Metrology Musings: Uncertainty? There's An App For That.

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> "A quantitative result without any kind of uncertainty estimate is not only useless, it is dangerous because it can be misused."
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> *Churchill Eisenhart, 1913-1994*

My smartphone is really smart. Really. It can serve as a phone, a camera, a computer, a radio, and a global positioning system (GPS). I also can choose from over 300,000 apps to download onto my phone, all designed to make my life fun and easy. Really. Want to Facebook your friends? There's an app for that. Need help with your taxes? There's an app for that…oops, you're too late for that. Want to transform your phone into a baby monitor? There's an app for that. Looking for a great example of measurement uncertainty? There's even an app for that.

One of my favorite phone apps is Google Maps, which also serves as a GPS. I've used it many times to navigate my way when I'm not quite sure where I'm going. Its ability to locate my position and generate accurate and precise directions amazes me. When I open this app on my phone my current position is indicated with a blue dot. A gray circle, outlined in blue, encompasses the blue dot.

It occurred to me recently that this is a great illustration of measurement uncertainty. The blue dot is Google's way of saying, "We *think* this is where you are." It represents their measurement of my location. The gray circle is Google's way of asserting, "We are *confident* you're located within here." That's exactly how we should approach our measurement results: I think this is it, and I am very confident that it's within this range. This leads me to my next point about measurement uncertainty…

A statement such as "the uncertainty of measurement is ± 0.5 mm" may be helpful, but it also conveys doubt. We need a different outlook. I believe somebody made a small - but critical - mistake when they named this concept "measurement ***uncertainty***." That's a pessimistic view of what should be a statement of confidence. What if we called it measurement ***certainty*** instead? That's what Google's gray circle represents – a statement of certainty, not uncertainty. Take a look at the following statement written by scientists reporting on their results of the heat capacity of ammonia – you can sense *confidence* in their results:

"*We think our reported value is good to 1 part in 10,000: we are willing to bet our own money at even odds that it is correct to 2 parts in 10,000. Furthermore, if by any chance our value is shown to be in error by more than 1 part in 1000, we are prepared to eat the apparatus and drink the ammonia*." [1]

Now that is a confident statement about measurements! Do you want to express your measurement results with the same kind of confidence? It all starts with a measurement ***certainty*** budget. Understanding the details of one - even if you never create one - will give you that assurance.

A measurement certainty budget is similar to a financial budget that you might have at home: it's an itemized list with numbers. The list in a certainty budget represents those factors which can influence a measurement – I've listed the common ones below:

- **Measuring instruments** are imperfect. (Yes, even the ones with digital readouts.) Errors due to aging, wear, drift, bias, and repeatability can affect a measurement.

- **Resolution of the instrument** is a factor, although it's usually insignificant. For example, if you measure time with a stopwatch and the result is 17.42 seconds, that last digit was either rounded up or down. The measured interval is somewhere between 17.415 and 17.425 seconds.
- The **reference standard** used for calibration isn't perfect either. The uncertainty associated with it comes along (some call this *imported uncertainty*) and is factored into the measurement uncertainty for your instrument.
- **Operator skill**. Guess what? No two people are the same and none are perfect either. Differences in reading measurements, applying force, and reaction times all affect the end result.
- **The environment**. Temperature, barometric pressure, and humidity can affect BOTH the measuring instrument AND the item being measured.

Now let's look at how these factors are incorporated into a certainty budget for the calibration of a laboratory stopwatch using an audio time signal obtained by a land line telephone [2].

Source of uncertainty	Standard uncertainty (s)	Notes
Human reaction time	0.230	A
Telephone delay deviation	0.030	B
Resolution of stopwatch	0.005	C
Combined uncertainty	0.232	D
Expanded *certainty*	**0.464**	**E**

Notes:

A. Based on a small study conducted at Sandia National Laboratories with four individuals.

B. Based on callers in the continental United States using land lines when calling the National Institute of Standards and Technology traceable audio time signal at (303) 499-7111.

C. For digital indicating devices, resolution uncertainty is half of the least significant digit.

D. Calculated by Root-Sum-of-Squares analysis (RSS). Square each component, add, and take the square root of the result.

E. The combined standard uncertainty can be thought of as equivalent to one standard deviation. Expanded *certainty* is usually expressed at a level of confidence of 95% by using a coverage factor $k = 2$.

There you have it. We won't go into all the budget details this time, but next time we'll explore further the numbers, the method of evaluation, types of distributions, and the math. However, two things should stand out in this budget example: (1) the bulk of the uncertainty is due to differences in human reaction time and (2) the expanded certainty is almost 0.5 seconds. Would you have guessed that such a simple measurement would have an expanded certainty that high?

No measurement is perfect but, with the help of a ***certainty*** budget, you can now confidently express your results and avoid, as Churchill (Eisenhart, that is) warns, being dangerous.

References

[1] Round-Table Discussion on Statement of Data and Errors, Nuclear Instrum. and Methods 112, 391 (1973).

[2] J.C. Gust, R.M. Graham, and M.A. Lombardi, "Stopwatch and Timer Calibrations," National Institute of Standards and Technology, Special Publication 960-12, January 2009.