The method of measurement for buried pipeline centerline based on data fusion

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Received 1 October 2014, www.cmnt.lv

Abstract

For the problem of long-distance oil and gas pipeline centerline measurement, a method of multi-sensor data fusion using the pipe centerline calculation is presented. The error model is set up by the system of navigation and nonlinear dynamic systems. Using the data of IMU and odometer to calculate the information of pig navigation. All of the errors were calculated by Kalman filter for estimation and compensation. It is concluded that the error for horizontal is 0.35m, the error for vertical is 0.74m for comparison of same pipeline centerline in different inspection time. One feature point is dug to verify the accuracy of the inspection which error is less than 1m. This method is effective for the buried pipeline to perform safely.

Keywords: in-line inspection of long distance pipeline, sensor fusion, inertia navigation, extended Kalman filter, error correction

1 Preface

With the continuous development of domestic oil and gas industry [1], more and more long-distance buried pipelines are used in the transportation of oil and gas products. Due to factors such as geological disasters that will cause pipe displacement or pipe deformation, thus great bending strain will be generated in local pipe body that which will result in additional stress leading to serious instability or material damage to the pipeline. To avoid pipeline failure accidents, Periodically and accurate pipeline centerline positioning measurements are needed in order to determine the specific location of the pipeline, and analysis situations such as pipe displacement, deformation and so on by calculating and comparing historical data, thereby making timely repair focusing on large deformation zone.

Pipeline inspection is the basic method to ensure pipeline safety and In-line Inspection is recognized as the most effective detect means of pipeline safety. Now, large foreign pipeline companies have been able to detect and analyze pipeline position using ILI tools mounted with IMU, due to the monopoly of foreign technology companies on this technology, the domestic research in this area started relatively late, and most research are still in the experimental stage.

In this paper, high-precision inertial measurement unit (IMU) oriented to long-distance gas pipeline centerline measurements was developed, and pipeline centerline location information was calculated through the use of multi-sensor data fusion technology, and a variety of errors generated were corrected by the sensors using the extended Kalman filter, measurement locus error correction was made by referencing Marker point information, and finally get a more accurate pipeline centerline.

2 Measurement systems in ILI

As shown in Figure 1, the Inertial Measurement Unit (IMU) was mounted within the sealed pipeline inspection gauge (PIG) [2-5], in order to the post processing of geographic information data, the master clock in IMU must sync to the GPS clock in above ground marker prior to the inspection. PIG move forward under the driven by the impetus of oil or gas in the pipeline. IMU system is composed of three-axis orthogonal high precision laser gyroscope and three-axis orthogonal accelerometers. Since the inertial navigation system error and odometer offset error accumulated over time, leading to the data migration, so transmitter with the ability to transmit low frequency signal to trigger the above ground GPS marker was also installed besides the odometer. By doing so, using these devices you can do inertial and non-inertial sensor information fusion to calibrate the pipe centerline position calculated from the PIG, Thereby obtaining high-precision pipe centerline data.

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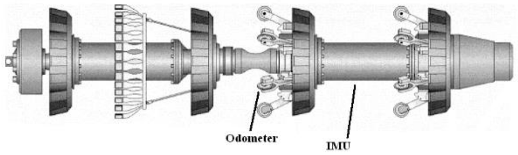

