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Volume error spectrum for estimation performance evaluation in dynamic systems

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Abstract—Error spectrum is a comprehensive metric for estimation performance evaluation in that it is an aggregation of many incomprehensive measures. However, the error spectrum is a two-dimensional curve for any estimand (i.e., the quantity to be estimated) of interest. Therefore, unless one error spectrum dominates the others, it is in general not straightforward to say which one is better. To alleviate this, a new metric called volume error spectrum is proposed in this study to extend the error spectrum measure to dynamic systems. First, in dynamic systems, we redefined the error spectrum. Second, the volume error spectrum is presented according to the above redefined error spectrum. Finally, numerical examples are provided to illustrate the effectiveness of the metrics. It is shown that the simulation results validate its utility and effectiveness.

Keywords—Error spectrum; estimation performance evaluation; volume error spectrum

I. INTRODUCTION

In recent years, estimation performance evaluation (EPE) has received a great amount of attention due to their increasing application in estimation/filtering (see, e.g. [1]-[2], [4]-[14]), track fusion [15], and target tracking [16], etc. To the best of our knowledge, EPE includes mainly two components: the estimator ranking and the estimator evaluation. For the estimator ranking, Pitman proposed a criterion known as the Pitman closeness measure (PCM) [17]. Since then, most existing research has focused on the improvement of the non-transitivity problem of the PCM (see, e.g. [18]-[20]), which is a major obstacle for EPE. Inspired by the PCM, the authors of [21] proposed an estimator ranking vector which includes several performance metrics. Furthermore, we use the error spectrum to multiple-attribute estimation ranking [22]. Clearly, a key aspect in EPE is the selection and proper interpretation of the metrics used for the estimator ranking and the estimator evaluation. The root mean square error (RMSE) is widely used in EPE, since it is the most natural finite-sample approximation of its theoretical counterpart. As pointed out in [1] and [2], the RMSE is easily dominated by large error terms and has no clear physical interpretation. Therefore, it was replaced with the average Euclidean error (AEE) in several applications [1]. Although the AEE has several advantages, it is still affected by extreme values. Therefore, several incomprehensive performance measures were proposed (see, e.g. [2]-[3]), such as the harmonic average error (HAE), the geometric average error (GAE), median error, and error mode. Furthermore, the iterative mid-range error (IMRE) was presented in [4], since the above-listed metrics are not robust.

Unfortunately, all of the above-listed metrics can reflect only one aspect of the estimator performance. Thus, three comprehensive performance measures—the error spectrum (ES), desirability level, and relative concentration and deviation measures were proposed in [6]-[7]. Among these metrics, the ES can reveal more information about the estimation because it is an aggregation of several incomprehensive metrics. Since then, most existing researches have focused on the improvement of the ES (see, e.g. [8]-[13]).

However, the ES has some limitations and drawbacks. On one hand, its calculation without the error distribution is not easy, though in [12] (a further development of [6]), the authors provided analytical formulae for the computation of the ES when the error distribution is given. Therefore, we give two algorithms to calculate the ES, which can be found in [13]. On the other hand, for dynamic systems, it's hard to analyze the estimator's performance because ES is a three dimensional (3D) plot over the total time span. For this reason, a dynamic error spectrum (DES) reflects the estimation accuracy of an estimator was presented in [8]-[9], which is in fact the average height of the ES. Although the DES does provide a solution to this problem, it still has some limitations. For example, the DES provides a ruler only to measure how large the estimation error is [10]-[11]. To alleviate this, we proposed two new estimation evaluation metrics, i.e., range error spectrum (RES) induced area (RESA) and the DES induced area (DESA), where the RESA is designed to quantify the flatness of an error spectrum curve, and the DESA is designed to measure the estimation accuracy of an estimator. As pointed out in [10] and [9], the DES and the RES were proposed to combine the three-dimensional plot (the ES curve in dynamic systems) into a single two-dimensional plot. However, the two-dimensional are still difficult to reflect which estimator performs better.

The main contribution of this paper is that a new metric called volume error spectrum (VES) is proposed to evaluate the estimation performance in dynamic systems. First, we extended error spectrum to dynamic systems, which is still an aggregation of many incomprehensive measures. Second, since the error spectrum becomes a three-dimensional plot over the total time span, it is a natural way to use the volume between the ES curve and the time axis. Finally, an approximated calculation algorithm is proposed to compute the VES.

This paper is organized as follows. The ES, the DES and the EES are summarized in Section II. In Section III, we give the definition of the ES in dynamic systems is proposed, then, the VES is presented according to the above ES. Furthermore, a numerical example is provided in Section III to illustrate the superiority of the proposed metrics. The paper is concluded in Section IV.

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