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用信息扩散估计进行水准网平差*

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摘 要 信息扩散估计(ISE)是一维参数估计中的较好方法,但不便于直接推广到多维参数估计中去。本文根据水准测量的特点,巧妙地将其推广到水准网平差这一多维参数估计中,部分地解决了信息扩散估计在测量数据处理中的应用问题。

关键词 信息扩散估计;水准网平差;分布

分类号 P207 文献标识码 A

在实际参数估计中,人们不是选用最小二乘估计,就是选用抗差估计。但由于不知道观测值的分布 $f(L)$,选用最小二乘估计可能使估计结果受到粗差的污染;而选用抗差估计,当不含粗差时,又会使估计结果不如最小二乘估计。为了使参数估计既不受粗差影响,又能得到最优无偏估计,文献[1]根据信息扩散原理提出了信息扩散估计。该方法是一维参数估计中的较好方法,且具有很好的抗差性。然而,由于该方法本身的限制,不便于直接推广到多维参数估计中去,而测量中的参数估计几乎全是多维参数估计的情况,这样就制约了信息扩散估计在测量数据处理中的应用。为了使这一好的估计方法能在测量数据处理中得到应用,笔者进行了大量研究,并根据水准测量的特点,成功地将信息扩散估计应用于水准网平差。

1 信息扩散估计简介

信息扩散估计就是对于一组观测值 L,先估计其分布 $f(L)$,公式为:

$$f(L)=\frac{1}{nh\sqrt{2\pi}}\sum_{j=1}^{n}\exp\left(-\frac{(L-L_j)^2}{2h^2}\right) \tag{1}$$

式中,L 为观测值;n 为观测值的个数;$h=\alpha(L_{\max}-L_{\min})/(n-1)$,系数 α 的取值见文献[1]。

然后再根据 $f(L)$ 采用任何一种现行的估计方法进行参数估计。文献[1]采用的是根据观测值 L 的分布 $f(L)$ 定权的最小二乘估计。

由式(1)知,观测值 L 的分布 $f(L)$ 与最大观测值 $L_{\max}$、最小观测值 $L_{\min}$ 和观测值的个数 n 有关,其计算非常简单。因此,这就要求观测值 L 必须是同一类观测值,且在理想状态下,各观测值应有相同的数学期望,即 $E(L_i)=\mu$。这一要求就限制了式(1)在测量数据处理中的应用。因为除对同一个量进行 n 次重复观测外,测量数据处理中的观测值一般不可能具有相同的数学期望。因此,要将式(1)应用于测量数据处理,还必须进行更深入的研究。

2 在水准网平差中应用的可能性

水准测量中的观测值是各测段的高差,一个水准网由 n 个测段组成。由于这 n 个测段的高差不相等,所以这 n 个观测值不可能有相同的数学期望。但在实际测量中,为了发现错误,规范规定各测段必须往返观测。这样,n 个测段就产生了 n 个往返测较差 d_i。假设在观测过程中两端点没有发生垂直位移,所以各测段的较差理论值应为零,即各测段较差的数学期望 $E(d_i)$ 为零。若将较差 d_i 视为数值0的观测值,则满足式(1)的要求。于是应用式(1)可求出较差 d 的分布 $f(d)$,即

$$f(d)=\frac{1}{nh\sqrt{2\pi}}\sum_{i=1}^{n}\exp\left(-\frac{(d-d_i)^2}{2h^2}\right) \tag{2}$$

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在实际测量中，当较差 d_i 小于规范规定的限差时，总是将往返观测高差的平均值作为该测段的高差观测值 L_i。因此，d_i 在分布 $f(d)$ 中的概率 $f(d_i)$ 越大，L_i 在分布 $f(L)$ 中的概率 $f(L_i)$ 也越大，于是就可以根据分布 $f(d)$ 来确定观测值 L_i 的权，然后再采用最小二乘平差。这样，就可将信息扩散估计顺利地应用于水准网平差中。

