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MINIMIZING DISTORTION IN TRUSS STRUCTURES VIA TABU SEARCH

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The shape control of large flexible space structures is of great interest to structural designers. A related problem is to seek ways to minimize the need for active controls by careful design and construction of the space structure. Consider a tetrahedral truss structure that is used to support a precision segmented reflector or antenna surface. The structure has a hexagonal platform and is characterized by the number of rings of members in the truss. For simplicity we assume that a flat truss geometry exists. Hence, all structural members and ball joints are required to have the same nominal length and diameter, respectively.

Inaccuracies in the length of member or diameters of joints may produce unacceptable levels of surface distortion and internal forces. In the case of a truss structure supporting an antenna, surface distortions may cause unacceptable gain loss or pointing errors. In this study we focus solely on surface distortion, however, internal forces may be treated in a similar manner.

One remedy is to impose stringent manufacturing tolerances on the hardware supplier, however this increases the cost of the space structure enormously. Alternatively, if the member lengths and joint diameters can be measured accurately it may be possible to configure the members and the joints so that root-mean-square (rms) surface error and/or rms member forces is minimized.

Following Greene and Haftka (1989) we assume that the member force vector f in a tetrahedral truss structure is linearly proportional to the member length errors e_M of dimension $NMEMB$ (the number of members) and ball joint diameter errors $\mathbf{e_J}$ of dimension $NJOINT$ (the number of joints), and that the displacement vector $\mathbf{d}$ is a linear function of f. Let $NNODE$ denote the number of positions (ball joints) on the top surface of the truss where error influences are measured. Let $\mathbf{U_M}$ ($NNODE$ x $NMEMB$) and $\mathbf{U_J}$ ($NNODE$ x $NJOINT$) denote the matrices of influence coefficients. Then, $\mathbf{d} = \mathbf{U_M e_M} + \mathbf{U_J e_J}$. Concatenating $\mathbf{e_M}$ with $\mathbf{e_J}$ and $\mathbf{U_M}$ with $\mathbf{U_J}$ yields $\mathbf{d} = \mathbf{Ue}$. Thus u_{ij} is the influence of a unit displacement error in member (or joint) j on surface distortion at surface node i.

Let $\mathbf{D}$ be a positive semidefinite weighting matrix (in our computational experiments we let $\mathbf{D}$ be the idenitity matrix of appropriate dimension) denoting the relative importance of the surface nodes where distortion is measured. The mean-squared displacement error can then be written as

$$d^2_{rms} = \mathbf{e^T U^T D U e} = \mathbf{e^T H e}$$

That is, we wish to find the permutation of the components of $\mathbf{e_M}$ and $\mathbf{e_J}$ that minimizes d^2_{rms}. Let $N = NMEMB + NJOINT$. Our combinatorial optimization problem DSQRMS, then, is

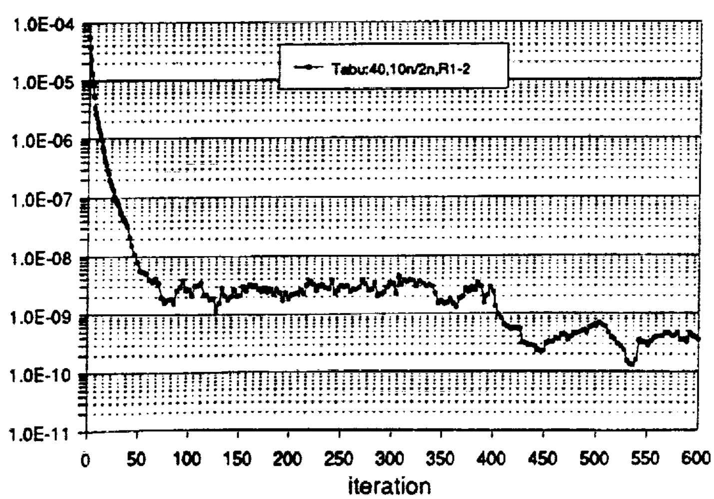
$$Min \sum_{j=1}^{N} \sum_{i=1}^{N} e_{\pi(i)} h_{ij} e_{\pi(j)}$$

over all permutations Π of {1,2,...,*NMEMB*} and {1,2, ...,*NJOINT*}. The plausibility of this technique has been its recent success on a variety of NP-Hard combinatorial problems including the quadratic assignment problem (see Skorin-Kapov (1990)).

Tabu search is a directed greedy procedure. A *move* is generated by choosing at random two members of the truss structure to exchange positions. If this move produces a decrease in the objective function value then a short term memory list of previous moves is scanned. If the current move is on this list it is disallowed, otherwise it is accepted. At each iteration of Tabu search a sampling of the space of all pairwise exchanges is made and the best accepted move in this sample space is kept. This procedure is repeated for *maxit* iterations.

To test our Tabu search code for DSQRMS we use the appropriate influence matrices for a flat, two-ring tetrahedral reflector truss generated by Greene and Haftka (1989). In this example there are 102 members (*NMEMB*) and 31 ball joints (*NJOINT*) of the same nominal length, respectively. Hence, all the members may be interchanged and all the joints may be interchanged. (This would not be the case if a parabolic reflector truss were used.) In addition, 19 positions on the surface of the truss (*NNODES*) were used to measure error influences.

After a variety of experiments a set of *good* parameters was chosen for Tabu search. The *sample size* at each iteration is 10 ∗ *NMEMB* and the short term memory size is 40. In addition four *pruning* rules were used to accelerate the search. Figure 1 displays a typical Tabu search output for this parameter set. Note that the y-axis is a log scale and that 200 of the 600 data points are displayed.



1. Greene, W.H., and R.T. Haftka, "Reducing Distortion and Internal Forces in Truss Structures by Member Exchanges," *NASA Technical Memorandum 101535*, January, 1989.

2. Shorin-Kapov, J., "Tabu Search Applied to the Quadratic Assignment Problem," *ORSA Journal on Computing*, 2,1990, pp. 33-45.