잡음환경에서 UKF를 이용한 원격센서시스템의 파라메타 추정

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Noisy Parameter Estimation of Noisy Passive Telemetry Sensor System using Unscented Kalman Filter

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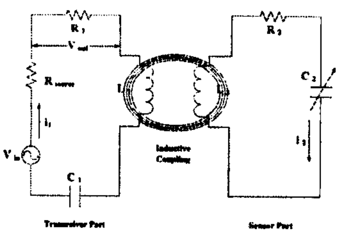
Abstract - In this paper, a noisy passive telemetry sensor system using Unscented Kalman Filter (UKF) is proposed. To overcome these trouble problems such as a power limitation and a estimation complexity that the general passive telemetry sensor system including IC chip has, the principle of inductive coupling was applied to the modelling of a passive telemetry sensor system (PTSS) and its noisy capacitive parameter was estimated by the UKF algorithm. Specially, to show the effective tracking performance of the UKF, we compared with the tracking performance of Recursive Least Square Estimation (RLSE) using linearization

1. INTRODUCTION

The earliest stimulus for the development of estimation theory was apparently provided by astronomical studies. To solve the this problem concerning the revolution of heavenly bodies, the method of least squares (LSM) was invented by Karl Friedrich Gauss. After then, this method has been based on most of the estimation methods like "Maximum Likelihood Method", "Minimum Mean-Square Estimation" and "Kalman Filter"[1]. In this article we focus mainly on passive telemetry sensor system(PTSS) which is nonlinear system[2]. Generally, this sensor system is modelled by inductive coupling theory and yields nonlinear model relating to estimator C_2 varying dependent on humidity, pressure, etc. Unscented Kalman Filter(UKF)[3] is presented for estimating noisy capacitive parameter C_2 of the PTSS. We demonstrate the applicability of the UKF to PTSS. The performance of the UKF algorithm in nonlinear system PTSS is evaluated and compared with the RLSE.

2. PASSIVE TELEMETRY SENSOR SYSTEM

The proposed PTSS is divided into two parts; transceiver and sensor part as following Fig. 1[2].



<Fig. 1> The Principle of PTSS

In Fig.1, transceiver part and sensor part are coupled inductively with mutual inductance M and impedance of sensor part Z_{sensor} is included in reflected impedance Z_T

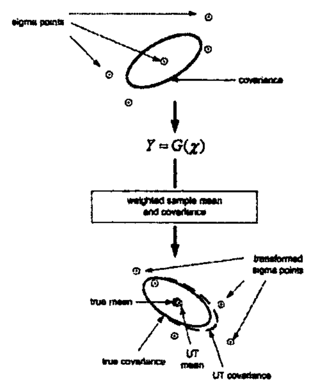
$$Z_T = \frac{(\omega M)^2}{Z_{sensor}} = \frac{\omega^2 M^2}{(j\omega L_2 + R_2 + 1/j\omega C_2)} \qquad (1)$$

where, ω means an angular velocity$[rad/\sec]$. The transfer ratio between the RF input voltage $V_{in}$and the measured voltage V_{out} across R_1 is equal to Eq. (2). Where, C_2 is unknown.

$$G(j\omega) = \frac{V_{out}}{V_{in}} = \frac{R_1}{(R_1 + R_0) + j(\omega L_1 - 1/\omega C_1) - (\omega^2 M^2 / (R_2 + j(\omega L_2 - 1/\omega C_2)))} \qquad (2)$$

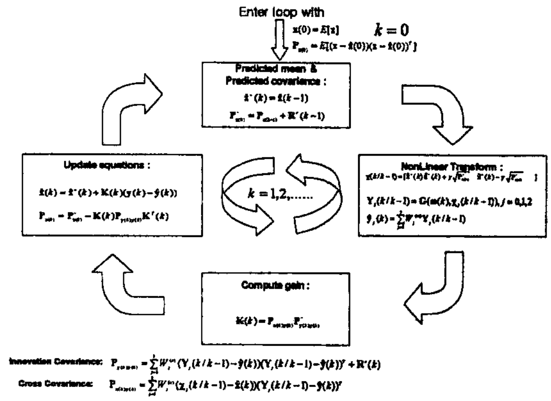
3. UNSCENTED KALMAN FILTER FOR PARAMETER ESTIMATION

The unscented transformation is founded on the intuition that it is easier to approximate a Gaussian distribution than it is to approximate an arbitrary nonlinear function or transformation[3]. Basic approach is presented in Fig 2.



<Fig. 2> The Principle of the Unscented

Random variable x has $n-by-1$ dimension and if sample mean and sample covariance are $\bar{x}$ and P_{xx}, a nonlinear function is mappin g to each point to transformed points $\bar{y}$ and P_{yy}. A recursive loop of UKF for parameter estimation is as following Fig. 3.



<Fig. 3> A recursive loop of UKF for Parameter Estimation

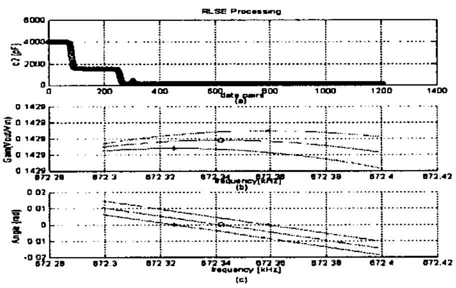
4. COMPUTER SIMULATION

In this section, the capacitive parameter estimation for the proposed system are performed to prove the availability of UKF algorithm for proposed PTSS. Table 1 shows the values of each component used in the proposed telemetry sensor system like Fig. 1.

