RCS Leakrate Calculation Using Bilateral Kernel Filters

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1. Introduction

The leakage from a RCS (Reactor Coolant System) is classified into 1) identified leakage which is defined as leakage into the closed system boundaries so that it can be captured and 2) unidentified leakage which is all other leakages. The timely and accurate detection of the unidentified leakage has significant meaning from a viewpoint of nuclear safety.

The unidentified leakage was typically determined by the RCS inventory balance method that NUREG-1107 recommended, which was the most preferable algorithm accepted in NPPs [1]. However, it turned out that the accuracy of the conventional method was quite susceptible to measurement uncertainty. To enhance the robustness of the RCS inventory balance method, NUREG/CR-6582 indicated such a trouble can be eliminated by using filtering techniques, for example, such as a linear regression [2]. On the basis of this recommendation, many of the NPPs including Korean NPPs have accepted the calculation algorithm which is based on the linear regression to eliminate noises or fluctuations [3]. It should be noted that there are still technical issues, for example, how to deal with transient conditions. Since the accuracy of leak rate calculation is also strongly dependent on the step change in thermo-hydraulic conditions or inventories, any transient conditions such as injection or discharge modes should be avoided during a test period. Particularly, as transient conditions take place, the linear regression is of no use and what's worse is it may output junk results, which must be very confused to operators. In order to enhance the capability of the RCS inventory balance method in transient conditions as well as steady state operations, the study using Kalman filter and smoother techniques which have the system state modeling capability was proposed [4]. After this study, we concluded that the study on the leak rate calculation would be worthwhile as not only a practical application to NPPs but also an academic concern. To extensively investigate the algorithm of the RCS inventory balance method, the subject was proposed and finally joined to the IAEA's Coordinated Research Project, entitled "Advanced Surveillance, Diagnostics, and Prognostics Techniques Used for Health Monitoring of Systems, Structures, and Components in Nuclear Power Plants " since December, 2008.

The study, therefore, aims at evaluating various and possible options to deal with transient conditions for more robust computation, and this paper is one of them; the feasibility of bilateral kernel filters to eliminate the noises or outliers during transient conditions.

2. Methods and Results

2.1 RCS Leakrate Calculation

Referring NUREG-1107, Fig. 1 provides the general framework of conducting the RCS inventory balance method in case of conventional PWRs. Normally, a test goes on during 2 hours. At the beginning and the end, the total mass of inventory inside a RCS pressure boundary in Fig. 1 is calculated respectively. If any deviation between them is detected, it is regarded as unidentified leakage.

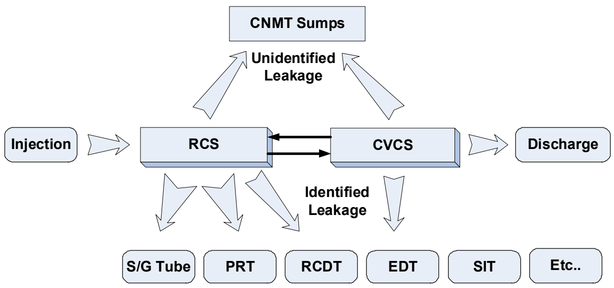

Fig. 1 Overall scheme of the RCS inventory balance method

2.2 Bilateral Kernel Filter

The bilateral filter is the technique preserving edges by mixing the moving average with nonlinear weights called 'kernel' on the basis of the proximity in space (or time) called 'distance' and local difference called 'feature' [5]. These two weights are expressed as a pair of Gaussian distributions:

$$\begin{aligned} k(t-t_i) &= k_D \times k_F \\ &= \exp(-d^2(t,t_i)/\sigma_t^2) \times \exp(-d^2(y,y_i)/\sigma_y^2) \end{aligned} \quad (1)$$

The Nadaraya-Watson kernel regression estimate of *y(t)* at specific time *t* is defined as

$$\hat{y}(t) = \sum y_i k(t-t_i) \Big/ \sum k(t-t_i) \quad (2)$$

where k_D is a distance kernel, and k_F is a feature kernel, $d(t,t_i)=\left(\sum|t-t_i|^p\right)^{1/p}$ is a distance in the Euclidean space, σ_t^2 and σ_y^2 are the variance called 'kernel bandwidth' of the spatial (or temporal) distance and the feature preservation respectively.

