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Freshness constraints of an age of information based event-triggered Kalman consensus filter algorithm over a wireless sensor network

Key words: Distributed Kalman consensus filter (KCF); Event-triggered mechanism; Age of information (AoI); Stability analysis; Energy optimization

Corresponding author: Hui SUN
E-mail: h-sun@cauc.edu.cn
ORCID: https://orcid.org/0000-0001-7199-9059

Motivation

It is a trend to design a real-time pollutant monitoring system within a wireless sensor network (WSN) in the aircraft environment since the fly-by-wireless technology becomes more and more important for modern aircraft design. However, the accuracy of pollutant concentration detection using WSN may be impacted by the environmental interference such as dust and communication factors.

The energy consumption of the network is another issue that should be considered.

To prolong the lifetime of WSN, an event-triggered mechanism is normally used to save the energy by handling the packet loss and path loss. However, the latest sampling information cannot be received due to some reasons, which will affect the effectiveness of the detection system. Therefore, the measurement of freshness of sampling information is considered in this study.

Main idea

- The timeliness of the detection information can be guaranteed by calculating the age of information (AoI) of the sampled information to measure the freshness of the information.
- An event-triggered Kalman consensus filter algorithm based on information freshness constraints of AoI is designed to reduce the network energy consumption.

Method

1. We adopt the output correction structure for each integrated sensor node; the corresponding scheme is shown in Fig. 1. It can be seen that the measurement result of the primary sensor is $\boldsymbol{z}_{\mathrm{p}i}$, and the measurement result of the secondary sensor is $\boldsymbol{z}_{\mathrm{s}i}$. The difference between two measurements, $\boldsymbol{z}_i$, is fused with the estimated values of the neighbor nodes by KCF. The optimal state estimate of the sensor error is obtained. Finally, the error estimate is used to correct the measurement value of the primary sensor to obtain an optimal estimate of the concentration, $\boldsymbol{z}_{\mathrm{o}i}$.

Method (Cont'd)

