Quiet, Please?

Like dust, noise is everywhere, and we usually don't like what we see or hear. When we look closely at any sensor signal, we notice a fine layer of raggedness. Since this layer is not what we set out to measure, we use filters to remove it. Frequency-domain insights allow us to suppress low- or high-frequency noise or perhaps a single unwanted harmonic. While we take these techniques for granted, they're really quite amazing.

Unfortunately, feedback control injects sensor noise into the plant as a kind of self-inflicted disturbance. While some control theories ignore noise—mainly in nonlinear control where the problems are already hard enough—the mark of a realistic theory is its ability to predict the response to noise. Some theories view noise as a stationary white or colored random process with a specified distribution, while others consider deterministic-but-unknown signals confined to a weighted ball of functions. Both approaches are mathematically attractive, and we have a warm feeling that these idealized noise models capture the messiness of the real world.

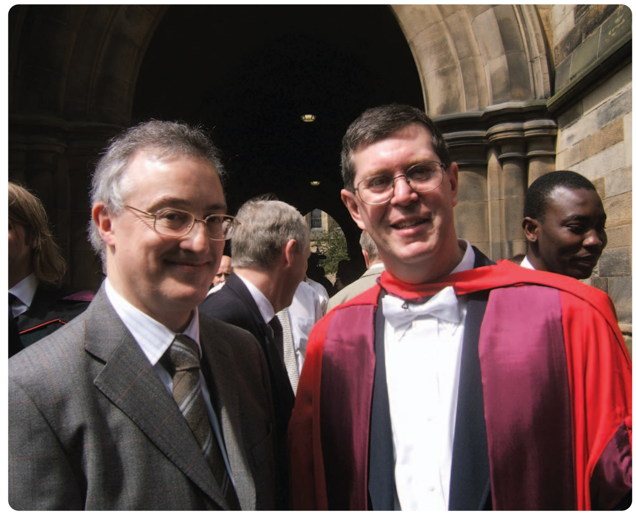
One hard fact of life is that we often don't know what the sensor noise properties are until we examine the data. Since the corrupting noise usually turns out to be worse than we had hoped for, the troubleshooting phase begins, in which every conceivable trick is tried in the hope of reducing the noise. Only after we've done the best we can, do we have a clear idea of how well the system can perform. The controller we ultimately implement must be designed to compensate for the sensor noise and its unique hardware-dependent characteristics.

For any signal, our main task is to distinguish between its information content and noise content. That distinction depends on the knowledge of the receiver, who risks—either due to carelessness or ignorance—overlooking

Atop Aonach Mor near Fort William, Scotland.

At the entrance to Fingal's Cave on Staffa Island off the west coast of Scotland.

Dr. Olatunbosun Ajayi and Hon. D. Eng. Dennis Bernstein attending post-graduation festivities at Glasgow University in July 2006.



Mike Grimble of the University of Strathclyde and Dennis Bernstein at the University of Glasgow.

valuable information when a signal appears to be mostly noise. After all, the discovery of the big bang hinged on the analysis of radio noise, which turned out to have interesting information content. In contrast, clues preceding 9/11 fell on deaf ears.

Ironically, even *noise* noise—that is, a truly informationless signal—has its virtues. The background noise inside an airplane saves me from overhearing every conversation in what is essentially a crowded room. Along the same lines, architects include pump-driven waterfalls in public places to provide background noise to mask private conversations. The sounds of rain and wind (of the moderate variety) are among the most beautiful noises, especially for those needing help to fall asleep.

(From left) Dennis Bernstein, Matthew Cartmell (University of Glasgow), and David Wilson (University of Leeds) at a research meeting in one of Glasgow's finest establishments.

By mimicking noise, we hide information. In cryptology, encoded information is faux noise, which looks like real noise to the outsider. Better yet, hiding information inside a blizzard of noise is even more effective since it's difficult to decode a signal that you can't find. Likewise, the wise adversary masks its intentions in noise, a ploy that any control engineer who has implemented a "D" gain can appreciate.

Noise can also do useful work. In Monte Carlo simulation, random signals are used to probe systems. We exploit the laws of probability to recover information, in a kind of useful-information-from-noise scenario. Although we could deterministically generate signals for simulation, we let nature do the choosing for us. Along the same lines, paradoxical paper titles that refer to "stabilization by noise" suggest that judiciously injected noise can make systems behave in useful ways.

What else can noise do? Evolution states that organisms are the product of random mutations, which provide the means to adapt and survive in a changing environment. In fact, stressed organisms are known to mutate at higher rates, using a kind of feedback-induced noise generator. The noise-induced mutations allow the organism to search for a more advantageous state, where its chances of survival are increased. Mating to produce offspring with recombined genes that produce novel features has a similar effect, although we usually view our choice of spouse as a noise-free decision. Who knows?

Dennis S. Bernstein
Editor-in-Chief
IEEE Control Systems Magazine