3 应用举例

武汉市轨道交通一号线一期工程水准网如图1所示，各测段往返较差如表1所示。由表1中的较差 d 按式(2)求得的分布 $f(d)$ 为：

$$f(d)=0.078\,173\,712\,91\sum_{j=1}^{39}\exp\cdot[-29.201\,191\,08(d-d_j)^2] \tag{3}$$

令

$$f(d_i)=0.078\,173\,712\,91\sum_{j=1}^{39}\exp\cdot[-29.201\,191\,08(d_i-d_j)^2]$$

按 $p_i=f(d_1)/f(d_i)$ 定权(即按分布定权)，见表1，其平差结果列于表2。由表2知，当无粗差污染时，按分布定权的平差结果与按距离定权的平差结果相差甚微。当在观测值3和观测值34中加上10mm的粗差时，按传统的平差方法(即按距离定权的最小二乘估计)的平差结果受到粗差污染，且有粗差污染时各点的高程中误差是无粗差污染时的两倍以上。而按分布定权的平差结果

表1 观测值及较差

Tab.1 Observations and Difference

序号	测段名	较差 d_i/mm	观测值 L_i/m	距离 S_i/km	按分布定权 p_i	按距离定权 p_i
1	Wu16—H31	−0.48	0.977 6	0.329	1.000 0	1.000 0
2	Wu16—GPS25	1.60	0.880 1	0.696	0.412 0	0.472 7
3	H31—GPS25	0.95	−0.098 7	0.345	1.948 4	0.953 6
4	GPS24—GPS22	−0.65	0.468 2	0.855	1.211 0	0.384 8
5	GPS20—GPS27	−0.50	−0.770 4	0.632	1.077 5	0.520 6
6	GPS22—GPS20	−0.60	−0.438 1	1.097	1.266 7	0.299 9
7	GPS23—GPS21	0.75	−0.874 6	0.990	1.564 1	0.332 3
8	GPS27—GPS21	0.18	−0.103 4	1.102	2.409 1	0.298 5
9	GPS27—H22	0.25	−2.910 1	0.884	1.954 5	0.372 2
10	H22—GPS16	−0.65	0.398 3	0.821	1.211 0	0.400 7
11	GPS16—GPS17	0.65	−0.614 3	0.366	1.288 1	0.898 9
12	GPS19—GPS20	0.95	0.367 0	0.967	1.948 4	0.340 2
13	GPS17—GPS19	0.20	3.528 9	0.977	2.291 2	0.330 0
14	GPS17—GPS15	1.40	0.873 4	0.661	0.913 8	0.497 7
15	GPS16—GPS14	0.43	−0.602 6	0.693	1.030 7	0.474 7
16	H17—GPS15	0.03	−0.525 0	0.786	2.493 6	0.418 6
17	H17—GPS12	0.08	1.600 7	0.366	2.656 7	0.898 9
18	GPS12—GPS14	1.12	−2.989 5	0.792	1.554 5	0.415 4
19	H17—GPS11	0.68	0.789 1	0.665	1.379 0	0.494 7
20	GPS24—GPS23	1.30	0.034 0	0.463	1.186 1	0.710 6
21	GPS12—GPS10	−1.18	0.063 7	0.546	0.565 4	0.602 6
22	H13—GPS08	−0.82	−0.383 2	0.356	0.625 4	0.924 1
23	H13—GPS11	1.03	−1.998 9	0.669	1.831 3	0.491 8
24	GPS10—GPS08	0.20	0.740 9	0.780	2.291 2	0.421 8
25	GPS06—H13	0.40	−1.509 0	0.865	1.116 7	0.380 3
26	H8—GPS06	1.20	2.822 2	1.183	1.364 6	0.278 1
27	H9—H11	0.00	0.425 0	0.772	2.306 2	0.426 2
28	H11—GPS08	0.00	−1.514 2	0.263	2.306 2	1.251 0
29	H8—H9	−0.10	2.020 0	0.679	1.412 2	0.484 5
30	H6—H8	0.10	−1.548 4	0.878	2.665 1	0.374 7
31	H5—H6	0.10	0.554 2	0.203	2.665 1	1.620 7
32	H7—H9	0.70	1.893 8	0.976	1.435 7	0.337 1
33	H4—H7	0.90	0.073 8	0.518	1.907 8	0.635 1
34	H4—H5	−1.20	0.943 2	0.136	0.563 1	2.419 1
35	H2—H5	1.30	0.466 0	1.862	1.186 1	0.180 2
36	H1—H2	1.00	−0.030 7	0.983	1.900 1	0.334 7
37	Wu15—H1	−1.90	1.034 6	0.883	0.281 0	0.372 6
38	GPS23—GPS25	0.03	−1.587 4	0.842	2.493 6	0.390 7
39	H31—GPS24	0.90	1.455 2	0.750	1.907 8	0.438 7