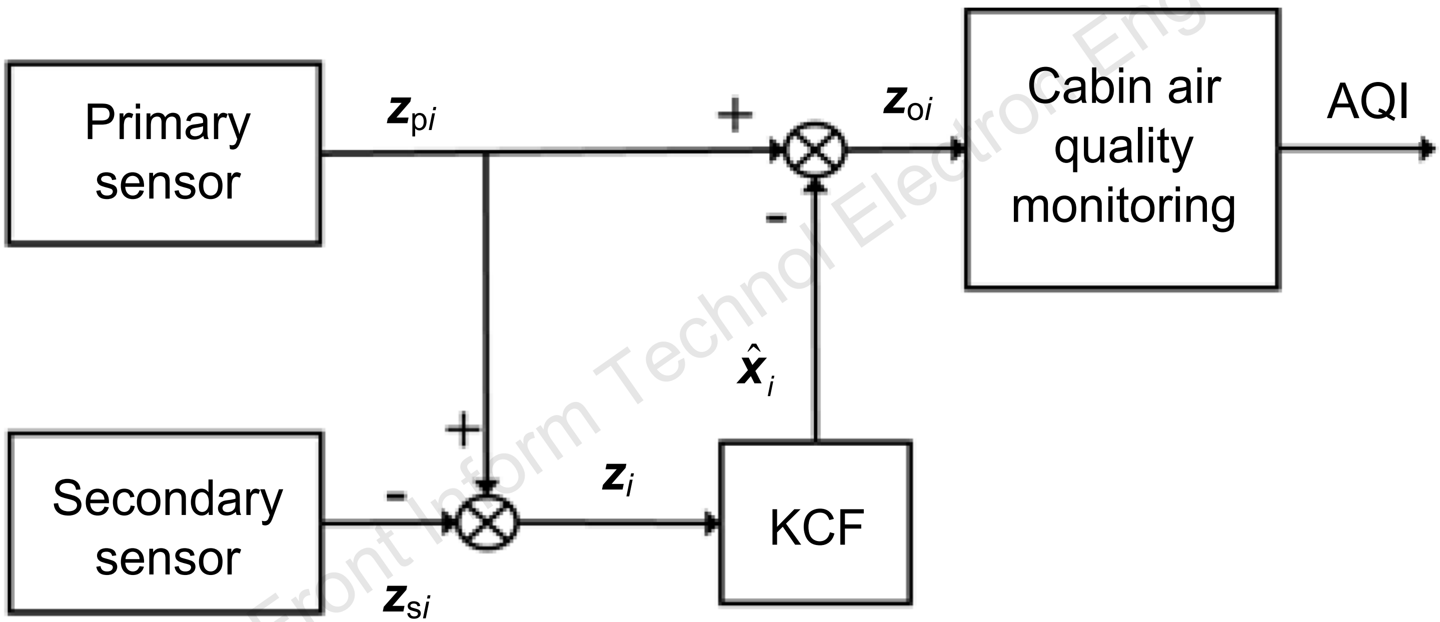


Fig. 1 Schematic of the output correction structure for an integrated sensor node (Wang et al., 2017)

Method (Cont'd)

2. To measure the freshness of the sampled information, the concept of AoI was introduced and the AoI of the sampled information was calculated under the *M*/*M*/1 queue model.

