Improved Greedy Algorithm Based Matrix Satellite Cable Connection Optimal Design

Yiyi Wang¹, Zhifu Wang¹, Ke Zong¹, Mian Ye¹, Xi Zhou¹ and Zhijie Wang¹

¹ Institute of Telecommunication Satellite, China Academy of Space Technology, Beijing 10094, China

Abstract. An improved greedy algorithm based matrix satellite cable optimal design method is presented in this paper aim to overcome the difficulties including designing complexity, designing cycle and iterative designing process. An optimal algorithm model is built to help designer not only to accomplish design correctly and efficiently, but also to obtain better designing outcomes. Firstly, matrix cable designing model is pre-translated by turning electrical interface to equivalent digital model. Then the digital model is turned into computer language. At last, optimal design rules and method are extracted according to improved greedy algorithm. Real project data are used to prove the feasibility and validity of the proposed method.

1 Introduction

Matrix circuit including matrix telemetry and command is a core technology of on-board integrated electronic technology [1] to reduce the amount of electronic components and cables. This technology is widely used in all kinds of satellites to observably lose the weight of satellite platform. The devices with matrix telemetry and command can be connected with integrated electronic subsystem by matrix cable to send commands and receive telemetries. Matrix cable design has great possibility to be improved by reducing the usage of cables because matrix circuit usually has a large number of brunches which may cause the redundancy of design.

Consequently, an improved greedy algorithm based matrix satellite cable optimal design method in presented in this paper aim to overcome the difficulties listed above. Computer based design can acquire correct and preferred outcome, meanwhile, improve the work efficiency.

2 Matrix cable contact design principle

Matrix command contact circuit comprises command drive device and command load device. Command drive device can control $m \times n$ pieces of load device by control m row cables and n column cables [2]. It takes $2(m+n)$ cables to control $m \times n$ pieces of load device if backup is included. Matrix telemetry contact circuit is using the same principle. Matrix cable contact design principle is to build a point-to-point mapping relation between drive devices and load devices. By building a physical cable connection, drive devices can control load devices to executive commands and receive telemetries.

3 Improved greedy algorithm based satellite matrix cable connection optimal design

1.1 Design model pre-processing

Circuit model is tuned into structural digital model to achieve optimal design. Assuming that a command load device has 9 matrix commands controlled by 3 row cables and 3 column cables, it can be shown as

$$M_{RC} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix}. \text{ Similarly, drive device can be shown as } N_{RC} = \begin{bmatrix} N & \dots & N \\ \vdots & \ddots & \vdots \\ N & \dots & N \end{bmatrix}_{R \times C}.$$

From the knowledge mentioned above, row 1 and column 1 take control of M_{11} . According to the principle, circuit connection can be translate into mapping relation between drive device model and load

$$\text{device model. If } N_{RC} = \begin{bmatrix} N & \dots & N \\ \vdots & \ddots & \vdots \\ N & \dots & N \end{bmatrix}_{5 \times 5}, \text{ the relation can be shown as } \begin{bmatrix} N & M & M & M & N \\ N & M & M & M & N \\ N & M & M & M & N \\ N & N & N & N & N \\ N & N & N & N & N \end{bmatrix}.$$

1.2 Formula expression of design model

* Corresponding author: wyywangyiyi@126.com

Formula expression of design model is $\{Rx, Cy, k\}$.

Rx represents for row cable, Cy represents for column cable, k represents for the number of matrix model on one device.

1.3 Improved greedy algorithm based matrix cable connection optimal design method

Optimal design is achieved by algorithm based programming on the basis of digital model and formula expression input.

A greedy algorithm does not consider the overall result, but aim to find a partial optimum. In most cases, a greedy strategy follows an optimal principle and takes partial optimum step by step. The greedy algorithm structure is as follows.

Beginning with an original solution for a problem,

While (making one step forward to final goal)

{

Use available strategies to find a solution

}

Get a final solution by combining all the solutions

VLSI routing problem^[3] and 2D packing problem^[4] chooses different row cable and column cable will get different matrix connections. Travelling salesmen problem^[5] has capacity restriction and mutual restriction. Unlike VLSI or TSP problem, this case is a 2D vehicle routing problem^[6] with confliction and capacity restriction. To solve this problem, this article raised an improved greedy algorithm with complexity of $O(M*n)$. M represents the maximum of row or column, N represents the amount of matrix.

