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抑制卡尔曼滤波发散的组合导航算法研究

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摘　要：卡尔曼滤波是一种递推线性最小方差估计算法，在组合导航数据融合中得到了广泛应用；但由于卡尔曼滤波要求系统模型和噪声统计特性精确已知，而实际中很难做到，因此常常出现滤波发散现象。鉴于此，着重研究了衰减记忆自适应卡尔曼滤波和渐消记忆卡尔曼滤波在 INS/GPS 组合导航中的应用，并通过对仿真数据的处理，验证了两种滤波算法在抑制滤波发散、提高组合导航系统精度和稳定性方面的可行性。

关键词：组合导航；卡尔曼滤波；渐消记忆
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惯性导航系统是一种完全自主的导航系统，不受外界干扰，能实现全天候、全球范围内的导航，提供三维的位置、速度和姿态信息，数据更新频率高；但受限于制造工艺，若较长时间工作，将导致导航、定位精度越来越差，直至难以容忍。卫星导航系统是一种全球性、全天候、高精度的导航系统，误差不随时间积累，且价格低廉，但卫星信号易受电磁波干扰和高大建筑物遮挡，高动态时卫星信号容易失锁。将这两种导航系统相结合，取长补短，再通过适当算法对数据进行滤波处理，就能减小系统误差，提高系统性能，组成一个精度高、成本低、体积小的导航系统。

组合导航数据处理最常用的方法是卡尔曼滤波技术。理想情况下，卡尔曼滤波为线性无偏最小方差估计；但实际中由于各种原因影响，滤波器可能会出现发散现象。若描述系统动力学特性的数学模型和噪声的统计模型不准确、不能真实反映物理过程，将导致模型与获得的量测值不匹配，估计值相对于实际被估计值的偏差越来越大，使得滤波器逐渐失去其估计作用，这就限制了卡尔曼滤波的应用。针对卡尔曼滤波的发散现象，本文采用衰减记忆自适应卡尔曼滤波和渐消记忆卡尔曼滤波算法，通过构造不同的加权因子、增加当前量测值的权重来抑制滤波发散。

1　卡尔曼滤波基本原理

卡尔曼滤波理论是由美国工程师 Kalman R E 于 1960 年首次提出的，是一种递推线性最小方差估计算法。假设被估计系统的方程为[1]：

$$X_k = \boldsymbol{\Phi}_{k,k-1} X_{k-1} + \boldsymbol{\Gamma}_{k,k-1} W_{k-1} \tag{1}$$

$$Z_k = \boldsymbol{H}_k X_k + V_k \tag{2}$$

式中，$\boldsymbol{\Phi}_{k,k-1}$ 为 $k-1$ 时刻到 k 时刻的状态一步转移矩阵；$\boldsymbol{\Gamma}_{k-1}$ 为 $k-1$ 时刻的系统噪声驱动矩阵；W_{k-1} 为 $k-1$ 时刻的系统噪声序列；$\boldsymbol{H}_k$ 为观测矩阵；Z_k 为 k 时刻的系统量测值；V_k 为 k 时刻的系统量测噪声序列。

其中，W_k 和 V_k 是相互独立的，且属于零均值白噪声序列，满足以下关系：

$$\begin{cases} E(W_k)=0 \quad E(V_k)=0 \quad \operatorname{cov}(W_k,V_j)=0 \\ \operatorname{cov}(W_k,W_j)=E(W_k W_j^{\mathrm{T}})=Q_k\delta_{kj} \\ \operatorname{cov}(V_k,V_j)=E(V_k V_j^{\mathrm{T}})=R_k\delta_{kj} \\ \delta_{kj}=\begin{cases}1 & k=j\\ 0 & k\neq j\end{cases} \end{cases} \tag{3}$$

根据卡尔曼滤波方程的估值准则、系统方程、量测方程以及噪声统计特性，可得到对状态量 X_k 估计值 $\hat{X}_k$ 的基本过程[1]。

1）状态一步预测方程为：

$$\hat{X}_{k,k-1} = \boldsymbol{\Phi}_{k,k-1} \hat{X}_{k-1} \tag{4}$$

式中，$\hat{X}_{k,k-1}$ 为对 X_k 的一步预测，是根据最小方差估计原则利用 $k-1$ 时刻和以前的量测值计算得到的。

2）系统状态估计计算方程为：

$$\hat{X}_k = \hat{X}_{k,k-1} + K_k\left(Z_k - \boldsymbol{H}_k \hat{X}_{k,k-1}\right) \tag{5}$$

