An Unscented Kalman Filter for Noisy Parameter Estimation of Passive Telemetry Sensor System

Kyung-Yup Kim+, Jong-Won Jeong++, Soo-Yol Ok+++, Joon-Tark Lee++++

Abstract : In this paper, a passive telemetry sensor system using Unscented Kalman Filter(UKF) is proposed. Specially, to show the effective tracking performance of the UKF, we compared with the tracking performance of Recursive Least Square Estimation (RLSE) using linearization.

Key words: unscented Kalman filter; recursive least square estimation; passive telemetry sensor system; 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].

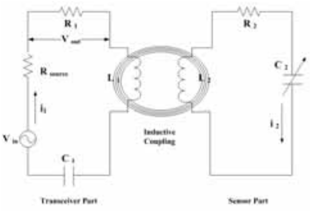

Fig. 1 The Principle of PTSS

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

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

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.

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

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.

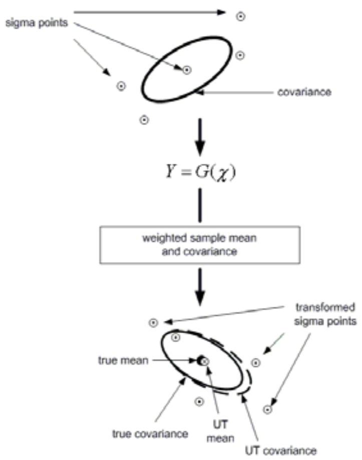

Fig. 2. The Principle of the Unscented

Random variable x has $n-by-1$ dimension and if

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sample mean and sample covariance are $\bar{x}$ and P_{xx}, a nonlinear function is mapping to each point to transformed points $\bar{y}$ and P_{yy}. A recursive loop of UKF for parameter estimation is as following Fig. 3

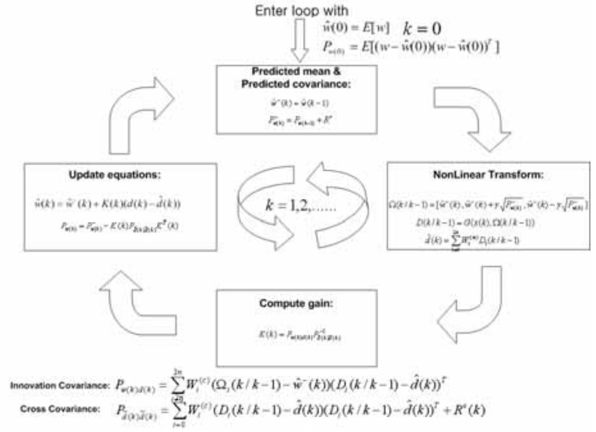


Fig. 3 A recursive loop of UKF for parameter estimation

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[H]	*Initial value of* C_2	500[pF]
C_1	80[pF]	M	8.2[H]
L_2	50[H]	R_{source}	30[Ω]
C_2	160,180,200 [pF]	R_2	10[Ω]
R1	5[Ω]	*span*	300[kHz] ~ 1.2[M*Hz*]
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.

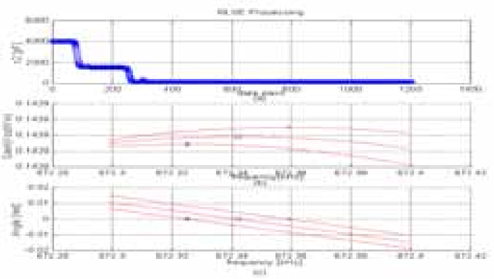
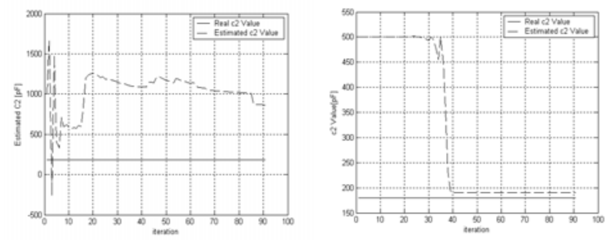


Fig. 4 Convergence Patterns, Gain and Phase Diagrams by RLSE

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. 5.



(a) (b)

Fig. 5 Parameter Estimation for the PTSS Problem: (a) with RLSE; (b)with the UKF

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.

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