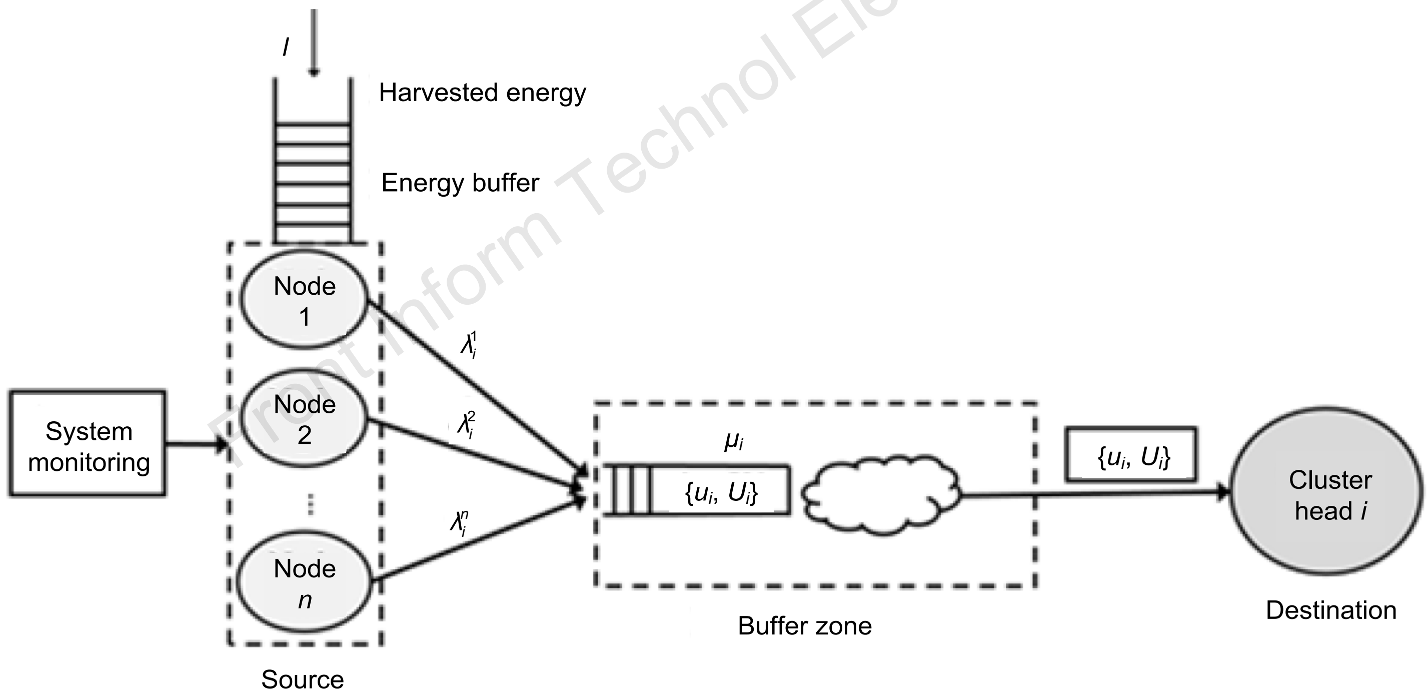


Fig. 2 Packet transfer model with energy harvesting in a cluster

Method (Cont'd)

3. We introduce the event-triggered mechanism designed using the freshness constraint of sampled information into the KCF algorithm to reduce the network transmission of expired information and reduce the network energy consumption.

The event-triggered function of the proposed freshness constraints of AoI based ET-KCF algorithm (FCET-KCF) is given as follows:

$$\xi_{i,k}=\begin{cases}1, & 0\le \dfrac{1}{\lambda_i^q}+\dfrac{1}{\mu_i}\le \Delta^*,\\[2ex] 0, & \dfrac{1}{\lambda_i^q}+\dfrac{1}{\mu_i}> \Delta^*,\end{cases}$$

Method (Cont'd)

The main idea about information freshness detection in the FCET-KCF algorithm is

$$\hat{\boldsymbol{x}}_{i,k} = \begin{cases} \hat{\boldsymbol{x}}_{i,k}, & \xi_{i,k} = 1, \\ \hat{\boldsymbol{x}}_{i,k-1}, & \xi_{i,k} = 0. \end{cases}$$

The latest estimate is transmitted when $\xi_{i,k}$=1; otherwise, for consensus calculation the previous estimate will be used to reduce the network energy consumption.

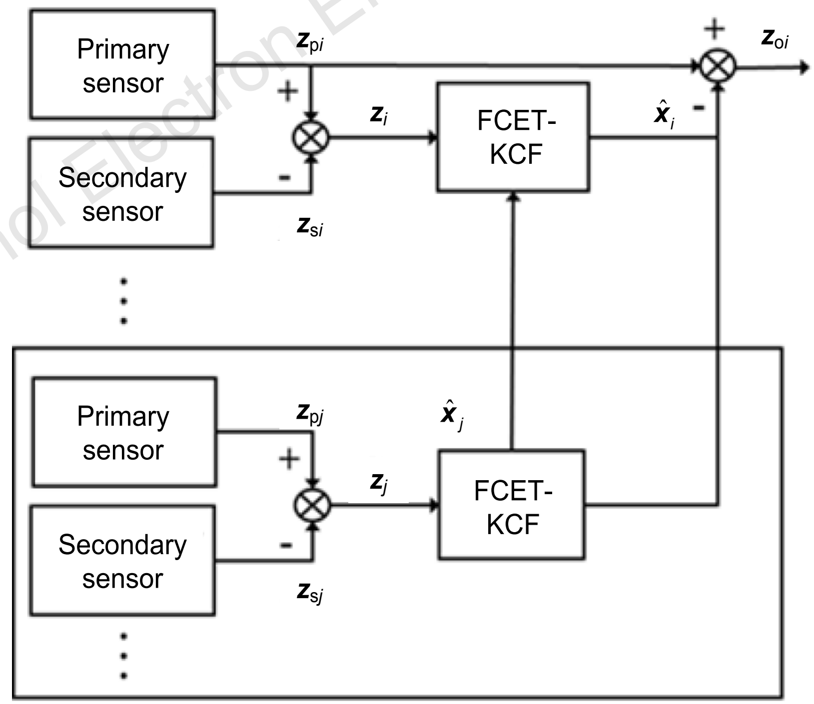


Fig. 5 Simulation configuration of the distributed monitoring sensor network

Major results

As shown in Fig. 6, when packet loss and path loss exist, KCF will diverge, while the ET-KCF algorithm proposed in Wang et al. (2019) and the FCET-KCF algorithm in this paper can still converge stably.