式中，$\hat{X}_k$ 为对 X_k 的最小方差估计，是在一步预测的基础上对残差进行加权计算得到的。

$$\begin{aligned} Z_k - \boldsymbol{H}_k \hat{X}_{k,k-1} &= \boldsymbol{H}_k X_k + V_k - \boldsymbol{H}_k \hat{X}_{k,k-1} = \\ &\boldsymbol{H}\hat{X}_{k,k-1} + V_k \end{aligned} \tag{6}$$

其中含有状态一步预测误差信息，被称为测量一步预测误差，又称新息。

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3）卡尔曼滤波增益方程为：

$$K_k = P_{k,k-1}\boldsymbol{H}_k^{\mathrm{T}}\left(\boldsymbol{H}_k P_{k,k-1}\boldsymbol{H}_k^{\mathrm{T}} + R_k\right)^{-1} \tag{7}$$

4）一步预测均方误差方程为：

$$P_{k,k-1} = \boldsymbol{\Phi}_{k,k-1}P_{k-1}\boldsymbol{\Phi}_{k,k-1}^{\mathrm{T}} + \boldsymbol{\Gamma}_{k-1}Q_{k-1}\boldsymbol{\Gamma}_{k-1}^{\mathrm{T}} \tag{8}$$

5）均方误差方程为：

$$P_k = \left(I - K_k\boldsymbol{H}_k\right)P_{k,k-1} \tag{9}$$

2　卡尔曼滤波发散修正的组合导航算法

2.1　衰减记忆自适应卡尔曼滤波

当系统模型不够准确时，新的量测值对系统状态估值的作用就会降低，而陈旧量测值对状态估值的修正作用就会相应增加，即系统不能很好地利用新的量测值对估计值进行修正，从而导致滤波发散现象的发生，因此可以考虑通过逐渐增大新的量测值权重的方法来抑制滤波发散[2]。

通常通过增大一步预测均方误差 $P_{k,k-1}$ 来增加系统对量测值的依赖。常用的方法是在公式 $P_{k,k-1}=\boldsymbol{\Phi}_{k,k-1}P_{k-1}\boldsymbol{\Phi}_{k,k-1}^{\mathrm{T}}+\boldsymbol{\Gamma}_{k-1}Q_{k-1}\boldsymbol{\Gamma}_{k-1}^{\mathrm{T}}$ 中加一个标量因子 S（$S>1$）。具体方程为：

$$\begin{cases} \hat{X}_{k,k-1}^{*} = \boldsymbol{\Phi}_{k,k-1}\hat{X}_{k-1}^{*} \\ \hat{X}_k^{*} = \hat{X}_{k,k-1}^{*} + K_k^{*}\left(Z_k - \boldsymbol{H}_k\hat{X}_{k,k-1}^{*}\right) \\ K_k^{*} = P_{k,k-1}^{*}\boldsymbol{H}_k^{\mathrm{T}}\left(\boldsymbol{H}_k P_{k,k-1}^{*}\boldsymbol{H}_k^{\mathrm{T}} + R_k\right)^{-1} \\ P_{k,k-1}^{*} = \boldsymbol{\Phi}_{k,k-1}\left\lfloor SP_{k-1}^{*}\right\rfloor\boldsymbol{\Phi}_{k,k-1}^{\mathrm{T}} + \boldsymbol{\Gamma}_{k-1}Q_{k-1}\boldsymbol{\Gamma}_{k-1}^{\mathrm{T}} \\ P_k^{*} = \left(I - K_k^{*}\boldsymbol{H}_k\right)P_{k,k-1}^{*} \end{cases} \tag{10}$$

