distracting fatigue, and increases the likelihood of finding interesting events.
- Signal processing load: reducing computer operations and required memory cuts energy use and frees up computing resources for other uses.
- Deployment and maintenance: since smart sensing adapts to different environmental conditions, a robust smart sensing solution can be deployed in a variety of environments, rather than tailoring solutions to suit different and changing environments.

Smart sensing evaluation and delivery require the following steps:

1. Participating in preliminary, “triage” discussions with smart sensing engineers, in an attempt to identify a sufficiently compelling value proposition to warrant further effort.
2. Investing in a smart sensor evaluation:
    a. Identifying key value metrics and determining how much improvement would be worthwhile.

b. Gathering data for measuring smart sensor value. Provide half the data for model identification and half for independent validation.
c. Identify a strong, robust smart sensor model for adding value based on evaluation data.
d. Measuring and validating smart sensor added value.
3. Investing in smart sensor deployment:
    a. Refining the model identified in step 2 for speed, compactness, and accuracy.
    b. Integrating the model into an embedded computing solution.
    c. Testing, evaluating, and delivering the final product.

Smart sensor potential added value must be balanced against required evaluation and delivery time and effort. Since time and money can always be spent in many useful ways, critical added value must usually be anticipated before taking even the first delivery step. The following example is typical.

Human Health Monitoring Example: extending battery life

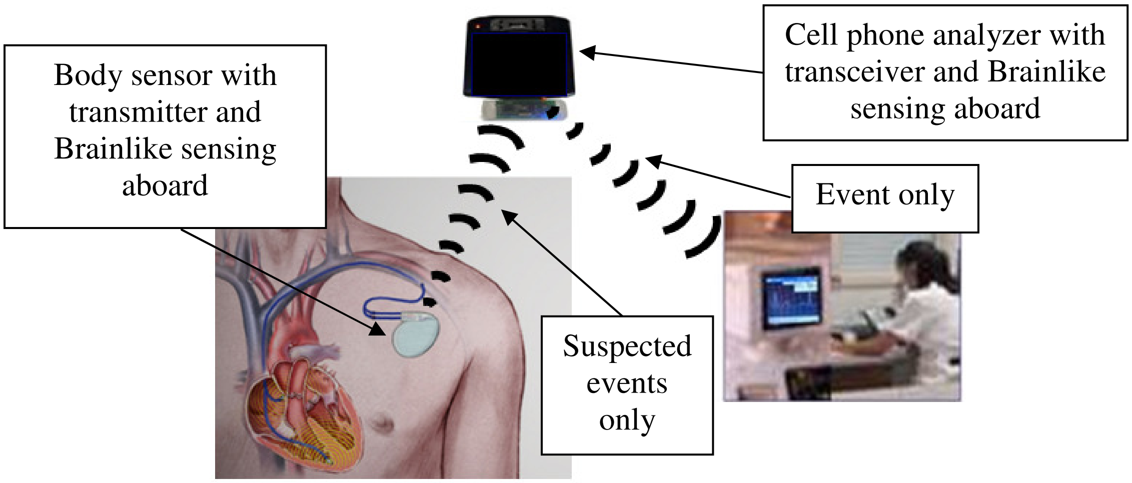

Figure 1. A Cardiac Monitoring System.

Some product and service providers in the rapidly expanding human health monitoring industry [6] supply wireless devices that continuously monitor health metrics and automatically supply a warning signal if they exceed normal limits. For example, Figure 1 resembles a system supplied by CardioNet [7]. The system includes a body sensor and a cell phone monitor. The body sensor produces electro-cardiogram (ECG) readings and transmits them to the monitor via an integrated wireless transmitter. When the monitor detects an abnormality, it automatically sends a signal to a monitoring center via a wireless cell phone transmitter. At the monitoring center, certified technicians analyze the data and report it as necessary to physicians.

The body sensor continuously transmits all body sensor ECG data. The monitor continuously extracts features from the ECG data, then uses the features to identify anomalous events, and then transmits the anomalous events when they occur.

The CardioNet system provides great value as it stands, improving health prospects of many patients, 24-7. The system could be even more valuable, in keeping with the following metrics:

- A reduction from continuous body sensor transmission of ECG data to one-tenth as much data.
- An extension of battery life from one day to 10 days. Reducing the data by ten times, while assuring that all potentially anomalous events were still sent, could improve battery life by up to 10 times, depending on how much additional processing on the body sensor was required.
- A reduction in feature extraction processing on the monitor. Reducing the processing by a factor of ten could improve monitor battery life substantially.

Adding value in this way could be achieved by adding a smart sensing processor to the body sensor unit, as shown in Figure 2. Smart sensing has the potential for adding value by removing ECG snippets that have no chance of being anomalous events, while transmitting only ECG snippets that could be anomalous events. Smart sensing has the potential for doing so while conventional sensing may not, because smart sensing continuously adjusts measured values for changing patient conditions such as heart rate changes due to resting or high physical activity. Smart sensing also automatically adjusts for individual differences and incorporates correlations among measured values and their recent history to identify candidate snippets with high precision. Most importantly for this application, smart sensing operates with very high efficiency, making smart sensor processing feasible on the very small microprocessor that is available on this body sensor.