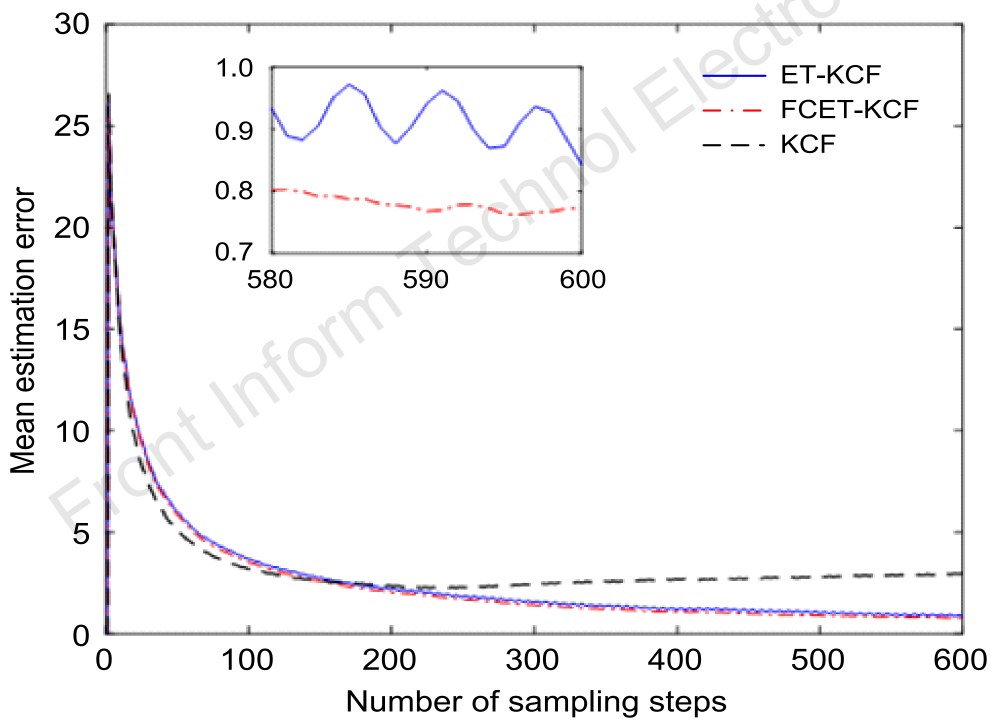


Fig. 6 Comparison of the average estimation error for different filters under packet loss and path loss

Major results (Cont'd)

According to Fig. 7, the average consensus error of FCET-KCF is nearly the same as that of ET-KCF and KCF. In the case of packet loss and path loss, the average consensus error of the system is much lower than that of the local Kalman filter.