由于 $S>1$，因此总有 $P_{k,k-1}^{*}>P_{k,k-1}$，进而可得出 $K_k^{*}>K_k$，这就意味着在衰减记忆自适应滤波中，量测值的权重得到了提升，从而抑制了滤波发散。然而，若标量因子始终保持不变，就不能很好地减弱陈旧量测值对估计值的修正作用。本文采用一个加权系数可变的方法来增加当前量测值的权重[3]。取加权系数为：

$$S_k = \frac{1-b^k}{1-b} \tag{11}$$

其中 $0<b<1$，这样不仅能保证 $S_k\geqslant 1$，还能保证 $S_{k+1}>S_k$。S_k 的增大使得 $P_{k,k-1}$ 增大，K_k 的范数也随之增大，便于系统更好地利用新的量测值对估值进行修正。一步预测均方误差方程可改写为：

$$P_{k,k-1}^{*} = \boldsymbol{\Phi}_{k,k-1}\left\lfloor S_k P_{k-1}^{*}\right\rfloor\boldsymbol{\Phi}_{k,k-1}^{\mathrm{T}} + \boldsymbol{\Gamma}_{k-1}Q_{k-1}\boldsymbol{\Gamma}_{k-1}^{\mathrm{T}} \tag{12}$$

然而，在衰减记忆自适应卡尔曼滤波方程中，b 的选择是一个难点，由于不可能准确知道系统的先验信息，因此一般采用尝试的方式选取 b 值。

2.2　渐消记忆卡尔曼滤波

鉴于在现实中无法得知系统的先验信息，而衰减记忆自适应卡尔曼滤波中衰减因子的选取需进行尝试，不利于组合导航系统进行实时数据处理，本文研究了一种加权因子自动选取算法，即渐消记忆卡尔曼滤波。

渐消记忆卡尔曼滤波[4]是一种利用渐消因子来限制卡尔曼滤波器的记忆长度，以便充分利用当前观测数据的方法。其一步预测均方误差方程为：

$$P_{k,k-1} = \lambda_k\boldsymbol{\Phi}_{k,k-1}P_{k-1}\boldsymbol{\Phi}_{k,k-1}^{\mathrm{T}} + \boldsymbol{\Gamma}_{k-1}Q_{k-1}\boldsymbol{\Gamma}_{k-1}^{\mathrm{T}} \tag{13}$$

若滤波正常，则取 $\lambda_k=1$；一旦判断滤波发散，则立即使用 λ_k 对 $P_{k,k-1}$ 进行加权计算，使验前协方差矩阵膨胀，从而降低陈旧观测历元数据的使用效率，使得新的观测信息能更好地修正系统误差，恢复滤波。

渐消记忆卡尔曼滤波的关键是渐消因子 λ_k 的确定。λ_k 的确定方法为：

$$\lambda_k = \max\left\{1, \frac{1}{n}abs\left(Tr\left(N_k\right)/Tr\left(M_k\right)\right)\right\} \tag{14}$$

$$\begin{cases} N_k = \boldsymbol{P}_{vk} - \boldsymbol{H}_k\boldsymbol{\Gamma}_{k,k-1}Q_{k-1}\boldsymbol{\Gamma}_{k,k-1}^{\mathrm{T}}\boldsymbol{H}_k^{\mathrm{T}} - R_k \\ M_k = \boldsymbol{H}_k\boldsymbol{\Phi}_{k,k-1}P_k\boldsymbol{\Phi}_{k,k-1}^{\mathrm{T}}\boldsymbol{H}_k^{\mathrm{T}} \end{cases} \tag{15}$$

式中，$\boldsymbol{P}_{vk}$ 为预测残差的协方差矩阵。

v_k 为 $\hat{X}_k$ 的残差向量，表达式为：

$$\boldsymbol{P}_{vk} = E\left(v_k v_k^{\mathrm{T}}\right) = \sum_i^k v_i v_i^{\mathrm{T}} \tag{16}$$

$$v_k = Z_k - \boldsymbol{H}_k X_{k,k-1} \tag{17}$$

渐消因子的算法在理论上具有最优性[5]。当预报残差增大时，必然会引起协方差矩阵增大，从而使得渐消因子增大；可通过渐消因子影响一步预测均方误差的大小，使得增益矩阵增大，以便能更好地利用当前的系统量测值。

3　组合导航算例分析

3.1　仿真结果

以 IMU/GPS 组合导航系统为例，仿真包括轨迹仿真、GPS 仿真和 IMU 输出仿真[6]；仿真轨迹包括匀速运动，加、减速运动，以及东、北、天向速度的突然增加和减少，并对 IMU 的输出增加了高频噪声[7]。初始位置为 108°E、39°N，高度为 205.879 5 m，初始航向角为 30″，初始速度为 −71.005422941.00500000.0000000 m/s，仿真时间为 2 000 s，GPS 采样频率为 1 Hz，IMU 采样频率为 100 Hz。假设 3 个陀螺仪和加速度计的误差特性一致，其中陀螺噪声中的陀螺漂移为 0.1°/h，陀螺时间相关漂移为 0.1°/h，加速度计零偏为 0.1 mgal；平台初始误差角为

