



Hanoi University of Mining and Geology



AGH University of Science and Technology

VIET-POL 2015
SECOND INTERNATIONAL CONFERENCE ON
SCIENTIFIC RESEARCH COOPERATION BETWEEN VIETNAM AND POLAND
IN EARTH SCIENCES

VIET-POL 2015
VIỆT-POL 2015

BACH KHOA PUBLISHING HOUSE

**Hanoi University of Mining and Geology
AGH University of Science and Technology**

VIET-POL 2015

**SECOND INTERNATIONAL CONFERENCE ON
SCIENTIFIC RESEARCH COOPERATION BETWEEN VIETNAM AND POLAND
IN EARTH SCIENCES**

BACH KHOA PUBLISHING HOUSE

Copyright ©2014 Hanoi University of Mining and Geology, Vietnam

All rights reserved. No part of this publication or the information contained herein may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, by photocopying, recording or otherwise, without written prior permission from the publisher.

Although all care is taken to ensure the integrity and quality of this publication and the information herein, no responsibility is assumed by the publishers nor the author for any damage to property or person as a result of operation or use of this publication and/or the information contained herein.

Published by: Bach Khoa Publishing house

ISBN: 978-604-938-550-6

Printed in Viet Nam

19	Study on the mapping forecast of micro-tectonic destruction level for coal seams in QuangNinh coal basin, VietNam <i>Pham Cong Khai , Le Van Canh, Tran Xuan Thuy</i>	267
20	Building estimation model of construction using Kalman filter <i>QuocKhanh Pham, TrungDung Pham, QuynhAn Tran</i>	276
21	The application of digital model to analyze and forecast sinking field (subsidence) in underground mining <i>Pham Van Chung, Nguyen Viet Nghia , Nguyen Quang Phich</i>	284
22	Indirect adjustment method with conditions and the issue of data processing of specialized geodetic network in engineering surveying <i>Nguyen Quang Phuc, Hoang Thi Minh Huong</i>	291
23	Application of Remote Sensing Technique to Detect Copper Mineral based Principal Component Analysis and Band Ratio Methods. A Case Study: Lao cai Province, Vietnam <i>Trinh Le Hung, Vuong Trong Kha</i>	300

Geophysics

1	How growing site and petrophysical properties of natural magnetite are correlated <i>Izabela Biało, Zbigniew Kąkol, Andrzej Kozłowski</i>	311
2	Characteristic of subsurface focused-fluid flow in sedimentary basins from 3D seismic data <i>Anh Ngoc Le, Tuan Van Pham, Muoi Duy Nguyen, Oanh Thi Tran, Ngan Thi Bui, Hoa Minh Nguyen</i>	320
3	Rare Earth, radioactive and selected elements in the iron oxide copper gold Sin Quyen deposit in North Vietnam <i>Jadwiga Pieczonka, Adam Piestrzyński, Phon Le Khanh, Chau Nguyen Dinh, Pawel Jodłowski and Hao Duong Van</i>	331
4	Total Organic Carbon from well logging in shale gas and tight formations <i>Jadwiga A. Jarzyna, Paulina I. Krakowska, Edyta Puskarczyk, Kamila Wawrzyniak-Guz, Marcin Zych</i>	354
5	Researching the procedures for survey and assessment of the radioactive environmental impacts due to mining and processing ores at the Sin Quyen cooper mine, Lao Cai province <i>Le Khanh Phon, Nguyen Thai Son, Tran Thien Nhien, Lai Manh Giau, Adam Piestrzynski, Jadwiga Pieczonka, Pawel Jodłowski, Nguyen Dinh Chau, Nguyen Van Lam, Nguyen Van Nam, Do Thi Huyen Thuong</i>	359

Building estimation model of construction using Kalman filter

QuocKhanh Pham¹, TrungDung Pham^{1,2}, QuynhAn Tran¹

¹ Hanoi University of Mining and Geology

² Stuttgart University, Germany

Summary

Kalman Filter has used popular on processing data in geodesy field over the world. However, this filter has been applied on the engineering surveying in Vietnam for few years. This paper presents a theoretical research and Kalman's applications for creating a prediction model of subsidence based on the subsidence value of points in the previous cycles. An experimental analysis using a real data demonstrates for precise and reliability of the prediction model relied on Kalman filter.