FIGURE 1 Measurement system for In-line inspection of Pipeline centerline

3 Pipeline centerline data fusion algorithm

When run in the pipeline, data collected by all sensors in PIG is stored in the built-in memory. Every movement was collected by the inertial navigation unit including the angular velocity and acceleration in three directions and so on. Odometer measure the mileage of the PIG, thus obtain speed of the PIG to compensate error of the inertial navigation unit [6-10]. The above ground GPS marker receive low frequency signals generated by the transmitter to obtain the exact current location information that error compensation can be done by post-processing. This paper adopt the extended Kalman filter to process the internal attitude, velocity and position information obtained by the PIG, Simultaneously merge the non-inertial odometer data and the ground coordinate data with inertial data [11-13]. The calculation process adopt both the state of forward and backward extended Kalman filter solver system and fix generated system errors. Where in the forward filter is used to calculate $\hat{x}_k$ the current state of the PIG, the backward filter is used to estimate $\delta\hat{x}_k$ the system state amount errors. Therefore the system current revision status is $\hat{x}_{C_k} = \hat{x}_k - \delta\hat{x}_k$. Pipeline centerline data fusion algorithm block diagram is shown in Figure 2.

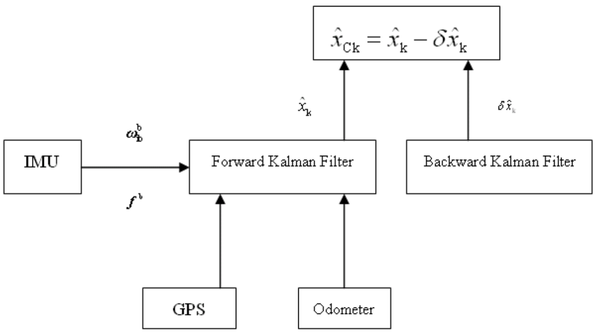

FIGURE 2 Data fusion algorithm diagram of pipeline centerline

3.1 INERTIAL NAVIGATION ALGORITHM

Strapdown inertial navigation system (SINS) and the PIG speed, position dynamic equations are as follows:

$$\dot{V}_e^n = C_b^n f^b - (2\omega_{ie}^n + \omega_{en}^n) \times V_e^n + g_l^n, \tag{1}$$

$$\dot{q} = \frac{1}{2} q \otimes \omega_{nb}^b, \tag{2}$$

$$\dot{L} = \frac{v_N}{(R_N + h)}, \tag{3}$$

$$\dot{l} = \frac{v_E}{(R_E + h)\cos L}, \tag{4}$$

$$\dot{h} = -v_D, \tag{5}$$

where $V_e^n = [v_N\ v_E\ v_D]^T$ is the velocity vector of the PIG, g_l^n is the gravitational acceleration, $q = [q_0\ q_1\ q_2\ q_3]^T$ is the four elements, f^b is collected force ratio value, L and l are respectively latitude and longitude h is the elevation. R_E and R_N are the earth radius under the WGS1984 geography coordinator system.

C_b^n is the transmit matrix from the PIG carrier coordinate system into the local navigation coordinate system that can be obtained by calculating the four elements [14-17], that is:

$$C_b^n = \begin{bmatrix} q_0^2 + q_1^2 + q_2^2 + q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 + q_0q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\ 2(q_1q_3 - q_0q_2) & 2(q_2q_3 + q_0q_1) & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}, \tag{6}$$

where ω_{ie}^n is the Earth angular velocity in the navigation reference, ω_{en}^n is the angular rate relative to the Earth navigation reference, ω_{nb}^b is the platform's angular rate of the navigation system. These angular rate expressions are:

$$\omega_{ie}^n = \left[\Omega\cos L \quad 0 \quad -\Omega\sin L\right]^T, \tag{7}$$

$$\omega_{en}^n = \left[\frac{v_N}{R_E + h} \quad -\frac{v_N}{R_N + h} \quad -\frac{v_N}{R_E + h}\tan L\right]^T, \tag{8}$$

$$\omega_{nb}^b = \omega_{ib}^b - C_n^b\left(\omega_{ie}^n + \omega_{en}^n\right). \tag{9}$$

Constant Ω is the Earth's rotation angular rate. Vector $\omega_{nb}^b = [\omega_{nbx}^b\ \omega_{nby}^b\ \omega_{nbz}^b]^T$ is the angular rate of the carrier system to the Geography coordinate system using to update the attitude angle is system. The inertial navigation coordinates of the pipeline centerline can be calculated by integrating all the data in Equations (1)-(9). As the pure inertial navigation results has an error accumulation characteristic, and therefore require additional auxiliary sensor information to eliminate the accumulated error.