30″，位置误差为 10 m，速度误差为 0.2 m/s。仿真轨迹如图 1、2 所示。

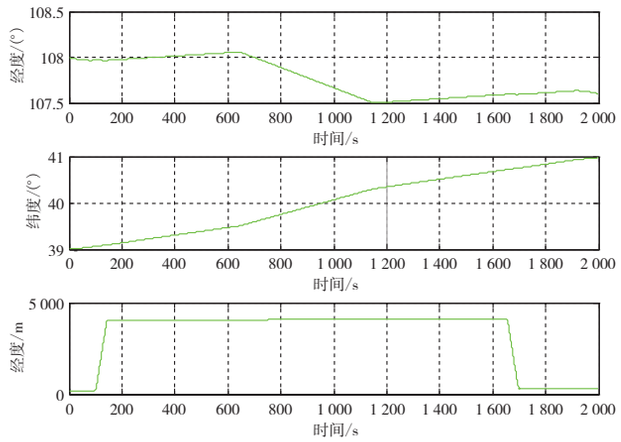

图 1　仿真位置图

为了研究不同组合导航算法的数据处理结果，本文采用经典卡尔曼滤波法、衰减记忆自适应卡尔曼滤波法、渐消记忆卡尔曼滤波法 3 种方法对仿真数据进行处理。3 种滤波算法采用的是位置、速度工作模式，用反馈校正的方式对系统进行校正 [8]。

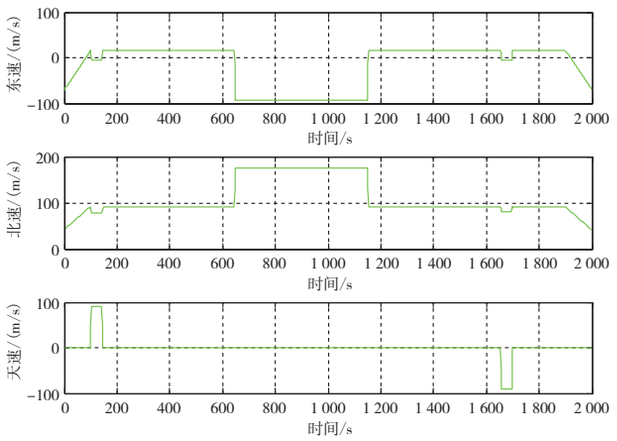

图 2　仿真速度图

在东北天坐标系中，取状态矢量 X_k 为：

$$X_k=\left[\phi_E\ \ \phi_N\ \ \phi_U\ \ \delta V_E\ \ \delta V_N\ \ \delta V_U\ \ \delta\varphi\ \ \delta\lambda\ \ \delta h\ \ \varepsilon_{bx}\ \ \varepsilon_{by}\ \ \varepsilon_{bz}\ \ \varepsilon_{rx}\ \ \varepsilon_{ry}\ \ \varepsilon_{rz}\ \ \nabla_x^b\ \ \nabla_y^b\ \ \nabla_z^b\right]^{\mathrm{T}} \tag{18}$$

式中，ϕ_E、ϕ_N、ϕ_U、δV_E、δV_N、δV_U、$\delta\varphi$、$\delta\lambda$、δh 为捷联惯导系统的姿态、速度、位置误差；ε_{bx}、ε_{by}、ε_{bz} 为陀螺仪的 3 个随机常值漂移；ε_{rx}、ε_{ry}、ε_{rz} 为一阶马尔科夫过程漂移；∇_x^b、∇_y^b、∇_z^b 为加速度计随机常值漂移。

设置矢量 W 为：

$$W=\left[\omega_{gx}\ \ \omega_{gy}\ \ \omega_{gz}\ \ \omega_{bx}\ \ \omega_{gy}\ \ \omega_{gz}\ \ \omega_{ax}\ \ \omega_{ay}\ \ \omega_{az}\right]^{\mathrm{T}} \tag{19}$$