1. Objective

Kalman filter is proposed by Rudolf E. Kalman in 1960's, an efficient recursive filter and a high effective way for dynamic models in a real time. Kalman filter method is popular in many fields with remarkable achievements (Phan, V.H., Pham Q.K., 2012; Bao, H, 2009; Wang Qi., 2009). In recent years, Kalman filter is widely used for processing data of important constructions like dam of hydro electric plans and big bridges, etc. In Vietnam's engineering surveying, the study of Kalman filter has been mentioned in a few scientific research (Dinh, X.V., 2009; Le, V.H., 2014). This paper presents the Kalman filter method applied for build a subside model using data of previous cycles, then evaluating the accuracy of these model and computing predicted subside of some cycles in the future.

2. Algorithms and Models

According to dynamic system, the KF, a recursive function, using the process and measurement equations for optimal estimation in the real time. Besides, It may be used for prediction of the state of the system in the future. Hence, KF is more likely to use for real time purposes and an immediate warning of dynamic systems.

Mathematical algorithm of KF includes the process model and the measurement model, the discrete model is given (Pham, Q.K., 2012; Phan, V.H., Pham Q.K., 2012):

$$X_k = \phi_{k/k-1} X_{k-1} + \Gamma_{k-1} W_{k-1} \quad (k = 1, 2, \dots) \quad (1)$$

$$L_k = H_k X_k + V_k \quad (k = 1, 2, \dots) \quad (2)$$

Where: X_k process vector ($k \in N$) at t_k ;

L_k measurement vector ($k \in M$) at t_k ;

$\phi_{k/k-1}$ is transition matrix ($m \times n$) from t_{k-1} to t_k ;

W_{k-1} process noise at t_{k-1} ;

Γ_{k-1} is matrix of disturbance quantities ($n \times r$);

H_k configuration matrix ($m \times n$) at t_k ;

V_k measurement noise at t_k .

If It is assumed that the average value of W is zero and the average value of V is zero. We have to further assume that no correlation exists between W and V .

$$\begin{cases} E(W_k) = 0 \\ E(V_k) = 0 \end{cases} \quad (3)$$

Then the covariance matrices of process noise and measurement noise are defined as follows:

$$\begin{cases} \text{Cov}(W_k, W_j) = Q_k \delta_{kj} \\ \text{Cov}(V_k, V_j) = R_k \delta_{kj} \\ \text{Cov}(W_k, V_j) = 0 \end{cases} \quad (4)$$

Where:

Q_k and R_k the process noise covariance and measurement noise covariance, respectively;

δ_{kj} is the Kronecker function, in accordance with:

$$\delta_{kj} = \begin{cases} 1, & k = j \\ 0, & k \neq j \end{cases}$$

The formulation of KF is given as follows:

(1) Predicted state vector

$$\hat{X}_{k/k-1} = \phi_{k/k-1} \hat{X}_{k-1} \quad (5)$$

(2) Cofactor matrix of predicted state vector

$$P_{k/k-1} = \phi_{k/k-1} P_{k-1} \phi_{k/k-1}^T + \Gamma_{k-1} Q_{k-1} \Gamma_{k-1}^T \quad (6)$$

(3) Kalman gain

$$K_k = P_{k/k-1} H_k^T (H_k P_{k/k-1} H_k^T + R_k)^{-1} \quad (7)$$

(4) Update state vector

$$\hat{X}_k = \hat{X}_{k/k-1} + K_k (L_k - H_k \hat{X}_{k/k-1}) \quad (8)$$

(5) Cofactor matrix of updated state vector

$$P_k = (I - K_k H_k) P_{k/k-1} \quad (9)$$

(6) Initial state vector

$$\hat{X}_0 = E(X_0) = \mu_0, \quad \hat{P}_0 = Var(X_0) \quad (10)$$

In the equation 5, the state vector $\hat{X}_{k-1}$ is known at epoch t_{k-1} . It is assume that $W_{k-1} = 0$, we can calculate the update state vector at epoch t_k . From the equation 7, the observation L_k at epoch t_k is known and which helps getting the best estimator of the $\hat{X}_k$ state at epoch t_k . This process is iterated for the next steps. Therefore, depending on the initial state vector and initial covariance, it could be used above equations from eqn (5) to eqn (10) to estimate.