3.2 DEAD RECKONING ALGORITHM

Dead reckoning algorithm utilizes the carrier's heading and attitude angle provided by the IMU with odometer speed to calculate the carrier's relative position to the starting point. Assuming $v_m^b = [0\ \ v_m\ \ 0]^T$ is the projection of the odometer output speed in the carrier coordinate system, where the speed of the navigation odometer system can be expressed as: $v_m^n = C_b^n v_m^b = [v_{mN}^n \quad v_{mU}^n \quad v_{mE}^n]^T$, then the position information calculated using dead reckoning algorithm is:

$$\begin{cases} \dot{L} = v_{mN}^n / (R_M + h) v_m^n \\ \dot{\lambda} = v_{mE}^n \sec L / (R_M + h) \\ \dot{h} = v_{mU}^n \end{cases}. \quad (10)$$

3.3 ERROR EQUATION OF NAVIGATION AND INERTIAL SENSORS

Run track of the PIG can be obtained by linearization the speed equation, and the speed error can be expressed as:

$$\delta \dot{v}^n = f^n \times \Psi + C_b^n \delta f^b - (2\omega_{ie}^n + \omega_{en}^n) \times \delta v^n - (2\delta\omega_{ie}^n + \delta\omega_{en}^n) \times v^n - \delta g_l, \quad (11)$$

$$\dot{\Psi} = -\omega_{in}^n \times \Psi + \delta\omega_{in}^n - C_b^n \delta\omega_{ib}^b, \quad (12)$$

where: $\delta v^n = [\delta v_N \quad \delta v_E \quad \delta v_D]^T$ is speed error vector of reference navigation $\Psi = [\delta\alpha \quad \delta\beta \quad \delta\gamma]^T$ describes the inclination and azimuth vectors, which can be approximately expressed as a smaller angle offset.

This gives a navigation error in the navigation coordinates:

$$\delta L = \frac{1}{R_N + h} \delta v_N - \frac{v_N}{(R_N + h)^2} \delta h, \quad (13)$$

$$\delta l = \frac{1}{(R_E + h)\cos L} \delta v_E + \frac{v_E \sin L}{(R_E + h)\cos^2 L} \delta L - \frac{v_E \sin L}{(R_E + h)^2 \cos L} \delta h, \quad (14)$$

$$\delta h = -\delta v_D, \quad (15)$$

where δL, δl and δh are the latitude, longitude, and elevation error.

3.4 ERROR EQUATION OF NON-INERTIAL SENSORS

Data fusion algorithm is used to process the inertial unit data and other non-inertial sensors data, in order to decrease inertial error brought by inertial navigation. The non-inertial sensors here are odometer and above ground GPS marking boxes. Continuous odometer data can be converted into an average speed used to represent v_m, the instantaneous speed of PIG. Assuming odometer ratio error factor is k_{fe}, and then the speed of the PIG can be expressed as:

$$v_m^b \approx v_x^b - k_{fe} v_x^b, \quad (16)$$

where v_x^b is the velocity component in the *x* direction of the PIG, v_v^n is the white Gaussian noise with zero mean generated in the measurement of the velocity. Therefore, error rate in the navigation frame can be expressed as:

$$\delta v_m^n = \hat{v}^n - C_b^n v_m^b = \delta\hat{v}^n + v_m^b k_{fe} + v_v^n. \quad (17)$$

The above ground marker (AGM) is used to receive the low frequency signal of transmitter, and can provide position information of the PIG. The position error model is:

$$\delta p_m = \hat{p}^n - p_m^n = \delta\hat{p}^n + v_p, \quad (18)$$

$\hat{p}^n$ is the estimated location coordinates (latitude and longitude, elevation), p_m^n is location coordinates vector, v_p is the zero mean Gaussian white noise generated by measuring the position.

