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OMTP: FORTRAN program for optimally solving indirect measurement problems

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OMTP — Optimal Measurement Transformation Program — is a WATFIV-compatible ANSI FORTRAN program (according to the 1966 standard) for computing optimal solutions to a variety of indirect measurement problems. The paper describes the capability and application of this program.

Introduction

OMTP is based on the theory described by Smit (1983). It provides for the simultaneous computation of a set of m unknown parameters, including accuracy estimates, from a set of n measured parameters and their corresponding maximal errors.

The measured parameters and their measurement errors are represented by the following function:

$$b(y) = 1 \quad \text{if } |Y_i - y_i| < \Delta Y_i \quad \text{for all } i = 1, \dots, m \\ = 0 \quad \text{otherwise}$$

in which y is an n -dimensional vector having the n measurable entities as components, Y_i is the i th meter reading, and ΔY_i is its maximal measurement error.

The measurement configuration is described by the operator $\hat{F}$ relating the measured parameters to the unknown ones according to $y = \hat{F}x$, in which x is an m -dimensional vector, having the m unknown parameters as its components.

The optimal solution for the unknown parameters can be proven to coincide with the unit-value region of the function $b(\hat{F}x)$. This region is called the optimal X -space uncertainty region.

OMTP is capable of tracing this region by using multi-dimensional scanning routines. In its present form the program has the potential to compute maximally 10 unknown parameters from maximally 20 measured ones.

The program source and a manual are available from the author at cost.*

2 Operation

To operate OMTP, the user has to provide a sub-routine which describes his measurement configuration (the operator $\hat{F}$), and a task description for OMTP. Both will be briefly discussed, a detailed description being given in the manual.

2.1 The user-supplied sub-routine

The user-supplied sub-routine has to describe the dependence of the measured parameters on the unknown ones.

* The source will be provided on a floppy disk (single-sided, single-density, soft-sectored, following the DEC RT-11 file structure), unless otherwise specified.

It has to be named FUNCS (X, Y, ICOUNT), in which X is a double precision array containing the measured parameters. FUNCS has to compute Y for a given value of X , which is provided by OMTP. (ICOUNT can be used for counting purposes.) As an illustration, the example used in Smit (1983), Eqns (6) to (8), has been programmed (Example 1).

Example 1 The user-supplied sub-routine

```
1      SUBROUTINE FUNCS (X, Y, IDUM)
2      DOUBLE PRECISION X
3      DIMENSION X(2), Y(3)
4      DATA PI, C /3.14159, 100./
5
6      C
7      Y(1) = DSQRT ( (X(1)+C)**2 + X(2)**2 )
8      Y(2) = DSQRT ( (X(1)-C)**2 + X(2)**2 )
9      Y(3) = 180. * (DATAN2 (X(1)+C, X(2))
10                + DATAN2 (C-X(1), X(2))) / PI
11
12      C
13      RETURN
14      END
```

2.2 The task definition

A task definition for OMTP contains (at least) three parts — one part describing the X - and the Y -space, one part describing the measurement result, and one part invoking the required procedures.

To illustrate the language, a task definition (Example 2) has been composed to solve the problem described by Smit (1983).

Example 2 The task description

```
1      RUN NAME
2      DELFT UNIVERSITY OF TECHNOLOGY / EXAMPLE
3      X-SPACE
4      2
5      Y-SPACE
6      3
7      GRID
8      900. 10.
9      900. 10.
10     U-REGION
11     1487. 10.
12     1345. 10.
13     6. 2.
14     SEARCH
15     BORDER
16     CONTOUR
17     PLOT
18     END
```

PARAMETER 2

PARAMETER 1

Fig 1 The output corresponding to the user-supplied sub-routine and the task description shown in the text

The first two lines provide for an output identification. Lines 3 and 4 define the number of dimensions of the X -space, lines 5 and 6 do the same for the Y -space. The scanning algorithms require a discretisation of the X -space; lines 7 to 9 define, for each dimension, a starting point and a step value for the scanning routines.

The measurement result is described in lines 10–13; for each parameter the measured value and the maximal measurement error are specified.