Increasing the kernel bandwidth stands for more distant points get an opportunity to affect the point at time *t*. As the bandwidth goes to infinity, the signal tends to the global average. Fig. 2 shows the performance of bilateral kernel filtering under some simulated conditions.

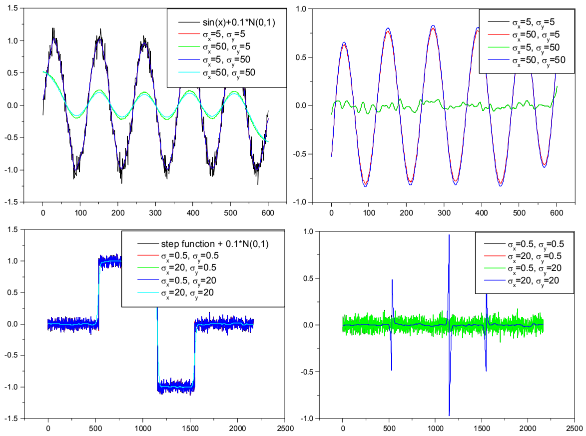

Fig. 2 Filtering results of sine signal (upper-left) and error (upper-right), step signal (lower-left) and error (lower-right)

2.3 Application of Bilateral Kernel Filter

Since the bilateral kernel filter can customize the smoothness of the regression by controlling the bandwidths, we tried to apply it to the signals involved in the RCS inventory balance method to clarify the identity of the signals during transient conditions.

All of the signals were classified into two groups: 1) a ramp dominant group including such as pressure or temperature and 2) a step dominant group including such as level or flowrate. The optimal bandwidths for distance and feature were decided such that the unidentified leakage is minimized when calculated by the RCS inventory balance method because the signals were acquired under no leakage condition. Fig. 3 shows the performance of bilateral kernel filtering for representative signals in Group 1 and Group 2 under different bandwidth conditions. Since the temperature of an EDT (Equipment drain tank) varies slowly, a larger distance bandwidth took a significant role to eliminate noise while a feature bandwidth did not contribute so much. The level of VCT (Volume Control Tank) behaves in a step manner, so a smaller feature bandwidth affects the filter performance.

3. Conclusion

This study attempted to enhance the numerical algorithm of determining a RCS leak rate using a bilateral kernel filter. We are going to investigate and validate more options to provide the best algorithm and implement the integrated package which can be delivered to commercial NPPs through the IAEA research program.

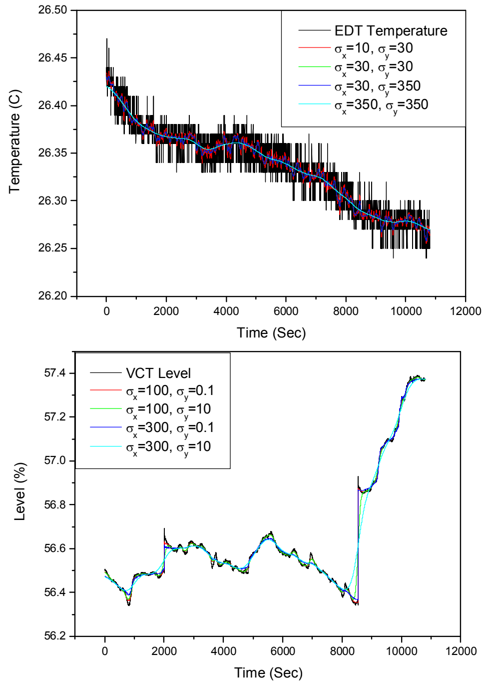

Fig. 3 Bilateral kernel filtering of an EDT temperature (upper) and a VCT level (lower)

ACKNOWLEDGMENTS

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