表 2　平差结果

Tab. 2　The Results of Adjustment

水准点名	无粗差影响				有粗差影响			
	按距离定权		按分布定权		按距离定权		按分布定权	
	H_i/ m	σ_i/ mm	H_i/ m	σ_i/ mm	H_i/ m	σ_i/ mm	H_i/ m	σ_i/ mm
Wu15	23.624 0		23.624 0		23.624 0		23.624 0	
Wu16	22.643 0		22.643 0		22.643 0		22.643 0	
H1	24.657 3	±1.4	24.653 7	±2.4	24.657 7	±3.7	24.656 3	±2.1
H2	24.625 1	±1.9	24.622 3	±2.5	24.625 9	±5.1	24.624 5	±2.5
H5	25.088 3	±2.4	25.087 1	±2.5	25.090 0	±6.2	25.089 4	±2.7
H6	25.642 2	±2.4	25.640 8	±2.6	25.643 3	±6.3	25.642 3	±2.8
H4	24.145 1	±2.4	24.143 8	±2.8	24.135 7	±6.3	24.143 7	±3.7
H8	24.092 8	±2.5	24.091 9	±2.6	24.090 9	±6.5	24.092 6	±2.9
H9	26.112 2	±2.4	26.111 3	±2.6	26.108 4	±6.4	26.111 9	±3.0
GPS06	26.914 4	±2.5	26.913 6	±2.6	26.912 0	±6.8	26.914 2	±3.0
H13	25.405 0	±2.4	25.404 1	±2.5	25.402 3	±6.4	25.404 7	±2.9
GPS08	25.022 0	±2.4	25.021 4	±2.6	25.019 0	±6.3	25.021 7	±2.9
GPS11	23.405 5	±2.5	23.404 7	±2.5	23.402 9	±6.5	23.405 1	±2.9
H17	22.615 7	±2.4	22.615 0	±2.4	22.613 2	±6.2	22.615 3	±2.8
GPS12	24.216 6	±2.3	24.215 8	±2.4	24.214 1	±6.2	24.216 2	±2.8
GPS15	22.089 7	±2.4	22.089 5	±2.4	22.087 4	±6.2	22.089 4	±2.8
GPS17	21.215 4	±2.2	21.214 7	±2.2	21.213 2	±5.8	21.215 0	±2.5
GPS16	21.829 4	±2.2	21.828 7	±2.2	21.827 0	±5.8	21.829 0	±2.6
GPS19	24.743 6	±2.2	24.743 2	±2.1	24.741 7	±5.8	24.743 4	±2.5
GPS20	25.109 9	±1.9	25.109 8	±2.0	25.108 2	±5.1	25.109 8	±2.2
GPS27	24.339 9	±1.9	24.339 8	±1.9	24.338 0	±5.1	24.339 8	±2.2
GPS22	25.546 4	±1.8	25.546 8	±1.9	25.545 4	±4.6	25.546 7	±2.1
GPS24	25.077 1	±1.3	25.077 4	±1.6	25.076 4	±3.4	25.077 4	±1.7
GPS23	25.110 8	±1.3	25.111 0	±1.6	25.108 8	±3.5	25.111 0	±1.7
H31	23.621 2	±0.8	23.621 9	±1.3	23.623 2	±2.1	23.621 6	±1.4
GPS25	23.522 9	±0.9	23.523 4	±1.5	23.518 2	±2.4	23.523 2	±1.5
GPS21	24.236 3	±1.8	24.236 4	±1.9	24.234 4	±4.8	24.236 4	±2.1
H22	21.430 5	±2.2	21.430 0	±2.1	21.428 5	±5.7	21.430 2	±2.5
GPS14	21.227 0	±2.4	21.226 2	±2.4	21.224 6	±6.2	21.226 6	±2.8
GPS10	24.280 6	±2.5	24.280 4	±2.6	24.277 9	±6.4	24.280 4	±3.0
H11	26.536 4	±2.5	26.536 0	±2.6	26.533 3	±6.4	26.536 4	±3.0
H7	24.218 7	±2.5	24.217 6	±2.8	24.211 3	±6.5	24.217 8	±3.4

