



Vocabulary WG report

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28th March 2018

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FIDUCEO tutorials

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Initial example: The measurement function



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Introducing the measurement function



As discussed in the video above, the FIDUCEO approach to uncertainty analysis and metrological traceability starts with the measurement function. The measurement function is defined from the 'measurement model' (plus known as the 'measurement equation'), which establishes the mathematical relations between the measurand (the output quantity) and the quantities used to determine its value (the input quantities). Often, we are able to explicitly write the measurement function in terms of an analytic expression of the form:

$$Y = f(X_1, X_2, \dots, X_n)$$

where:

- X_1, X_2, \dots, X_n are the input quantities
- Y represents the output quantity (the measurand)

There are, however, cases in which it is necessary to define the measurement function in a different way, for example as an iterative solution of a model implemented through code. In FIDUCEO we perform our uncertainty analysis by considering the different input quantities to the measurement function. Each input quantity may be influenced by one or more error effects, each of which has an associated probability distribution. Our aim is to use this information to establish the probability distribution of the output quantity, through the process of uncertainty analysis. A summary of this approach is shown schematically in the figure below.

Notice here that each input quantity, X_i , is sensitive to an error from one or more error effects, each of which has an associated probability distribution in the figure above. One error effect is shown to influence both X_1 and X_2 ; this implies that there is a common error and hence correlation between the input quantities. We'll return to the ideas of common error and correlation in a separate lesson, but first, let's look at the measurement function in more detail, and introduce the concept of a 'plus zero' term.

What is a measurement function?

1. Introducing the measurement function
2. Introducing the 'plus zero' term
3. Introducing an uncertainty analysis tree
4. Building an uncertainty analysis tree



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Introducing the 'plus zero' term

On the previous page, we introduced the measurement function, and saw that input quantities are sensitive to errors from one, or more, error effects.

However, when conducting an uncertainty analysis, there is an additional factor that we must also consider: the extent to which the measurement function describes the true physical state of the measurement process. We can account for this factor by including 'plus zero' term in the measurement function:

$$Y = f(X_1, X_2, \dots, X_n) + \theta$$

Here, this 'plus zero' term does not alter the value of the measurand, but will have an associated uncertainty in recognition of the fact that all measurement functions are approximations to the physical process they describe. In other words, this term considers the extent to which the equality of the measurement function may not hold. For example:

- if the measurement function is a linear equation, the 'plus zero' term considers the extent to which the instrument may be non-linear;
- if the measurement function is a spectral integral determined numerically using a trapezium or rectangular rule, the 'plus zero' term considers the extent to which this rule acts as an approximation of the integrated quantity;
- if there is an assumption that quantities or effects cancel each other out, the 'plus zero' term considers the uncertainty to the extent to which they cancel;
- if there is an assumption that the effects of tiny light are negligible, the 'plus zero' term considers the extent to which the assumption is valid.

Once we have a clear picture of the extent to which the measurement function describes the true physical state of the measurement process and the effects that influence each input quantity, we can determine the uncertainty in the measured through the process of uncertainty analysis. We'll examine uncertainty analysis in detail later in a separate lesson, but before we do, it will be useful to examine the benefits of representing the measurement function graphically in the form of an uncertainty analysis tree, which we'll look at on the next page.



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Introducing an uncertainty analysis tree

As we've seen, in most cases the measurand (Y) is not measured directly, but is instead obtained from a number of input quantities (X_n) via a mathematical relationship that we call the measurement function.

Importantly, whereas some of these input quantities are directly determined by measurement, parameterisation or data analysis, others are determined through their own measurement function of other input quantities. In other words, there can be a hierarchical aspect to uncertainty analysis.

To help organise a measurement-function-centred analysis of uncertainty, it can therefore be useful to prepare a graphical representation in the form of an uncertainty analysis tree, an example of which is shown below. On the next page, we'll examine this diagram in more detail and discuss the process that led to its construction.

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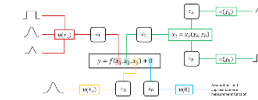


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Examining the uncertainty analysis tree

On the previous page, we introduced the concept of an uncertainty analysis tree, which is focused on the measurement function. On this page, we'll examine this diagram, which is reproduced below, in more detail.



As can be seen from the diagram above, this uncertainty analysis tree is centred on the hypothetical measurement function:

$$Y = f(X_1, X_2, X_3) + \theta$$

Notice from the diagram that there are three effects that contribute to the uncertainty in the first term, $w(X_1)$, and that this uncertainty is, in turn, propagated to an uncertainty in the measurand (y) using a sensitivity coefficient, c_1 . We'll examine sensitivity coefficients in detail in the next recipe of this series.

Moving on, we can see that the second term has its own measurement function:

$$\theta = w(\theta, X_n)$$

The uncertainty in the terms in this measurement function, $w(X_n)$ and $w(\theta)$, is again propagated to an uncertainty in the measurand in this case, again via a sensitivity coefficient, and the uncertainty in X_n , $w(X_n)$, is propagated to an uncertainty in the measurand (y) via the sensitivity coefficient c_2 .

A number of effects contribute to the uncertainty in the third term, $w(X_3)$, but it is not possible to quantify them separately; instead, their combined uncertainty has been evaluated and propagated to the measurand using the sensitivity coefficient c_3 .

Finally, the uncertainty associated with the 'plus zero' term, $w(\theta)$, has been evaluated and is propagated to the measurand via the sensitivity coefficient $c_4 = 1$.

It should be noted at this point that the uncertainty analysis tree presented above is a simplified example, designed to introduce the basic concepts involved in later recipes; we'll look at a real-life example of a diagram of this type and see how we can expand our approach, but before we do, let's look at errors, uncertainty and sensitivity coefficients in more detail in the next recipe.

1. Introducing the measurement function
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3. Introducing the uncertainty analysis tree
4. Examining the uncertainty analysis tree

We haven't got this out yet...

- Kurt's comments this morning – to make progress we need:
 - Energetic leadership
 - A clear goal that is sufficiently specific
 - A willingness to make it “good enough” rather than “perfect”

Not the concepts associated with
“vocabulary discussions” ... but let's
have a go

Clear goal

1. A dictionary: all (“correct enough”) definitions in use for different words, collated in one place
2. Tutorial materials to help give the message of CalVal out to the broader community
 - How to do uncertainty (preflight/onboard cal, vicarious cal/val, level 2a?)
 - How to think about traceability to SI or other references
 - How to consider comparisons (averaging different calibrations / comparisons)