<Table 1> Passive Telemetry Sensor System Parameters

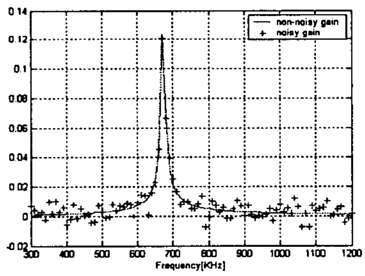
Parameter	Value	Parameter	Value
L_1	700[μH]	*Initial value of* C_2	500[*pF*]
C_1	80[*pF*]	*M*	8.2[μH]
L_2	50[μH]	R_{source}	30[Ω]
C_2	160,180,200 [*pF*]	R_2	10[Ω]
Rl	5[Ω]	*span*	300[kHz] ~ 1.2[*MHz*]
λ	1	Distance between two coils	2.5[*cm*]
R^r	0	R^e	1e-8

When measurement noise is not considered in this system(process noise R^r = 0, measurement noise R^e= 0), Fig. 4(a) is shown as the convergence pattern for estimator C_2, and Fig. 4(b),(c) are shown as the gain and the phase of the sensor system for each C_2 according to the RLSE system using linearization.



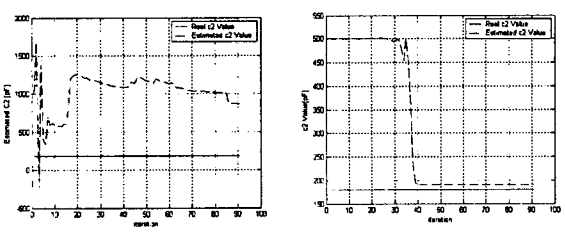
<Fig. 4> Convergence Patterns, Gain and Phase Diagrams

Observed gain (= Vout/Vin) data with noise whose covariance R^e is 10^{-8} applies to estimate capacitive parameter C_2 as shown Fig. 5. Specially, this data is collected in a range of the resonance of the PTSS to include the nonlinearity



<Fig. 5> Noisy gain (=Vout/Vin) data used in estimation

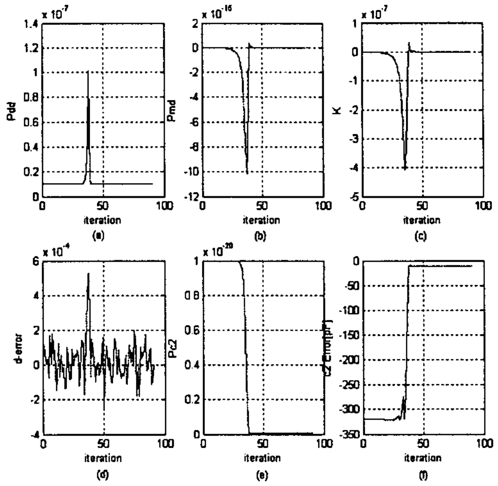
In case of noisy gain data ($= V_{out}/V_{in}$), the predicted capacitive parameter are plotted to compare the performance between the UKF and the RLSE using linearization in Fig. 6.



(a) (b)

<Fig. 6> Parameter Estimation for the PTSS Problem: (a) with RLSE; (b)with the UKF

Total 90 iterations have been done with same data obtained from noisy PTSS and in above figure ,straight solid line means desired capacitive value C_2 and dash line presents the tracking to the target. In order to show the performance of this filter, statistic parameters like covariance and errors are in Fig. 7.



<Fig. 7> Estimated errors and estimatedcovariances calculated by an UKF: a)Innovation covariance; (b)Cross correlation matrix; (c) Kalman gain; (d)Innovation; (e) Prediction covariance (f)Error between estimator and real (=180[pF])

In the state-space approach to parameter estimation, absolute convergence is achieved when the parameter covariance $\mathbf{P}_{c2}$ goes to zero (this also forces the Kalman gain to zero)[4] and same results are confirmed clearly in Fig. 7(c), (e), (f).

5. CONCLUSION

The UKF was applied to the parameter estimation of the proposed Passive Telemetry Sensor System, and its performance was compared with RLSE algorithm. In regard of convergence, the tracking trace using UKF has already approached the desired value in 40th iteration, whereas the tracking one using RLSE has a large error after finished the estimation. In terms of the convergence, the UKF is superior to RLSE, which uses linearization of the nonlinear model in noisy environment. In a view of estimation ability compared with the RLSE, the UKF algorithm is able to achieve rapid convergence property and more accurate estimation for noisy PTSS.

[REFERENCE]

[1] H.W.Sorenson, "Least-square estimation: from Gauss to Kalman", IEEE Spectrum, vol.7. p63-68, Jury 1970

[2] K.J.Cho and H. Harry Asda, "A Recursive Frequency Tracking Method for Passive Telemetry Sensors," d'Arbeloff Laboratory for Information Systems and Technology, 2003

[3] S.J.Julier and J.K. Uhlmann, "A new Extention of the Kalman Filter to Nonlinear System," in Proceedings of AeroSence: The 11th International Symposium on Aerospace/Defence Sensing, simulation and controls, 1997

[4] E.A.Wan and R.van der Merwe, "The Unscented Kalman filter," in Kalman filtering and Neural Networks Edited by S.Haykin, John Wiley and Sons, Inc., 2001