Lines 14 to 16 involve a scanning procedure, which will be explained in the next section. Line 17 specifies a plot of the result. It is shown in Fig. 1.*

3 Algorithms

With the theory developed by Smit (1983), the problem of finding the optimal X -space uncertainty region can be reduced to the problem of finding the unit-value region of the function $b(\hat{F}x)$.

For more-than-two-dimensional regions, this region can be represented by the extreme values which each parameter takes within it, or by a plot of its projections on to one or more co-ordinate planes.

The first representation can be conceived of as the projection of the uncertainty region on to a co-ordinate axis. The second one as its projection on to a co-ordinate plane. The scanning problem can thus be decomposed into two scanning problems: one in the projection space (one- or two-dimensional) and one in the complementary sub-space (see Fig 2).

3.1 Scanning the complementary sub-space

A point in the projection space is judged to be part of the projection as soon as the complementary sub-space going through this point contains at least one point of the uncertainty region.

An economic way to verify whether this is the case is by using a search procedure for finding the uncertainty region within the framework of the complementary sub-space.

As such, we can use an optimisation procedure which optimises within the sub-space the distance $|Y - \hat{F}x|$; or

Fig 2 The projection space and a complementary sub-space going through the point P_c of the projection space

* The region shown is a little smaller than the region depicted in Smit (1983). This is due to the coarse step values specified in the task description.

Fig 3 The numbering of the adjacent points for the contour-following procedure

better; the normalised distance $|N(Y - \hat{F}x)|$ (see Smit, 1983, Section 5).*

As soon as a point within the uncertainty region is found, the search can be stopped. If the optimum falls outside the uncertainty region, the considered point is judged to be no part of the projection.

An obvious problem here is the reliability of the search procedure. If it has convergence problems, we may make erroneous decisions which will always lead to over-optimistic predictions for the uncertainty region. This problem can be solved by a straightforward intensive scan in the relevant region, which will, however, increase the required computation time considerably.

An embarrassment in implementing a sophisticated search procedure follows from computation time considerations; because the search procedure will be invoked many times (each time requiring the evaluations of $\hat{F}x$), this procedure has to be fast.

3.2 Scanning the projection space

3.2.1 One-dimensional projection

The extreme values of the projection can be found by directly scanning in positive and negative directions with fixed step size, starting at a member point of the projection. Such a member point can be found with the search procedure of Section 3.1.

3.2.2 Two-dimensional projection

Plots of a two-dimensional projection are interesting because they provide geometrical information about the shape of the uncertainty region.

An economic and reliable procedure to determine the shape of the projection is the method described by Freeman (1970). We choose, for each parameter in the projection plane, a fixed step size. Next, starting from an arbitrary point of the contour, we trace those two of the eight surrounding points (see Fig 3) between which the contour

is crossed so as to enter the projection in a left cyclic direction. From these points we then select the internal one as the next contour point and repeat the procedure from this point. This procedure is followed until the contour is closed.

To find a point on the contour, we first have to apply a search procedure to find a member point of the projection, then a procedure to bring the pointer to the border of the projection, and finally the contour-following procedure itself. (These three steps are reflected in the three commands SEARCH, BORDER, and CONTOUR: lines 14 to 16 of the illustrative task description.)

If the X -space is more-than-two-dimensional, and a search procedure is used to scan the complementary subspaces, the reliability of this procedure is limited by the reliability of the search procedure.

3.3 Other scanning procedures

An alternative to the one-dimensional projection method is the following one: we determine the (normalised) least-squares estimate corresponding to the corner points of the Y -space uncertainty region (see Smit, 1983, Fig 3) and take for each parameter the extrema over the transformed points. The reliability of this method is also limited by the search procedure which is used to find the transformed corner points.

The most reliable, but also most time-consuming method, is a direct scan of the relevant region.

4 Comments

All procedures described are available in the present version of OMTP. Additional information about x -parameters which are not relevant by themselves (Smit, 1983, Section 4.1) can be easily made effective. Furthermore, several facilities are offered for detecting malfunctioning of the search procedure.

Experience has shown that the contour-scan procedure works satisfactorily. The applied search procedures with a fixed step size for each parameter are less satisfactory, especially for those cases in which the distance function is highly non-linear. Better alternatives deserve study.

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* A third alternative is to use the distance to the uncertainty region itself.