A MAXIMUM LIKELIHOOD-BASED UNSCENTED KALMAN FILTER FOR MULTIPATH MITIGATION IN A MULTI-CORRELATOR BASED GNSS RECEIVER

Cheng Cheng[1], Quan Pan[1], Vincent Calmettes[2], Jean-Yves Tourneret[3]

1. School of Automation, Northwestern Polytechnical University, Xi'an, China 2. SCANR/DEOS-ISAE, University of Toulouse, Toulouse, France 3. IRIT-ENSEEIHT-TéSA, University of Toulouse, Toulouse, France

{cheng.cheng, vincent.calmettes}@isae.fr, {cheng.cheng, quanpan@nwpu.edu.cn}, jean-yves.tourneret@enseeiht.fr

INTRODUCTION

Signal Model

Received complex baseband signal associated with a given GNSS satellite affected by M multipath (MP) signals

$$r(t) = \sum_{m=0}^{M} a_m c(t-\tau_m)\exp(j\varphi_m) + \omega(t) \text{ with } \frac{d\varphi_m}{dt} = 2\pi f_m^d$$

a_m - signal amplitude τ_m - code delay time

φ_m - carrier phase f_m^d - Doppler frequency

Unknown received signal parameter vector

$$\boldsymbol{x}_k = (\boldsymbol{x}_{0,k}, \boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k})^{\mathrm{T}}$$

LOS signal parameter vector: $\boldsymbol{x}_{0,k} = (a_{0,k}, \tau_{0,k}, \varphi_{0,k}, f_{0,k}^d, \xi_{0,k}^d)^{\mathrm{T}}$

mth MP signal parameter vector: $\boldsymbol{x}_{m,k} = (a_{m,k}, \tau_{m,k}, \varphi_{m,k}, f_{m,k}^d)^{\mathrm{T}}$

M: number of MP signals.

Multipath mitigation techniques inside the GNSS receiver are often based on statistical estimation methods trying to estimate the parameters of the LOS and MP signals.

Problem description

The presence or absence of multipath signals depends on several factors:

- the relative motion between the receiver and GNSS satellites,
- the environment where the receiver is located.

Thus it is difficult to use a specific time propagation equation to accurately capture the dynamics of multipath signal parameters when the GNSS receiver is moving in urban canyons or other severe obstructions.

Two kinds of equations for describing the LOS and MP signal parameters

- LOS signal parameter: a dynamic equation

$$\boldsymbol{x}_{0,k} = \boldsymbol{F}_{k|k-1}\boldsymbol{x}_{0,k-1} + \boldsymbol{\Gamma}_{k-1}\boldsymbol{\omega}_{k-1}$$

- MP signal parameter: a likelihood equation

$$\boldsymbol{z}_k = \mathbf{h}_0(\boldsymbol{x}_{0,k}) + \mathbf{h}_1(\boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k})$$

$\boldsymbol{z}_k$ is measurement vector consisting of the multi-correlator outputs.

PROBLEM FORMULATION

Posterior probability density function of $\boldsymbol{x}_k$

$$p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k}) = p(\boldsymbol{x}_{0,k}, \boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k}|\boldsymbol{z}_{1:k})$$

$$p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k}) \propto p(\boldsymbol{z}_k|\boldsymbol{x}_{0,k}, \ldots, \boldsymbol{x}_{M,k}, \boldsymbol{z}_{1:k-1})p(\boldsymbol{x}_{0,k}|\boldsymbol{z}_{1:k-1})\underbrace{p(\boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k}|\boldsymbol{z}_{1:k-1})}_{\text{uninformative prior}}$$

$$p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k}) \propto p(\boldsymbol{z}_k|\boldsymbol{x}_{0,k}, \boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k}, \boldsymbol{z}_{1:k-1})p(\boldsymbol{x}_{0,k}|\boldsymbol{z}_{1:k-1})$$

No closed-form expression for $p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k})$.

PROPOSED SOLUTION

An iterative approach is proposed to compute the Bayesian estimators of the received signal parameter vector $\boldsymbol{x}_k$.

Step 1 Posterior pdf of $\boldsymbol{x}_k$ for a given LOS parameter vector $\boldsymbol{x}_{0,k}$

$$p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k}) = p(\boldsymbol{x}_{0,k}, \boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k}|\boldsymbol{z}_{1:k}) \propto p(\boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k}|\boldsymbol{z}_{1:k})$$
$$\propto p(\boldsymbol{z}_{1:k}|\boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k})$$

The posterior estimation of $\boldsymbol{x}_k$ can be implemented by using a maximum likelihood estimator of MP parameter vectors $(\boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k})$.

Step 2 Posterior pdf of $\boldsymbol{x}_k$ for given MP parameter vectors $(\boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k})$

$$p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k}) = p(\boldsymbol{x}_{0,k}, \boldsymbol{x}_{1,k}, \ldots, \boldsymbol{x}_{M,k}|\boldsymbol{z}_{1:k}) \propto p(\boldsymbol{x}_{0,k}|\boldsymbol{z}_{1:k})$$

The posterior estimation of $\boldsymbol{x}_k$ can be implemented by using the posterior estimation of the LOS parameter vector $\boldsymbol{x}_{0,k}$ (unscented Kalman filter).