式中，ω_{gx}、ω_{gy}、ω_{gz} 为陀螺仪随机白噪声漂移；ω_{bx}、ω_{by}、ω_{bz} 为一阶马尔科夫驱动白噪声；ω_{ax}、ω_{ay}、ω_{az} 为加速度计随机白噪声漂移。

组合后位置速度误差如图 3～8 所示。

3.2　结果分析

通过比较 3 种滤波算法的 RMS 误差（表 1），可得到的结论为：

1）由于仿真过程中对速度进行了突然的加、减速处理，且在短时间内速度加速度较大，导致滤波过程中出现了较大的位置和速度误差，但速度突变完成后，误差又恢复至正常水平，说明上述算法对速度突变的跟踪能力不强。在第 1 900～2 000 s 速度呈缓慢减少趋势，但位置和速度误差均未出现跳变，再次印证了上述结论。

2）经典卡尔曼滤波的位置误差在 30 m 以内，速度误差在 0.3 m/s 以内，但在速度突变时位置误差最大达到 100 m，速度误差也达到了 3 m/s。第 1 200 s 后位置误差和速度误差均值逐渐偏离水平坐标轴，说明滤波逐渐成发散状态。

3）衰减记忆自适应卡尔曼滤波效果略优于经典卡尔曼滤波，其中衰减因子中的 b 是对 RMS 值反复筛选得到的。滤波后位置误差在 20 m 以内，速度误差在 0.2 m/s 以内，且误差成收敛趋势，说明衰减因子 S 对增加新的量测值权重起到重要作用；但在速度突变时误差依然很大。其主要原因是随着滤波步数的增加，在计算机舍入误差的影响下，衰减因子会趋于一个大于 1 的常值，不能根据误差大小进行实时调整，以消除陈旧量测值对系统的修正作用。

4）由于加入了渐消因子，渐消记忆卡尔曼滤波通过新息大小实时调整验前状态协方差矩阵，并使其膨胀相应的倍数，从而降低历史数据的使用效率 [9]。由图 3～8 可知，渐消记忆卡尔曼滤波对数据处理后得到的结果优于其他滤波结果；由表 1 可知，渐消记忆卡尔曼滤波所得的各方向 RMS 值比其他两种方法小很多，说明渐消因子的采用限制了滤波器的记忆长度，提高了新量测信息的使用效率，对滤波发散起到了一定的抑制作用。

表 1　3 种滤波算法的 RMS 比较

RMS	位置/m			速度/(m/s)		
	X 轴	Y 轴	Z 轴	X 轴	Y 轴	Z 轴
经典 Kalman 滤波	7.605	12.217	7.004	0.115	0.248	0.217
衰减记忆自适应 Kalman 滤波 b=0.254	10.142	4.96	6.274	0.136	0.117	0.109
渐消记忆 Kalman 滤波	5.327	3.971	6.251	0.094	0.095	0.102