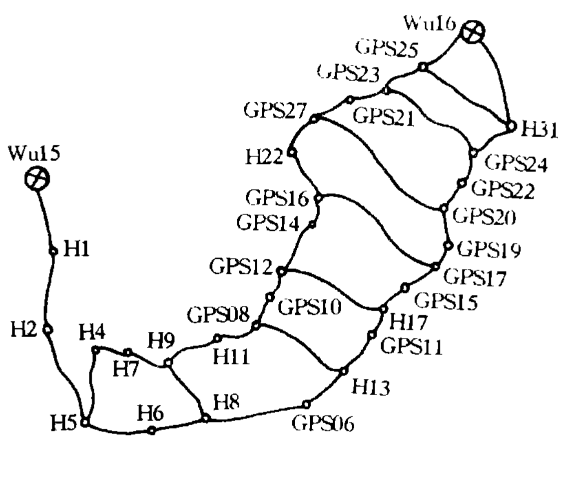

图 1　水准网形示意图

Fig. 1　Leveling Network

仍然与无粗差污染时的平差结果相同。这表明, 信息扩散估计(即按分布定权的平差)具有较好的抗差性, 同时也说明信息扩散估计具有一定的合理性和实用性。

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Adjustment of Leveling Network by Information Spread Estimation

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Abstract It is supposed that observations obey a certain distribution in all the methods of parameter estimation nowadays. But in the practical surveying, due to the different observation conditions, the observations obtained under different observation conditions may obey different distributions. So the supposition is not true. To solve the problem, Wang (1999) has developed an estimation method called information spread estimation, which is a very good estimation method for one parameter. But when the parameters are over one, the estimation method is not suitable. To apply information spread estimation to the adjustment of leveling network, this paper presents a method to use the special feature of leveling. By use of the method information spread estimation can be applied to the adjustment of leveling network conveniently. The results of the adjustment of a leveling network show when gross error is not included in the observations the estimation results obtained by information spread estimation are the same as that by least square estimation. When some gross errors are included in the observations the estimation results obtained by information spread estimation are more effective than the estimation results by least square estimation. So the method presented in this paper is a very useful method for leveling network adjustment.

Key words information spread estimation; adjustment of leveling network; distribution

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the Earth with respect to the nutation frame, which represents the polar motion. Together with the definition of the nutation frame (as the definition of the nutation frame is arbitrary at some extent), one can solve simultaneously for forced and free nutation and polar motion. As demonstrative examples, studies of nutation and polar motion are made by assuming the nutation axis to be the Earth's figure axis, rotation axis and angular momentum axis respectively. And the case of the celestial ephemeris pole is also studied. Particularly, the Tilt-Over-Mode which appears only in mode theory of Earth rotation can also be found in the theory of this paper as well. In summary, this paper gives a new uniformed formulation for the problems of forced and free Earth rotation by introducing an arbitrarily rotating nutation frame. Although no new result is obtained for the phenomenon of Earth rotation, the formulation of the Earth rotation problem of this paper may be advantageous for educational purpose.

Key words Earth rotation equation; nutation; polar motion

GUO Junyi, male, 37, Ph. D, professor. His main research interests are on global geodynamic problems including Earth tides, Earth rotation, Earth gravity field, and physics of the core. He has authored two books and 7 scientific publications.

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