1.3.1 Optimal Design rules summary

Step 1 List all Matrix signals. $\{T\}$ is the set of telemetries; $\{C\}$ is the set of commands. $\{T_M\}$ is the set of matrix telemetries; $\{C_M\}$ is the set of matrix commands. $T_M \in T$, $C_M \in C$. $\{T_M\}$ and $\{C_M\}$ should be managed separately.

Step 2 Separate all devices into different sections. Put devices into corresponding section lists by recognize their coordinates.

$$T_M \begin{cases} \text{South Part} \begin{cases} +X \\ -X \end{cases} \\ \text{North Part} \begin{cases} +X \\ -X \end{cases} \end{cases} \quad C_M \begin{cases} \text{South Part} \begin{cases} +X \\ -X \end{cases} \\ \text{North Part} \begin{cases} +X \\ -X \end{cases} \end{cases}$$

Definition 1 T_{Max} is the matrix telemetry with maximum of row or column in $\{T_M\}$.

Definition 2 C_{Max} is the matrix command with maximum of row or column in $\{C_M\}$.

Definition 3 T_{Sum} is the matrix telemetry with maximum sum of row and column in a specific set of telemetries.

Definition 4 C_{Sum} is the matrix command with maximum sum of row and column in a specific set of commands.

Step 3 Find T_{Max} and C_{Max} . If there are more than one T_{Max} or C_{Max} , we get $\{T_{Max}\}$ or $\{C_{Max}\}$. Then we find T_{Sum} or C_{Sum} . If there are more than one T_{Sum} or C_{Sum} , the priority is random.

Rule 1 Using row cable is prior to column cable if the total increment and partial increment are fixed.

Definition 5 If one device has been appointed to be D_{Aim} , algorithm cannot move on to other device until all the matrix signals are allocated.

Definition 6 The set of all matrix telemetries of D_{Aim} except T_{Max} is T_{Next} . The set of all matrix commands of D_{Aim} except C_{Max} is C_{Next} .

Step 4 When T_{Max} or C_{Max} is chosen, the device T_{Max} or C_{Max} becomes D_{Aim} . T_{Next} of C_{Next} must be assembled with T_{Max} or C_{Max} to get the minimum sum of rows and columns in order to use cables as less as possible.

Definition 7 The set of devices on the same branch of D_{Aim} except D_{Aim} is $\{D_{Next}\}$.

Definition 8 T_{Aim} or C_{Aim} is the matrix signal which is going to be allocated then.

Step 5 When finished D_{Aim} , repeat step 3 and 4 for $\{D_{Next}\}$.

Rule 2 The second junction point is the flag of where a branch starts.

Rule 3 If there are more than one position with minimum cost increment, length increment is the solution to find the best choice.

Step 6 When $\{D_{Next}\}$ is finished, repeat step 1 to 5 for the rest.

Rule 4 Choose matrixes which have the same structure as T_{Aim} or C_{Aim} to assemble if priority cannot be recognized so that unnecessary blank can be avoided as far as possible. This rule is also made to reduce the usage of cable and shorten cable length.

Step 7 After all matrix signals were allocated, do a final check to see if any adjustment can be done to get a better result.

1.3.2 Improved greedy algorithm based matrix cable connection optimal design

Definition 9 $S_{R \times C}$ is the capacity of matrix cable allocation.

Definition 10 $\Delta Cost$ is the cost increment when choosing position.

Definition 11 $\Delta Length$ is the length increment.

Definition 12 P is insertion point. P is on the first line and first row of T_{Aim} or C_{Aim} .

$$\begin{bmatrix} C & \dots & C \\ \vdots & \ddots & \vdots \\ C & \dots & C \end{bmatrix}_{16 \times 24}$$

If $S_{R \times C} = \begin{bmatrix} C & \dots & C \\ \vdots & \ddots & \vdots \\ C & \dots & C \end{bmatrix}_{16 \times 24}$, 16 row lines and 24 column lines can be shown in a sketch map as follows. In figure 1, judgment flags as TRUE or FALSE are set at junction point, such as M, N, P.