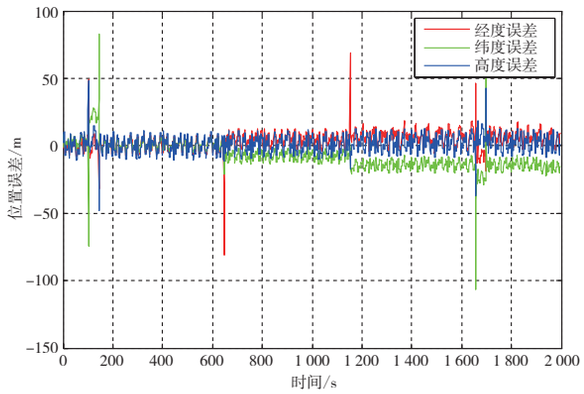

图 3　经典 Kalman 滤波位置误差

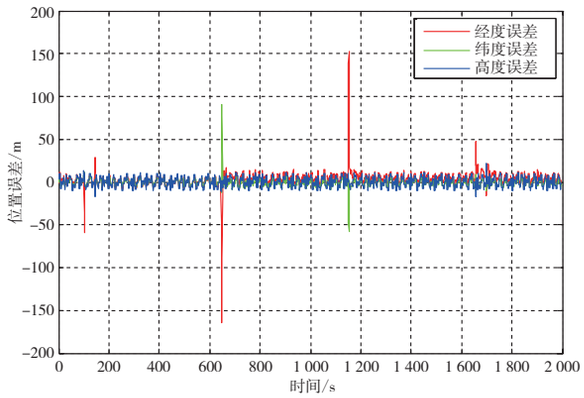

图 4　衰减记忆自适应 Kalman 滤波位置误差（b=0.254）

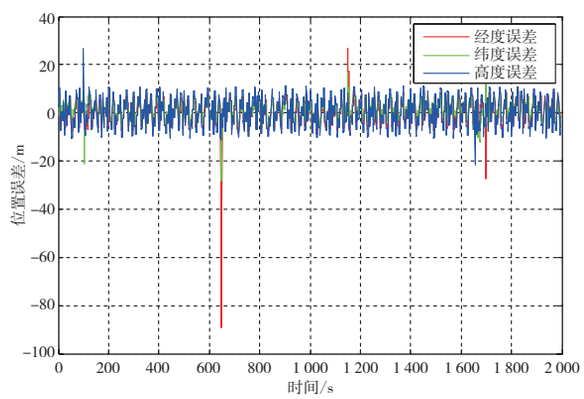

图 5　渐消记忆 Kalman 滤波位置误差图

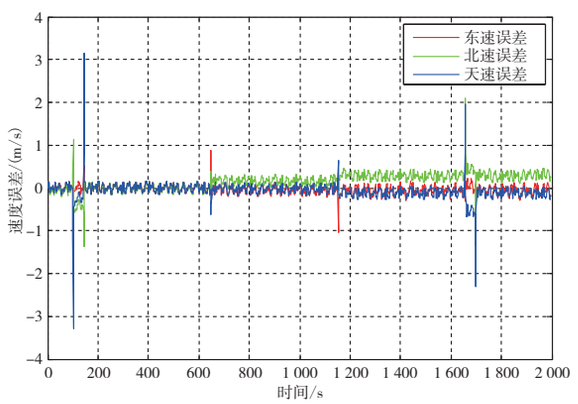

图 6　经典 Kalman 滤波速度误差

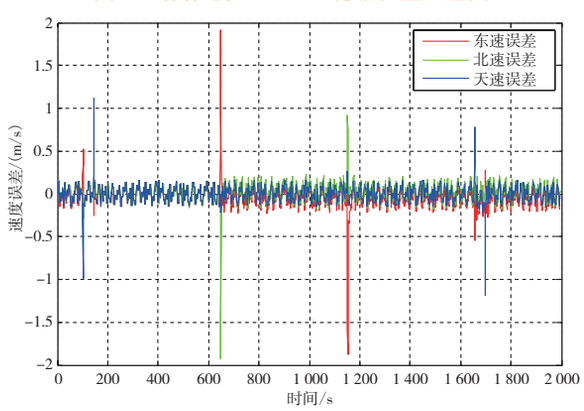

图 7　衰减记忆自适应 Kalman 滤波速度误差（b=0.254）

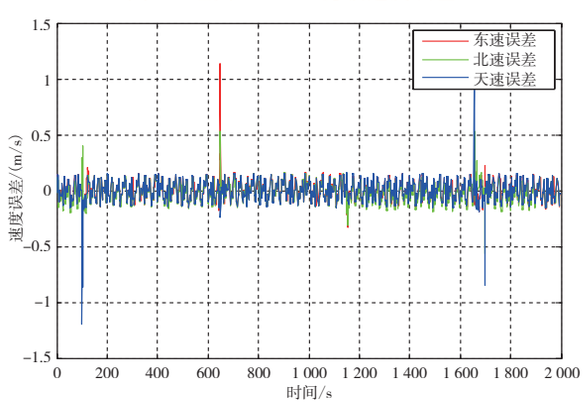

图 8　渐消记忆 Kalman 滤波速度误差

4　结　语

以 IMU/GPS 组合为例，本文分别采用经典卡尔曼滤波、渐消记忆卡尔曼滤波和衰减记忆自适应卡尔曼滤波对仿真数据进行了滤波处理。在仿真数据加入了较大误差的前提下，得到了较好的数据处理结果，并归纳了一些有意义的结论：渐消记忆卡尔曼滤波和衰减记忆自适应卡尔曼滤波能抑制滤波的发散，但在速度的动态跟踪上还存在一些问题。