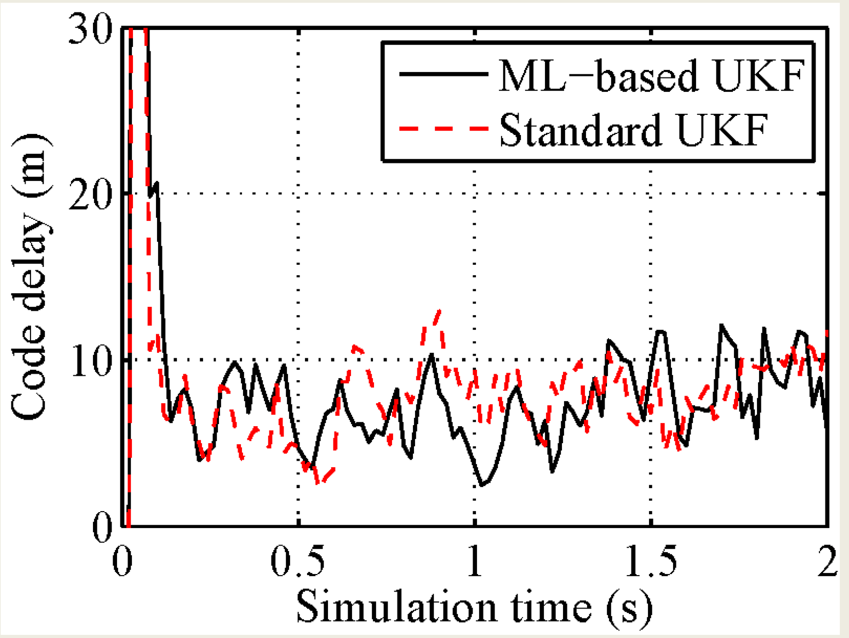
ALGORITHM

1. Compute $\hat{\boldsymbol{x}}_{0,k|k-1}$ and $\boldsymbol{P}_{k|k-1}$ according to the dynamic equation of LOS signal parameter vector at time k.
2. for $i = 1, \ldots, N$ do % N is the iteration times
3. if $i = 1$ implement **Step 1** by using $\hat{\boldsymbol{x}}_{0,k|k-1}$ and $\boldsymbol{P}_{k|k-1}$.
4. else implement **Step 1** by using $\hat{\boldsymbol{x}}_{0,k|k}^{(i)}$ and $\boldsymbol{P}_{k|k}^{(i)}$.
5. end if
6. implement **Step 2** by using $(\hat{\boldsymbol{x}}_{1,k}^{(i)}, \ldots, \hat{\boldsymbol{x}}_{M,k}^{(i)})$.
7. end for
8. LOS estimation $\hat{\boldsymbol{x}}_{0,k|k}^{(N)}$ and MP estimation $(\hat{\boldsymbol{x}}_{1,k}^{(N)}, \ldots, \hat{\boldsymbol{x}}_{M,k}^{(N)})$.

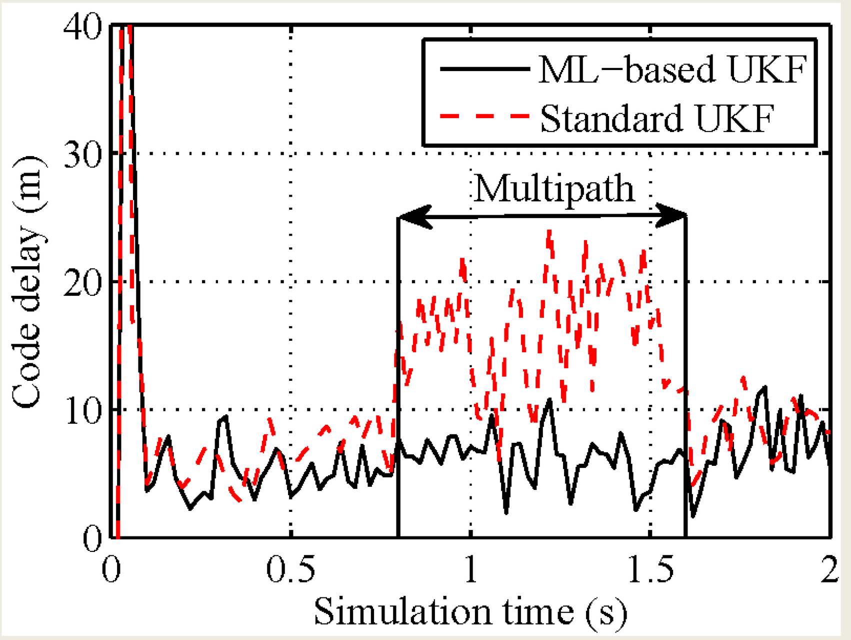
RESULTS

Scenario 1. Only a LOS signal is processed inside the receiver.

Scenario 2. The relative delay of MP is $(\tau_1 - \tau_0) \sim \mathrm{U}(0, 0.2)$.



Scenario 1



Scenario 2

- Efficient tracking of the LOS signal parameters.
- Same performance as a standard UKF.

- The standard UKF is strongly impacted contrary to the proposed estimator.
- Improve the accuracy of the code delay estimator.

CONCLUSION

- An iterative approach (maximum likelihood-based UKF) is investigated to estimate the LOS signal parameters in the presence of MP interferences.
- In the absence of MP interferences, the performance is equivalent to that of the standard UKF.
- In the presence of MP interferences, the estimation accuracy for the LOS signal parameters is improved.

FUTURE WORK

- Convergence analysis and accuracy evaluation.
- Validation using a realistic MP channel model developed by the DLR (Steingass and Lehner).