3. On the application of Kalman Filter for monitoring construction

3.1. Process model and measurement model

In general, the positions of monitoring marks in three dimension are attained by GPS receivers or total stations. In case of using GPS, the coordinate of monitoring marks may be determined in the spatial system (X, Y, Z) , in the geodetic system (B, L, H) , or in the independent system of construction (x, y, h) . For example, if a position of measured point is $X = (x, y, h)^T$, the velocity of this point is $\dot{X} = (\dot{x}, \dot{y}, \dot{h})^T$, and the acceleration of this point is $\ddot{X} = (\ddot{x}, \ddot{y}, \ddot{h})^T$, the process equation and the measurement equation are given by:

$$\begin{bmatrix} X \\ \dot{X} \\ \ddot{X} \end{bmatrix}_k = \begin{bmatrix} E & \Delta t_k E & \frac{1}{2} \Delta t_k^2 E \\ 0 & E & \Delta t_k E \\ 0 & 0 & E \end{bmatrix} \begin{bmatrix} X \\ \dot{X} \\ \ddot{X} \end{bmatrix}_{k-1} + \begin{bmatrix} \frac{1}{6} \Delta t_k^3 E \\ \frac{1}{2} \Delta t_k^2 E \\ \Delta t_k E \end{bmatrix} W_{k-1} \quad (11)$$

Where:

0 and E is zero matrix and identity matrix with level of three, respectively;

$\Delta t_k = t_k - t_{k-1}$ is the different time at epoch k and epoch k-1.

If observations are defined in 3D, we have measurement model may be written:

$$\begin{bmatrix} x \\ y \\ h \end{bmatrix}_k = \begin{bmatrix} E & 0 & 0 \end{bmatrix} \begin{bmatrix} X \\ \dot{X} \\ \ddot{X} \end{bmatrix}_k + V_k \quad (12)$$

Eqn (11) and eqn (12) are a mathematical model of a single point applying KF for deformation monitoring.

The choice of state of parameters relates to not only deformation monitoring objects also measurement frequency. If monitoring targets are unstable and quickly variable, it is need to concern velocity and acceleration of measuring points. Conversely, If monitoring targets are stable and they have a slow tendency of deformation with a quite high frequency, It should be considered the chancing velocity of measured points while moment's velocity is given a random error. In consequences, the process model and measurement model are written by:

$$\begin{bmatrix} X \\ \dot{X} \end{bmatrix}_k = \begin{bmatrix} E & \Delta t_k E \\ 0 & E \end{bmatrix} \begin{bmatrix} X \\ \dot{X} \end{bmatrix}_{k-1} + \begin{bmatrix} \frac{1}{2} \Delta t_k^2 E \\ \Delta t_k E \end{bmatrix} W_{k-1} \quad (13)$$

$$\begin{bmatrix} x \\ y \\ h \end{bmatrix}_k = \begin{bmatrix} E & 0 \end{bmatrix} \begin{bmatrix} X \\ \dot{X} \end{bmatrix}_k + V_k \quad (14)$$

It is consider that the process model is a discrete linear function with a thick repetition of measurement. In a very short time, the movement of position is neglected or, in other words, moment's chancing position is a random error. Therefore, the process of prediction with time is used as follows:

$$\begin{bmatrix} x \\ y \\ h \end{bmatrix}_k = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ h \end{bmatrix}_{k-1} + W_{k-1} \quad (15)$$

$$\begin{bmatrix} x \\ y \\ h \end{bmatrix}_k = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ h \end{bmatrix}_k + V_k \quad (16)$$

3.2. Determining initial state vector

From the KF algorithm, to determine the state of system at t_k , at the beginning the initial value must be know. In practical, before filtering, the initial state vector is not easy to choose fine values. Normally, rough values is selected in this step. However, If these initial value have a big deviation, it causes the results of filter getting a quite large. In other words, the monitoring value is not real even leads to

disperse. Therefore, determining the initial value is very important, these includes the initial vector of X_0 , the initial covariance P_0 , covariance of process noise Q_k , and covariance of measurement noise R_k .