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Application of 3DGIS + BIM Integrated Technologies in Urban Subway Management Information System by *XIE Mingxia*
Abstract Based on the analysis of application characteristics of 3DGIS and BIM and the existing problems, we integrated BIM and 3DGIS from three aspects, such as data integration, function integration and application integration, and analyzed data integration emphatically. Taking urban subway management information system development of Tiantian Square for example, we described the development and implementation process of 3D basic terrain data generating, Revit data conversion integration, the integrated roaming of the subway and Tiantian Square, the information coordination between 3DGIS and BIM, the spatial management of BIM model, the facilities and component management for integration of 3DGIS and BIM, and emergency management in detail. Thus, we verified the practicability and feasibility of the proposed integration method.
Key words 3DGIS, BIM, integration, urban subway, Tiantian Square (Page:86)

Impact Analysis of High-rise Building Construction in Vertical Deviation of GNSS Positioning Results by *LI Jiangwei*
Abstract In this paper, we used EGM2008 model to calculate the vertical deviations of all municipal jurisdictions in the 34 provincial capitals of the country. The statistical analysis results show that there are differences in vertical deviation between different provincial capitals. There is little difference in the vertical deviation between the municipalities of the provincial capitals in the Northeast, East China, Central China, and South China, and there is a relatively large difference in the vertical deviation between other provincial capitals, especially in some western provincial capitals. The project should make corresponding corrections to the GNSS positioning results, based on the specific numerical values of the vertical deviation of the construction area and the heights of high-rise buildings.
Key words EGM2008, vertical deviation, provincial capital, GNSS, high-rise building (Page:90)

Global Applicability Analysis of Topographic Map Subdivision and Numbering by *LIU Xiaoqiang*
Abstract Starting from the problem in the current topographic map subdivision and numbering work, we briefly expounded the current situation of the topographic map subdivision and numbering in our country, analyzed the problems related to the numbering of the topographic maps in different regions and solutions, and put forward a solution for the topographic map subdivision and numbering problem in the global geographical information resource construction project. It is of great reference significance to realize the unified subdivision and numbering of global topographic maps.
Key words subdivision and numbering, global, topographic map, standard (Page:92)

Rapid Extraction Algorithm of Impervious Surface from Difficult Region by *XIA Yu*
Abstract Difficult regions like arid and semi-arid regions, low-density impervious surface regions and mountainous areas have features such as weak lighting, scattered spatial layout and many surroundings obstructions. At present, the large-scale extraction researches of impervious surface perform badly on difficult region. In order to solve these problems, we proposed a threshold filtering method based on multi-temporal Sentinel SAR data and optical images, supplemented by lights and DEM data. Taking Yan'an Province, southern Vietnam, Dubai and southern Bangladesh as research areas, we extracted the impervious surface, and compared the extraction results with GlobalLand 30 products in 2010. The results show that the average precision and Kappa are above 88.58% and 0.76. It is concluded that the proposed method can enhance the effect of impervious surface extraction, and has a key guiding significance for the large-scale and global impervious surface extraction.
Key words Sentinel SAR, impervious surface, difficult region, Google Earth Engine (Page:95)

Monitoring of Relocation and Reconstruction of Old Industrial Area in Gutian, Wuhan City by *CHENG Qi*
Abstract Based on the multi-phase high resolution remote sensing images, the geographical conditions census and monitoring data, and the data of basic geographical information, land planning, environmental quality, local chronicles and statistical yearbooks, we reviewed the history of the formation, development and relocation of Gutian old industrial area, monitored the changes of land use, housing construction, ecological environment, public facilities and industrial heritage of this area in 2003, 2008, 2014 and 2017, and analyzed the progress and effect of relocation and reconstruction. This study is of referential significance to evaluate the effect of old industrial area reconstruction in other cities.
Key words old industrial area, relocation and reconstruction, implementation monitoring (Page:99)

Application of Surveying and Mapping Technology in the Major Project of Yan'an Channel Engineering by *JING Hui*
Abstract The major land remediation project of Yan'an channel engineering is the new model of land construction under the strategy of sustainable development. Surveying and mapping technology is a powerful guarantee for the major land remediation project. In this paper, we summarized the traditional field topographic surveying, surveying of details, the low-altitude UAV aerophotography and oblique photography at first. Then, we introduced the functions, advantages and disadvantages of traditional surveying and mapping technologies and new surveying and mapping technologies. The result shows that the traditional technologies and new technologies complement each other. The use of local conditions can make the best use of them.
Key words surveying and mapping technology, channel engineering, application (Page:103)

