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What are Interval Computations, and How Are They Related to Quality in Manufacturing?

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I. One of the Major Aspects of Quality in Manufacturing

One of the major aspects of quality
of the manufacturing product
is that all relevant numerical characteristics
of this product
should lie in the prescribed limits,

be it the fuel efficiency of an engine, the size of a machine part, etc. So, to ensure the quality, we must measure the values of these characteristics, and check that the characteristics fit into the prescribed limits.

Since measurements cannot be absolutely accurate, the resulting estimate $\tilde{y}$ may differ from the actual value y of the desired characteristic. To be sure that the actual value y satisfies our requirements (i.e., that it lies in the required tolerance interval $[y^-, y^+]$), it is thus not sufficient to know that the estimate $\tilde{y}$ belongs to this interval. We must also know the *accuracy* of this estimate.

It is important to distinguish between the following two cases:

- Some of these characteristics (e.g., size) can be measured *directly*, i.e., by directly applying a measuring instrument. In these cases, we can read the accuracy from the documentation that has been supplied with this measuring device (and is thus guaranteed by the manufacturer of this device; if the manufacturer does not guarantee anything, then it is not a measuring device at all).
- For other characteristics (e.g., for fuel efficiency) there is no sensor that would immediately produce the desired result. Such a characteristic y can be measured *indirectly*. Namely, we measure some other characteristics $x_1, ..., x_n$ that are directly measurable, and then use a computer to transform the results $\tilde{x}_1, ...\tilde{x}_n$ of these direct measurements into an estimate $\tilde{y}$ of the desired characteristic.

  In this case, from the documentation, we can only extract the accuracies of the direct measurements x_i. We need to transform these accuracies into the accuracy of y.

So, we arrive at the following *problem*:

II. Problem

Estimate the accuracy
of indirect measurements.

For simple transformations, the solution to this problem is well known in engineering. However, in many cases, the transformations from x_i to y involve complicated computations (e.g., filtering, image processing, etc), and thus the problem of estimating the accuracy of y becomes non-trivial. Here, we also have to consider two cases:

- If we *know the probability* distribution of errors, then this problem can be solved by using existing statistical techniques.
- However, in many cases, the *only information* about the errors that the manufacturer guarantees is the *upper bound for the error*. In these cases, new methods are needed.

Such methods have been developed in applied mathematics. Since our ultimate goal is to check whether a characteristic fits into a given tolerance interval, one of the names for this field is *Interval Computations*.

III. Summarizing: What Is Interval Computations (From the Viewpoint of Manufacturing Applications)

Interval Computations is a methodology
that estimates accuracy of indirect measurements,
and thus helps to check the quality.

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IV. What Manufacturing Quality Problems Can Be Solved By Interval Computations Methodology

The need for interval computation methods appears if the following conditions are satisfied:

- We are checking the value of the characteristic y that cannot be measured directly. Therefore, we have to use an indirect measurement, in which we first measure some other other characteristics $x_1, ..., x_n$, and then apply an algorithm f to estimate y.
- This algorithm f is complicated.
- Statistical characteristics of the errors of measuring x_i are unknown.

V. Interval Computations Are Useful Not Only For Controlling the Quality of the Result, But Also for Checking the Quality of the Manufacturing Process

We have shown that Interval Computations are useful for checking the quality of the final product. Analyzing the final product is a necessary part of *quality testing*, but the most important goal of quality control is to *improve quality*. In many cases, we know the manufacturing process that can guarantee the desired quality on condition that all parameters of this process (e.g., temperature, pressure, etc) are maintained within the prescribed limits. So, in order to guarantee the quality of the manufacturing process, we must monitor the relevant parameters and check that they are within the limits.

This problem is similar to the above-described problem of checking the quality of the final product, and thus, it also requires some complicated algorithms. Such algorithms have been developed in interval computations.

VI. A Brief History of Interval Computations

- *It started here, in the US.*

  The main ideas of Interval Computations appeared in the USA, in the Ph.D. Dissertation of R. E. Moore that was defended at Stanford in 1962. The first application of interval computation was presented by R. E. Moore in 1959 [1]. The first monograph, also by R. E. Moore, appeared in the USA in 1966 [2].

- *Moved to Europe.*

  Later, the center of interval computations moved to Europe, mainly to Germany. One of the reasons was that in the US, manufacturers were, in average, less cost-conscious, and they were thus less worried about inaccuracy of sensors: "if a sensor is not good enough, let's spend some more money and buy a better one". The main users of this techniques were scientists, for whom this solution did not work, because they were working at the cutting edge of accuracy, and they were already using the best possible sensors to measure their micro-quantities.

  As a result, Interval Computations is not widely known in the US, while in Germany, it is a part of the standard qualifying exam for several areas of Numerical Mathematics. Germany was the place where the first specialized journal appeared. Germany still hosts regular conferences in interval computations.

- *A recent outburst of activity.*

  Recently, there has been an outburst of activity in the USA and internationally, related to Interval Computations:

  - A new international journal *Interval Computation* has been launched in 1991 (starting from 1995, it is issued under the new title *Reliable Computing*).
  - In 1993, a well-represented International Conference on Interval Computations was held in Lafayette, LA.

VII. There Are Already Many Intersting Applications, But Interval Computations Still Have a Large Unexploited Application Potential

In spite of many successful applications (some of them are presented in this volume), there are still many areas where interval methods can be applied. To our viewpoint, the main reason obstacle to future applications in manufacturing is lack of communications:

- Engineers who are involved in real manufacturing rarely have a knowledge of this field. So, when they encounter the accuracy problems that can be in principle solved by interval methods, then, instead of using the existing techniques, they try to invent techniques of their own.
- People who are experts in interval computations are not very knowledgeable in manufacturing problems. Therefore, although they would love to apply their methods for solving real-life problems, instead, they apply them to simulated "toy" problems.

VIII. The Goal of This Workshop

The main goal of this workshop was to bring together people who are interested in different applications of interval computations, and thus, to promote cooperation between them.

This volume contains applications in different fields. We hope that it will be helpful to researchers.

References

[1] R. E. Moore, **Automatic error analysis in digital computation**, Lockheed Missiles and Space Co. Technical Report LMSD-48421, Palo Alto, CA, 1959.

[2] R. E. Moore, **Interval analysis**, Prentice Hall, Englewood Cliffs, NJ, 1966.