3.5 EXTENDED KALMAN FILTER

The error of inertial navigation results is an accumulating amount over time, and the error will greatly affect the output accuracy of navigation and positioning system. Navigation and positioning algorithm is an iterative calculation, If the calculation errors cannot be corrected, Navigation and positioning system will not accurately reflect the operation situation of the PIG. So, after analysis all the errors generated by the system extended Kalman filter is used for the system error correction.

As the real-time state of the system is obtained by a series of non-linear formula, so the extended Kalman filter is used to calculate. The basic idea of Extended Kalman Filter is to distribute processing first, and then does the global integration; obtain global estimates based on all observations information data, it integrates speed, location measurement of INS and odometer, above ground GPS location marker boxes information. Extended Kalman filter is described by the following equation:

1) state and output equations

$$x_{k+1} = f(x_k, u_k, k) + w_k, \quad (19)$$

$$z_k = h(x_k, k) + v_k. \quad (20)$$

2) the state estimates partial derivative matrix after each calculation the time interval ($t = kT$) by the filter is:

$$A_k = \frac{\partial f(x_k, u_k, k)}{\partial x_k}\Big|_{x=\hat{x}_k}, \; H_k = \frac{\partial h(x_k, k)}{\partial x_k}\Big|_{x=\hat{x}_k}. \quad (21)$$

3) filter update equation:

$$K_k = P_k H_k^T (H_k P_k H_k^T + R)^{-1}, \quad (22)$$

$$\hat{x}_{k+1} = f(\hat{x}_k, u_k, k) + K_k (z_k - h(\hat{x}_k, k)), \quad (23)$$

$$P_{k+1} = A_k(I - K_k H_k)P_k A_k^T + Q \,, \tag{24}$$

where v_k is the measurement error vector, z_k is the measurement vector.

$$\begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \\ z_6 \end{bmatrix} = \begin{bmatrix} 0&0&0&0&1&0&0&0&0&0 \\ 0&0&0&0&0&1&0&0&0&0 \\ 0&0&0&0&0&0&1&0&0&0 \\ 0&0&0&0&0&0&0&1&0&0 \\ 0&0&0&0&0&0&0&0&1&0 \\ 0&0&0&0&0&0&0&0&0&1 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \\ v_N \\ v_E \\ v_D \\ L \\ l \\ h \end{bmatrix}_k + \begin{bmatrix} \delta_{v_N} & 0 & 0 & 0 & 1 & 0 \\ 0 & \delta_{v_E} & 0 & 0 & 0 & 1 \\ 0 & 0 & \delta_{v_D} & 0 & 0 & 0 \\ 0 & 0 & 0 & \delta_L & 0 & 0 \\ 0 & 0 & 0 & 0 & \delta_l & 0 \\ 0 & 0 & 0 & 0 & 0 & \delta_h \end{bmatrix} \begin{bmatrix} v_{v_N} \\ v_{v_E} \\ v_{v_D} \\ v_L \\ v_l \\ v_h \end{bmatrix}_k . \tag{25}$$

By Equation (19)-(25), a system state equation was obtained from the system error model, which establishes the relationship between the speed, position error and the other error amount, between the previous error amounts. All the errors can be estimated through the forward Kalman filter, and then obtain the values of each state amount.

3.6 THE BACKWORD KALMAN FILTER

Filtering relevant information can be saved in the forward filtering and the error of each estimate can be got in the backward Kalman filtering, calibrated result $\hat{x}_{C_k}$ can be calculated finally. The backward Kalman filter using the following formula [18-20].