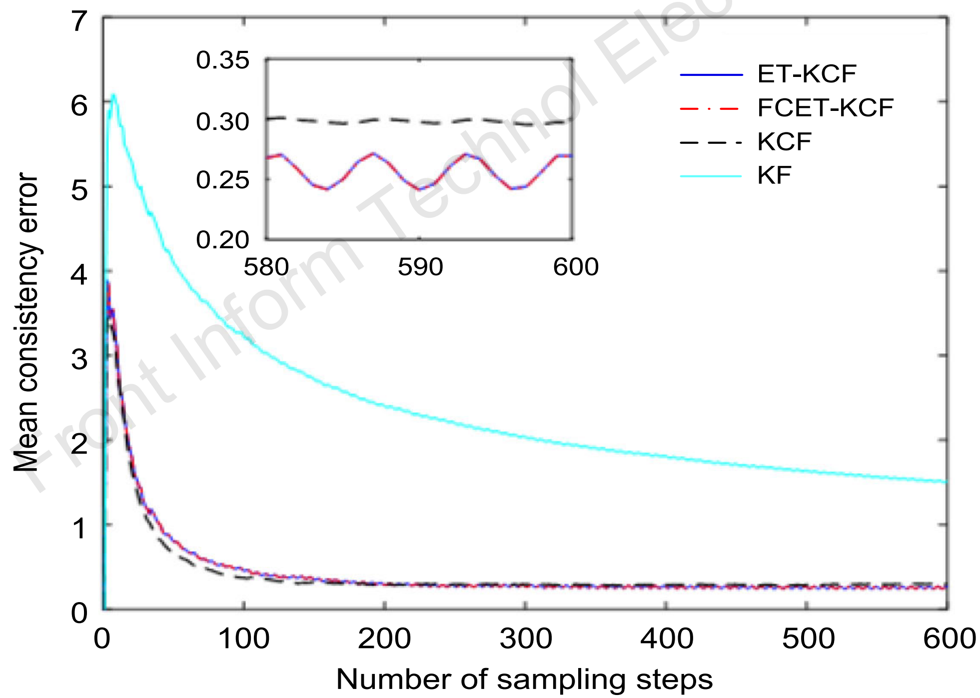


Fig. 7 Comparison of the average consensus error for different filters under packet loss and path loss

Major results (Cont'd)

Fig. 8 compares the energy consumption between FCET-KCF and ET-KCF. FCET-KCF consumes node energy after about 350 sampling steps, while ET-KCF consumes energy after about 100 steps. The simulation results demonstrate that FCET-KCF can reduce the bandwidth pressure and save system energy while ensuring the stability of the estimation algorithm.

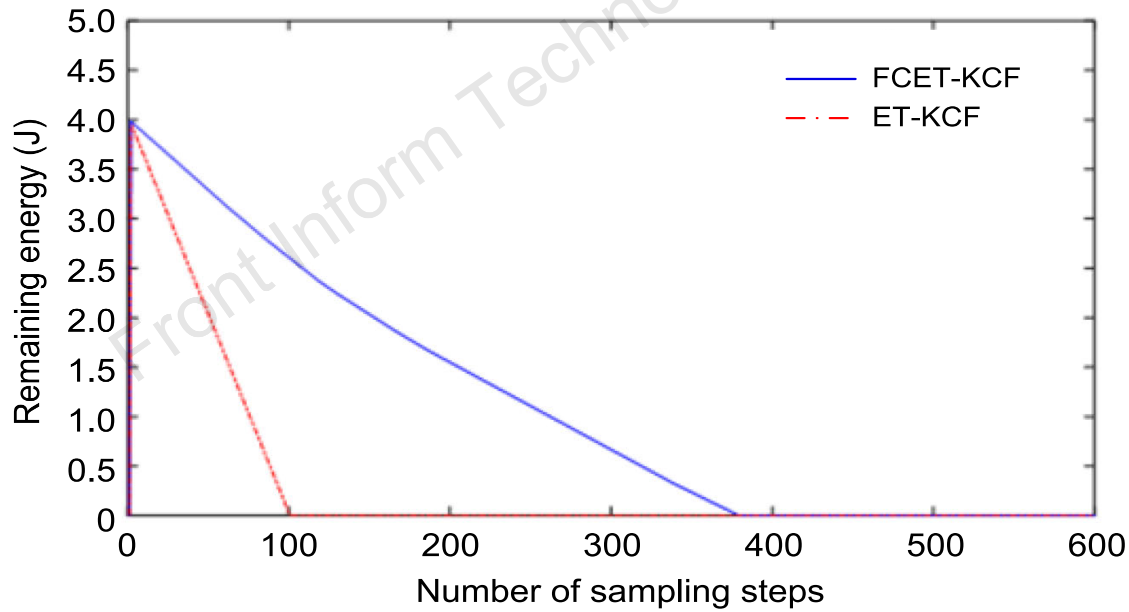
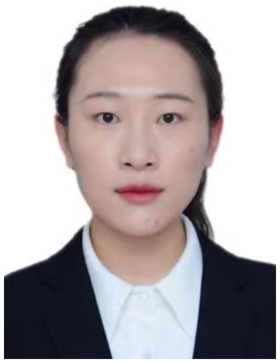