According to figure 1, $C_{Max} = \begin{bmatrix} C & C & C & C \\ C & C & C & C \\ C & C & C & C \end{bmatrix}_{4 \times 4}$, $\{C_{Next}\}$ has $\begin{bmatrix} C_{N1} & C_{N1} \end{bmatrix}_{1 \times 2}$ and $\begin{bmatrix} C_{N2} & C_{N2} \end{bmatrix}_{1 \times 2}$. We can get $\begin{bmatrix} C & C & C & C \\ C & C & C & C \\ C & C & C & C \\ C & C & C & C \end{bmatrix}$ to make $\Delta Cost$ least. Now, $C_{Max} = \begin{bmatrix} C & C & C \\ C & C & C \\ C & C & C \end{bmatrix}$. P has 10 probable positions as $\begin{bmatrix} C & C & C & C & P \\ C & C & C & C & P \\ C & C & C & C & P \\ C & C & C & C & P \\ C & C & C & C & P \\ P & P & P & P & P \end{bmatrix}$. To make both $\Delta Cost$ and $\Delta Length$ least, the final position is $\begin{bmatrix} C_{Max} & C_{Max} & C_{Max} & C_{Max} & C_{Aim} & C_{Aim} & C_{Aim} \\ C_{Max} & C_{Max} & C_{Max} & C_{Max} & C_{Aim} & C_{Aim} & C_{Aim} \\ C_{Max} & C_{Max} & C_{Max} & C_{Max} & C_{Aim} & C_{Aim} & C_{Aim} \\ C_{Max} & C_{Max} & C_{Max} & C_{Max} & C_{Aim} & C_{Aim} & C_{Aim} \\ C_{N1} & C_{N1} & C_{N2} & C_{N2} & & & \end{bmatrix}$.

Total cable length that C_{Max} used: $8 \times QA = 8 \times 8 = 64$

Figure 1 Cable layout sketch map

C_{N1} and C_{Max} belong to the same device, they share same column lines. C_{N1} brings a new row line. So $\Delta Cost = 1$, $\Delta Length = QA = 8$. Then C_{N2} and C_{Max} belong to the same device, C_{N2} share the same column lines with C_{Max} , meanwhile, share the same row line with C_{N1} . So $\Delta Cost = 0$, $\Delta Length = 0$. Total length of D_{Aim} is $64 + 8 = 72$. In $\{D_{Next}\}$,

$$C_{Max} = \begin{bmatrix} C & C & C & C \\ C & C & C & C \\ C & C & C & C \end{bmatrix}, \quad \Delta Cost = 0 + 3 = 3, \quad \Delta Length = 4 \times NB + 3 \times BQ = 4 \times 8 + 3 \times 14 = 32 + 52 = 84.$$

After D_{Aim} is allocated, the judgment flags of M and N turned to TRUE as shown in figure 2 because these junction points have been used once. When moving to next step, algorithm searches the first TRUE point to the direction back to the driver. At last, we got

Figure 2 branch judgment flag

4 Design example

4.1 Programming

Interface 1 CountWidth

Interface 2 HeightComparator

Interface 3 Cell

Interface 4 SortCellUtil

The programming sturcture for interfaces is showed in figure 3.

Figure 3 structure sketch

Figure 4 Programming logic

4.2 Real project data verification

Figure 5 Optimal design result

Comparing with original design result, the optimal design result reduces total cable weight by 8% which is 0.416 kg.

5 Conclusion

An improved greedy algorithm based matrix cable connection optimal design method is proposed in this article and the method is tested by real data project to prove its reasonableness and effectiveness. The result shows that optimal design result reduced weight by 8% comparing with original design result. Some complicated situation may occur in real projects such as branch terminals and layout adjustments. Later we will make further improvement of this optimal design method.

Acknowledgments

This work has been supported by Project of the Program of National Natural Science Foundation of China under the Grant Number 61471360.

This work has been supported by the 13th Five-Year Plan Pre-research special technology project from Space System Division.

References

1. Mingfeng Li, Yanyan Hao, Xiao Chen. New telecommunication satellite integrated electronic system research [J]. Space International, 6, 46-50,(2013)

2. Ke Zong, Zhifu Wang, Hangyan Xu. Optimal Mechatronic Design Research for Matrix Cables Used on Satellite [J]. Spacecraft Engineering,8(26),15-21 (2017)
3. Xiaoping Tang, Ruiqi Tian, and Martin D.F.Wong. Minimizing wire length in floorplanning[J]. IEEE Transaction on Computer-Aided Design of Integrated Circuits and Systems, 25(9), 1744-1753,(2006)
4. Gerhard Wäscher, Heike Haubner, Holger Schumann. An improved typology of cutting and packing problems [J]. European Journal of Operational Research, 183(3), 1109-1130,(2007)
5. Tolga Bektas, The multiple traveling salesman problem: An overview of formulations and solution procedures [J]. Omega, 34(3),209-219,(2006)
6. Kris Braekers, Katrien Ramaekers, Inneke Van Nieuwenhuyse. The vehicle routing problem: State of the art classification and review [J]. Computers & Industrial Engineering, 99,300–313,(2016)