Assuming the estimated value and variance of each state are $\bar{x}_{k+1}$ and $\bar{p}_{k+1}$ at time $k + 1$, then: single stepping state predictive value:

$$\hat{x}_{k+1,k} = \phi_{k+1,k}\bar{x}_k \,. \tag{26}$$

Single stepping state prediction error covariance matrix

$$\hat{p}_{k+1,k} = \phi_{k+1,k}\bar{p}_k\phi_{k+1,k}^T + \Gamma_{k+1,k}Q_k\Gamma_{k+1,k}^T \,. \tag{27}$$

Time filter gain matrix at time K:

$$J_k = \bar{p}_k\phi_{k+1,k}(\phi_{k+1,k}\bar{p}_k\phi_{k+1,k}^T + \Gamma_{k+1,k}Q_k\Gamma_{k+1,k}^T)^{-1} = \hat{p}_k\phi_{k+1,k}\bar{p}_{k,k-1}^{-1} \,. \tag{28}$$

State estimation error at time K:

$$\delta\hat{x}_k = J_k(\hat{x}_{k+1} - \hat{x}_{k+1,k}) \,. \tag{29}$$

The estimated status value at time K:

$$\hat{x}_{C_k} = \hat{x}_k - \delta\hat{x}_k \,. \tag{30}$$

4 Field validation and data analysis

4.1 FIELD TEST EQUIPMENT AND PERFORMANCE INDICATORS

Most domestic oil pipeline are heating transportation, and pass through mountain, hills, rivers and other complex environmental areas, the technical and safety requirements of electrical equipment of which is extremely strict. To be able to safely detect the actual pipeline, IMU should not only meet the technical performance, but also consider the actual situation of the pipe and the external environment in order to ensure the detection successfully and safely conducted. Technical performances of inertial devices used in the field test are shown in Table 1; the environmental targets need to meet are shown in Table 2.

TABLE 1 Characteristic of Sensors

Sensor	Characteristics	Magnitude
Gyroscope	bias	<0.01°/h
	Random walk	$0.002°/\sqrt{h}$
Accelerometer	Bias Stability	<50ug
	Scaling factor	<50ppm
Odometer	Scaling factor	<0.3%
	White noise	<0.1m/s
Landmark	White noise	<±1m

TABLE 2 Characteristics of Circumstances

Characteristics	Magnitude
Temperature	0~60℃
Vibration	6g（RMS）
Impaction	30g
Pressure	3MPa

IMU inertial navigation unit is mounted on the PIG shown in Figure 1. The data collected by the system is stored in the built-in memory. The data in the built-in memory is downloaded at the end of the field test via the communication cable and then carry out post-processing.

4.2 DATA ANALYSIS

Two centerline measurement field tests were conducted on one crude oil pipeline of PetroChina Pipeline Company, and the two tests' relevant information are basically the same, here use the correlation results of the second trial as test instructions. Throughout the test, the PIG runs at an average speed of 1.16m/s in the pipe, the maximum speed is 1.27m/s, and the entire trial took about 54 hours and 15 minutes. An above ground GPS Marker is set just on the ground above buried pipeline centerline every 2Km to obtain the time that PIG pass through the Marker to perform error correction on the measurement results.

Integrate the IMU data, odometer data and the above ground GPS Marker data using the data fusion algorithm describes in this article can obtain a more accurate pipeline centerline. The following uses the first 30km trial data as an example of the data analysis, Figures 3 and 4 show the track and height of the pipeline centerline during inspection obtained by the PIG. As can be seen from the figure, the height of pipeline changes significantly and fluctuated considerably, while the PIG's speed traveling in the pipe is more stable and run in a relatively stable state.