Discussion on the Continuity of Subsidence Observation Data in High-rise Building by *LU Yonghong*
Abstract In this paper, aiming to restore the observation data of damaged subsidence observation points, we solved the continuity problem of subsidence observation data through various mathematical methods such as linear regression. This study can provide the complete and continuous observation data for the subsidence of high-rise building, and technical guarantee for on-site construction and building safety.
Key words subsidence observation, continuity, linear regression, data processing (Page:106)

Research on Combined Navigation Algorithm for Suppressing Kalman Filter Divergence by *TAN Pan*
Abstract Kalman filter is a cursive minimum variance estimation technique, and has been widely used in combined navigation data fusion. However, Kalman filter requires the system's model and noise statistical characteristics to be accurately known, and it is difficult to do so in practice. Therefore, Kalman filter divergence often occurs. In this paper, we studied the application of adaptive Kalman filter and fading memory Kalman filter in INS/GPS combined navigation. And then, we verified the feasibility of these two filter algorithms in suppressing the divergence of filter and improving the precision and stability of the combined navigation system through processing the simulation data.
Key words combined navigation, Kalman filter, fading memory (Page:109)

Application of Residual Modified GM(1, 1) Model in Landslide Displacement Prediction by *FENG Zifan*
Abstract According to the research status of landslide displacement monitoring, we used the Matlab programming and the displacement monitoring data of Xintan landslide monitoring points A3 and B3 to build GM(1,1) prediction model and the first-order residual modified GM(1,1) model, and compared the deformation prediction results of two gray prediction models. The experimental result shows that the prediction accuracy of the residual modified GM(1,1) model is significantly higher than that of the traditional GM(1,1) model.
Key words landslide monitoring, gray model, residual modification (Page:113)

Application of Partial-EIV Data Snooping Method in 3D Coordinate Transformation by *WANG Zhengyao*
Abstract In the 3D coordinate transformation, there may be outliers between the start and target coordinates. When the coordinate transformation parameters are solved by the total least square method, the calculation results will be greatly affected. In order to reduce the influence of the outliers on the calculation results, we used the data snooping method based on Partial-EIV model to remove the outliers, to ensure the correctness of the results.
Key words 3D coordinate, outlier, total least squares, Partial-EIV, data snooping method (Page:116)

Application of 3D Laser Scanning Technology in Measurement of Highway Strip Graph by *HUANG Yongsheng*
Abstract To verify the applicability of on-board 3D laser scanning technology in the highway strip graph, we discussed the process and method of its application, used the coordinate comparison method to assess the accuracy of 3D laser scanning system, and verified its working efficiency in this paper. The results show that the plane precision of 3D laser scanning system is up to 0.077 m, which is conformed to the requirements of the latter mapping. Compared with the traditional measurement methods, the overall efficiency is improved by 50% using the on-board 3D laser scanning technology. All of them indicate that the on-board 3D laser technology has good applicability and efficiency in the measurement of highway strip graph.
Key words on-board 3D laser scanning technology, the measurement of highway strip graph, the coordinate comparison method, accuracy (Page:119)

Quality Analysis and Improvement of Pipeline Surveying Results by *LIU Jinhu*
Abstract In this paper, we reviewed the quality control research status of the pipeline detecting and surveying project, introduced the quality requirements of pipeline surveying, and analyzed the typical problems of pipeline surveying results. Then, we put forward the measures and suggestions for improving result quality, such as using process quality control theory and method based on control input and risk prevention principles, giving key points of internal control in control surveying, and general survey of underground pipeline.
Key words pipeline surveying, quality problem, quality requirement, quality improvement (Page:123)

Automatic Numbering Method of Discrete Pattern Spot Based on Spatial Aggregation by *DA Xing*
Abstract Focusing on the disadvantages of disorder numbering in automatic numbering by coordinates of discrete pattern spot, we used the Python language and ArcPy site packages to develop program, proposed the numbering methods of automatic grouping and manual grouping based on the principle of spatial aggregation, and elaborated the important technical details in the process of program implementation. Then, taking the project of building area assessment in Wuhan Changjiang New Town for example, we carried out program testing, in order to provide an effective solution for automatic numbering of discrete pattern spot in complex situation.
Key words spatial aggregation, numbering, Python, ArcPy (Page:126)