According to deformation monitoring by cycles, the subsidence value X and the rate of change $\dot{X}$ of measured points are the state vector. Hence, it is assume that the adjustment value in the second cycle X''_k are initial state vector with a correlative covariance. The average rate of subsidence of two cycles $\Delta t^{-1}(X'' - X')$ is parameter of subsidence $\dot{X}_0$, the covariance matrix is $\Delta t^{-2}(P'_X + P''_X)$. The matrix of measurement noise is defined by measured data. The matrix of process noise is $Q_k = 4\Delta t_k^{-4}R_k$ because the acceleration of measured point is considered the process noise (Bao, H, 2009).

4. On application of KF in prediction for deformation monitoring

Experimental data is collected during eleven cycles with one month per cycle at Foreign Trade University from December, 2008 to November, 2009. The optical level (Ni004) and the invar staff are used to create basis and monitoring verticle networks with level of standard I and II, respectively. The monitoring net has 30 marks, two of them (M18 and M19) is used for build and calculation predicted values in this research. Table 1 shows measured data of two marks M18 and M29.

Table 1. Subsidence values of M18 and M29 during 11 cycles (mm)

No Cycle	M18	M29	No Cycle	M18	M29
1	0.00	0.00	7	-3.33	-3.44
2	-0.86	-0.41	8	-3.93	-4.06
3	-1.57	-1.34	9	-4.55	-4.70
4	-1.66	-1.74	10	-4.53	-5.21
5	-2.38	-2.60	11	-5.98	-6.54
6	-2.93	-3.34			

From these data, we built two estimation model as follows:

The first case: Using the data of the first seven cycles, applied the KF algorithm above that is carried out establishment of the subsidence model and calculation for estimation value of the next four cycles (from 8th cycle to 11st cycle). The results are obtained by comparing between estimate values and real ones shown in the table 2:

Table 2: The results are based on KF method in the first case

Obsevation mark M18 (mm)				Obsevation mark M29 (mm)			
No cycle	Real value	Estimated value	Deviation	No cycle	Real value	Estimated value	Deviation
1	0.00	0.00	0.00	1	0.00	0.00	0.00
2	-0.86	-0.79	-0.07	2	-0.41	-0.34	-0.07
3	-1.57	-1.45	-0.12	3	-1.34	-1.19	-0.15
4	-1.66	-1.72	0.06	4	-1.74	-1.77	0.03
5	-2.38	-2.33	-0.05	5	-2.60	-2.57	-0.03
6	-2.93	-2.93	0.00	6	-3.34	-3.34	0.00
7	-3.33	-3.36	0.03	7	-3.44	-3.54	0.10
Model error: 0.05				Model error: 0.07			
Estimated value				Estimated value			
8	-3.93	-3.81	-0.12	8	-4.06	-3.80	-0.26
9	-4.55	-4.26	-0.29	9	-4.70	-4.06	-0.65
10	-4.53	-4.71	0.18	10	-5.21	-4.31	-0.90
11	-5.98	-5.15	-0.83	11	-6.54	-4.57	-1.97

Figure 1 and figure 2 illustrate subsidence model using KF algorithm.

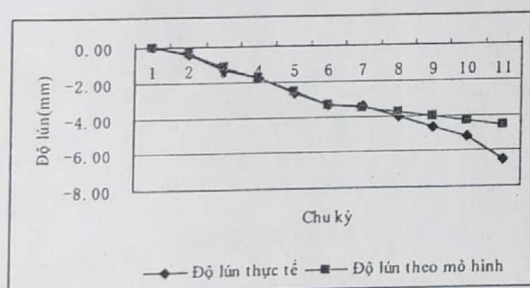


Figure 1. The graph of predicted mark M18

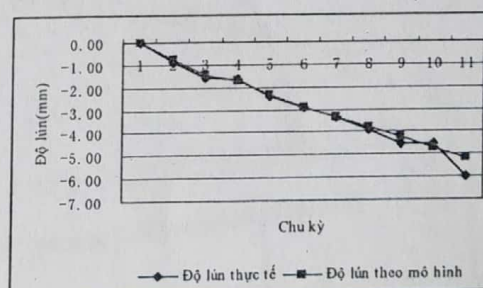


Figure 2. The graph of predicted mark M29

The second case: Using the data of the first nine cycles, the subsidence model and calculation for estimation value is computed for the next two cycles (10th cycle and 11st cycle). The computation is carried out like the first case, we achieve the results in table 3:

Table 3 The results are based on KF method in the second case

Obsevation mark M18 (mm)				Obsevation mark M29 (mm)			
No cycle	Real value	Estimated value	Deviation	No cycle	Real value	Estimated value	Deviation
1	0.00	0.00	0.00	1	0.00	0.00	0.00
2	-0.86	-0.79	-0.07	2	-0.41	-0.15	-0.26
3	-1.57	-1.45	-0.12	3	-1.34	-1.22	-0.12
4	-1.66	-1.72	0.06	4	-1.74	-1.81	0.07
5	-2.38	-2.33	-0.05	5	-2.60	-2.58	-0.02
6	-2.93	-2.93	0.00	6	-3.34	-3.34	0.00
7	-3.33	-3.36	0.03	7	-3.44	-3.54	0.10
8	-3.93	-3.91	-0.02	8	-4.06	-4.02	-0.04
9	-4.55	-4.54	-0.01	9	-4.70	-4.67	-0.03
Model error: 0.04				Model error: 0.07			
Estimated value				Estimated value			
10	-4.53	-5.15	-0.62	10	-5.21	-5.30	-0.09
11	-5.98	-5.77	0.21	11	-6.54	-5.92	0.62

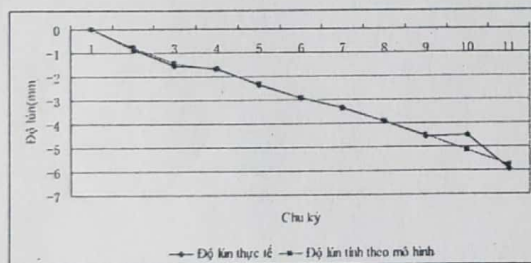


Figure 3. The graph of predicted mark M18

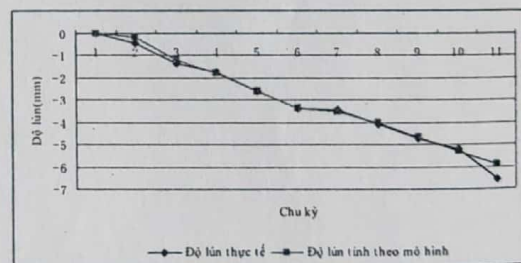


Figure 4. The graph of predicted mark M29

From the graphs of two case above, we can consider that:

The prediction values of two monitoring points applied the KF are approximate to the real measurements with small model errors at the dormitory of Foreign Trade University.

From the tendency of subsidence line, this algorithm is efficient to predict a regular trend of subsidence in a short term.

5. Conclusions

KF algorithm is more likely to build the monitoring deformation model and the results are suitable for the tendency of subsidence monitoring marks. Besides, KF should be use to predict for next few cycles. Finally, It is needed to study this method for auto deformation monitoring in a real time.

References

1. Bao, H., 2009. Theoretical research and application monitoring system real-time deformation of the big ones, PhD thesis, Chinese language.
2. Dinh, X.V., 2009. Study monitoring methods, data processing and deformation analysis of industrial-civil conditions in Vietnam, PhD Thesis, HaNoiUniversity of Mining and Geology.
3. Le, V.H., 2014. The study measured value adjustment combining GPS and terrestrial measurements of perpendicular coordinate system horizon geospatial application for building geodesy networks, PhD Thesis, HaNoiUniversity of Mining and Geology.
4. Pham, Q.K., 2012. Deformation monitoring data processing and application in Vietnam, PhD thesis in China, Chinese language.
5. Phan, V.H., Pham Q.K., 2012. Data processing of deformation monitoring, Vietnam Science & Technology Publishing House.
6. Wang Qi., 2009. Application of Kalman filter analysis method in deformation monitoring data procession, Chinese journal of engineering geophysics, Vol6.No5, p.608-611, Chinese language.