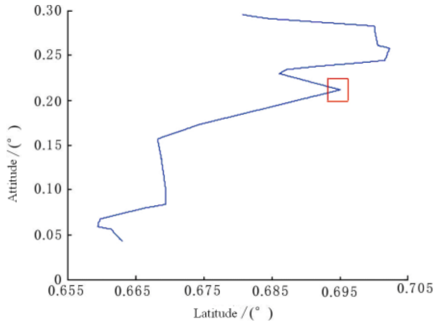

FIGURE 3 Curve of pipeline for measurement of In-line inspection

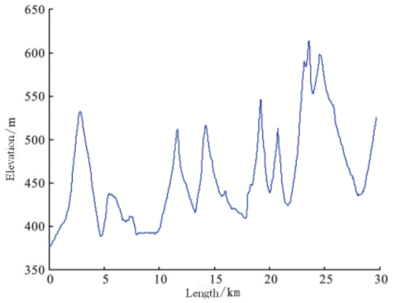

FIGURE 4 Height of the curve for measurement of In-line inspection

The twice measurement results of this pipe section were comparative analysed to calculate the repeatability between the two measurements. Since using 300m as an error analysis unit that there will be a total of 100 points in the first 30Km. As can be seen from Figures 5 and 6, the error curve and the error distribution of the two measurements as follows, the error between the two obtained pipeline centerline is small. The error statistics shows that the error in the horizontal direction is 0.35m (1σ), while in the height direction is 0.74m (1σ).

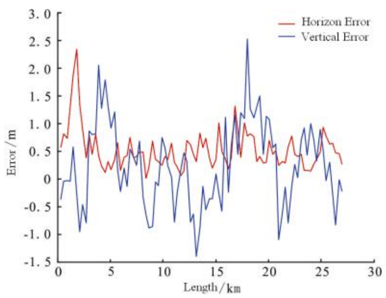

FIGURE 5 Horizon and height error for two measurements

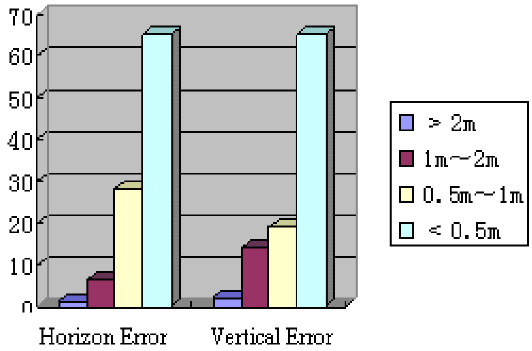

FIGURE6 Horizon and height error of the measurement distribution for two measurements

4.3 EXCAVATION VERIFICATION OF FEATURE POINTS

To further validate the accuracy of the measurement results, select the middle point of the right bend in Figure 3 as excavation verification point to verify the accuracy of IMU measurements. The location point calculated by IMU measurement result locates 0.4 meters downstream the target point while locates 0.7 meters right side in the vertical direction of the oil flow. This error is equal to the analysed repeatability error between two measurements in last section. From this we can see that the accuracy of IMU can achieve to less than 1m which meets the accuracy requirements in actual work.

5 Conclusion

1) This paper studied a buried pipeline centerline measurement method based on inertial navigation technology and multi-sensor data fusion, integrating inertial navigation systems, odometer data and ground GPS data to calculate the coordinates of buried pipeline centerline;
2) Through the use of high-precision, strong impact vibration resistance devices, improved system's security, reliability, and successfully applied to the site inspection of actual crude oil pipeline;
3) All the errors generated in the inspection process were effectively inhibited by this method and the accuracy of the measurement results was improved. Through repeatability error analysis between the two measurements and feature points excavations verify shows the actual positioning accuracy of PIG was within 1m.
4) The above ground GPS marker boxes trigger rate is not high due to factors such as the depth, conductivity of soil and so on. To improve GPS Marker boxes trigger rate then further improve positioning accuracy, a suitable ground tracking technology should be further researched.