Fig. 8 Comparison of residual energy for the two filter algorithms

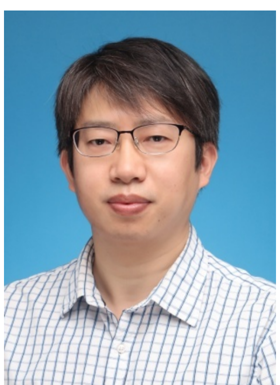
Conclusions

- In the WSN based aircraft cabin environment monitoring system, observed packet loss, communication packet loss, and path loss are considered comprehensively.
- We calculate and minimize the average AoI of the sampled information to select a suitable threshold.
- We propose a novel event-triggered Kalman consensus filter algorithm based on freshness constraints of AoI in a pollutant concentration monitoring system of aircraft cabins to enhance the real-time performance of the estimation system and reduce the system energy consumption.

王蕊，中国民航大学电子信息与自动化学院副教授，于2011年获得美国欧道明大学电气与计算机工程博士，目前主要从事分布式无线传感网络建模与应用、非线性/线性系统控制建模与仿真、多智能体容错协同控制等研究。担任2019、2021 Int Conf on Modelling, Identification and Control国际会议执行主席，2020~2021中国智能会议出版主席，*Int J Model Ident Contr*期刊编委等，中国人工智能学会智能空天系统专委会委员，CAA无人飞行器自主控制专委会委员，天津市“131”创新型人才培养工程第二层次人选。



李雅辉，中国民航大学控制科学与控制工程专业在读硕士生。



孙辉，中国民航大学电子信息与自动化学院教师，于2012年获得美国诺福克州立大学硕士学位，主要从事认知无线传感器网络的系统建模和分析、多智能体容错协同控制等研究，担任2019 Int Conf on Modelling, Identification and Control国际会议出版主席。

张友民博士是加拿大康考迪亚大学机械、工业与航空工程系及康考迪亚航空设计与创新研究所终身教授。是加拿大机械工程师学会(CSME)会士，美国航空航天学会(AIAA)和IEEE高级会员。张友民教授长期从事控制理论与工程应用方面的研究与开发工作，专长于故障检测与诊断、容错控制、感知与避障、飞行器导航、制导与控制、多智能体/多运动体容错协同控制及其与遥感测量技术相结合进行森林防火与森林资源管理、电力巡线与监测、环境监测、以及搜救与救援等领域的研究与应用开发。自1992年共发表500余篇期刊和会议论文及5本专著。目前担任ICUAS执行委员会委员，ISAS指导委员会委员，国际智能无人系统学会(ISIUS) 主席。张友民教授曾担任国际期刊*J Instrum Autom Syst*创刊主编（目前任荣誉主编），*J Intell Robot Syst*执行顾问委员会委员和北美区域负责人，*IEEE Trans Neur Networks Learn Syst*、*IET Cyber-Syst Robot*及与无人系统相关的多本期刊编委。担任国际自动控制联合会(IFAC)故障检测、监控和安全的技术过程技术委员会委员，AIAA无人系统集成专委会委员，IEEE机器人与自动化协会空中机器人和无人驾驶技术委员会委员，美国机械工程师学会(ASME)/IEEE机电一体化技术、嵌入式系统和应用技术委员会委员，中国自动化学会“技术过程故障诊断与安全性”“控制理论”“过程控制”“大数据”“导航、制导与控制”与“人工智能与机器人教育”专业委员会委员以及“可信控制”专业委员会副主任委员。