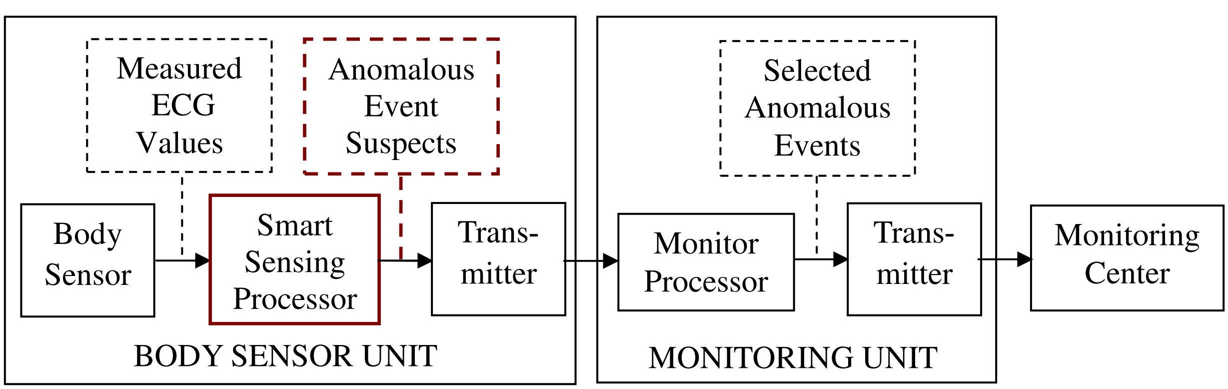

Figure 2. Cardiac Body Sensor with Enhanced Smart Sensing.

Regarding the four delivery steps outlined earlier, the ten-fold reduction in transmission and ten-fold improvement in body sensor battery life might or might not be sufficiently compelling to warrant further effort. If not, goals might be changed accordingly, and the evaluation decision and metric identification decisions (might be made in favor of evaluating the data reduction prospect). If so, data would be obtained for which a substantial number of anomalous events had been identified. Some of that data would be held back for independent validation. The remainder would be provided to smart sensor analysts who would attempt to identify a powerful, robust model that passed all anomalous event ECGs while removing a substantial number that were not anomalous. If a) the analysts could establish such a model, b) the model could be successfully tested with independent data, and c) the model could be affordably deployed in a way that reduced overall power consumption, the smart sensing solution would evidently be viable.

Figure 3 illustrates body sensor unit improvement potential and Figure 4 illustrates monitoring unit improvement potential. As shown, battery life on both units can be improved by reducing body sensor transmission and processing to only a small number of anomaly suspects. On the body sensor, battery life would be improved by reducing transmission load. For example, sending an average of 150 suspect ECGs per day, each being one minute long, instead of continuous transmission all day (1,440 minutes), could reduce transmission load by about a factor of ten. On the monitor, battery life would be improved by reducing processing load. For example, processing only the 15 suspect ECGs instead of continuous processing would reduce processing load by the same factor. In both cases, improvement by a factor of seven instead of a factor of 10 is shown, because transmission and processing deplete most, but not all energy for the body sensor and monitor respectively.

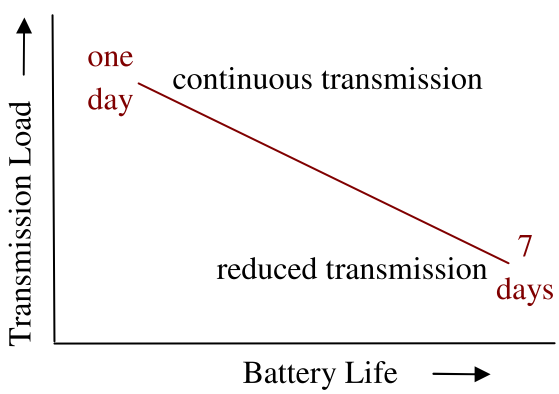

Figure 3. Body Sensor Unit Improvement Potential.

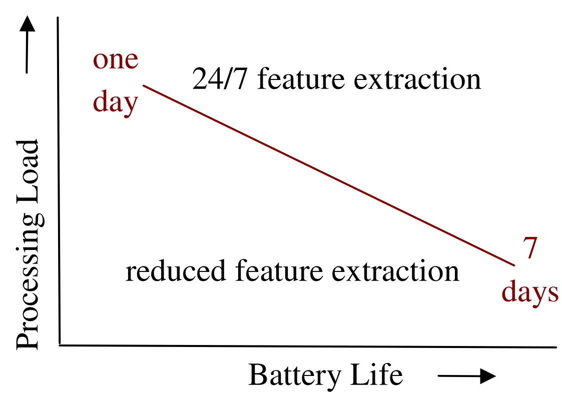

Figure 4 Monitoring Unit Improvement Potential.

Conclusion

In summary, smart sensing added value can be directly measured in terms of improving remote sensor transmission rates, power use, false alarm rates, and signal processing load, as well as reducing deployment and maintenance costs. Smart sensing evaluation and delivery require three steps: 1) preliminary triage to establish potential value, 2) smart sensor added value evaluation, and 3) smart sensor deployment. This report has focused on human health monitoring in general, and on body sensor monitoring in particular. An example has shown how a smart sensing module could be deployed on a low energy microprocessor, residing on a body sensor. The example has highlighted body sensor battery life as the key metric for evaluating smart sensor added value. Insofar as the first two steps proceed successfully, smart sensor solution deployment should be considered.

References

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