References

[1] Qi A 2009 Chinese oil and gas pipeline transport development status and analysis of associated problems International Petroleum Economics **17**(12) 57-60 *(in Chinese)*

[2] Yang J, Li R, Gao S, et al. 2012 Navigating and positioning technique for inner detection of pipeline Journal of Shenyang University of Technology **34**(4) 427-32 *(in Chinese)*

[3] Zhang Y, Wang L, Zhan X, et al 2008 The New Advancement and Trend of Inertial Navigation Technology *Shipbuilding of China* 2008 **49**(S1) 134-44 *(in Chinese)*

[4] Liu B Qi Y, Yang Y 2010 Application of Kalman filtering in pipeline geographical coordinates positioning system *Journal of Shenyang University of Technology* **32**(5) 564-8 *(in Chinese)*

[5] Yue B, Tang Y, Zhang Y, et al 2008 Application of integrated navigation technology in inertial pipeline surveying system *Journal of Chinese Inertial Technology* **16**(6) 712-6 *(in Chinese)*

[6] Yu J, Lee J G, Park C G 2005 An off-line navigation of a geometry PIG using a modified nonlinear field-interval smoothing flitter *Control Engineering Practice* 13(11) 1403-11 *(in Chinese)*

[7] Hart J D, Powell G H, Hackney D, Zulfiqar N 2002 Geometry Monitoring of the Trans-Alaska Pipeline *Cold Region Engineering* 110-21

[8] Czyz J A, Falk J 2000 Use of Geopig for Prevention of Pipeline Failures in Environmentally Sensitive Areas *The Pipeline Pigging* Integrity Assessment and Repair Conference Houston February 2000

[9] Simmons G G, Alto J V 1988 Pipeline Curvature by Polynomial Approximation *Proceedings of the Conference on Pipeline Infrastructure* ASCE Pipeline Division Boston Massachusetts June 1988.

[10] Paeper S, Brown Bm Beuker T 2006 In-line Inspection of Dents and Corrosion Using "High Quality" Multi-Purpose Smart-Pig Inspection Data *2006 International Pipeline Conference* IPC2006-10157 **2** 243-8

[11] Wang Z 2008 Precision Location Technology of Pipeline Robot Based on Multi-Sensor Data Fusion *Robot* **30**(3) 238-41

[12] Reber K, Beller M, Willems H, Barbian O A 2002 A new generation of ultra-sonic in-line inspection tols for detecting, sizing and locating metal loss and cracks in transmission pipelines Proceedings of the 2002 IEEE Ultrasonics Symposium Piscataway NJ USA **1** 665-71

[13] Li M 2004 The study of accurate in-line inspection technology to offshore pipeline route *China Offshore Platform* **19**(6) 46-9

[14] Li J, Chen H, Zhang X 2006 Localization Technique of Pipeline Robot Based on Multi-sensor Data Fusion *Control and Decision* 2006 **21**(6) 661-5

[15] Hang L, Nassar S, El-Sheimy N 2010 Accurate Pipeline Surveying Using Two-Filter Optimal Smoothing of Inertial Navigation Data Augmented with Velocity and Coordinate Updates Proceedings of the 2010 International Technical Meeting of The Institute of Navigation 49-56

[16] Nassar S 2003 Improving the Inertial Navigation System (INS) Error Model for INS and INS/DGPS Applications *PhD thesis* UCGE Reports No. 20183 The University of Calgary Calgary Alberta Canada

[17] Liu H 2009 Optimal Smoothing Techniques in Aided Inertial Navigation and Surveying Systems *MSc thesis* UCGE Report No. 20298 University of Calgary Calgary Alberta Canada

[18] Wang F 2012 Inertial surveying internal detection method and its application in oil and gas pipeline *Oil & Gas Storage and Transportation* **31**(5) 372-5 *(in Chinese)*

[19] Sadovnychiy S, Ponomaryov V, Ramirez T, Herrera E 2001 Navigation system for automation of pipelines inspection missions *Instrumentation and Development* **5**(1) 3-15

[20] Zirnig W, Hausamann D, Schreier G 2001 A concept for natural gas transmission pipeline monitoring based on new high-resolution remote sensing technologies IGRC 2001 November Amsterdam

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