論文 / 著書情報
Article / Book Information

題目(和文)	スパース性を活用した区分的連続信号・システムの推定に関する研究
Title(English)	A Study of Sparsity-Aware Estimation of Piecewise Continuous Signals and Systems
著者(和文)	黒田大貴
Author(English)	Hiroki Kuroda
出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第11135号, 授与年月日:2019年3月26日, 学位の種別:課程博士, 審査員:山田 功,植松 友彦,府川 和彦,尾形 わかは,笠井 健太,湯川 正裕
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第11135号, Conferred date:2019/3/26, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

A Study of Sparsity-Aware Estimation of Piecewise Continuous Signals and Systems [Outline]

Hiroki KURODA
Advisor: Prof. Isao YAMADA

Department of Information and Communications Engineering
Tokyo Institute of Technology

February 2018

Outline

Estimation of piecewise continuous signals from noisy observations has been a challenging problem in science and engineering, e.g., piecewise polynomial signals and piecewise sinusoidal signals. In many scenarios, such a signal can be expressed as, in a certain time-interval, a finite linear combination of known continuous basis functions. We refer to such a class of signals as finite-dimensional piecewise continuous (FPC) signals. A major challenge in the estimation of FPC signals is to localize *change points* from discrete noisy samples where change points are characterized by changes of linear combinations of basis functions across them.[1] Such challenges also arise in change detection applications which try to identify abrupt changes in signals, e.g., frequency-hopping communications, wind power production and optical fiber fault analysis.

The difficulty in the localization of change points is clearly seen from the fact that searching optimal estimates result in certain combinatorial problems intractable except for small-scale tasks. To reduce computational costs, most existing methods rely on local judges, e.g., statistical tests in short time-segments, pruning methods, and non-convex optimizations. However, there is no guarantee that estimates by these methods are optimal. In addition, the estimation accuracy is often degraded due to the local judges. For instance, it has been reported in that statistical tests in short time-segments are sensitive against model mismatch.

To avoid such difficulties, a promising alternative would be realized if one can extract features which can be exploited for the estimation problem from the special structure of the class of problems of interest. One of such powerful features is *sparsity* as extensive researches in past decades show that sparse vectors can be effectively estimated by, e.g., convex optimization using the ℓ_1 norm. In fact, such approaches have recently appeared in the literature. However, to exploit sparsity for the estimation problem, these approaches rely on a redundant representation space whose dimension is several times larger than the number of samples. This sparsity would be amplified due to the redundant spaces, and would not capture precisely the inherent feature of signals to be estimated. This concern suggests that, if an inherent sparsity hidden in FPC signals is available without introducing redundant dimensions, such a sparsity, say *sparsity in tight-dimensional spaces*, is expected to capture more precisely the feature of signals, and to yield more accurate estimation.

One of the main goals of this thesis is to present exploiting a hidden sparsity in a certain tight-dimensional representation space for estimation of FPC signals. More precisely, we first strategically

[1] We consider the situation where a FPC signal is not necessarily discontinuous on the change points. For instance, only the derivative of signal can be discontinuous.

design a tight-dimensional linear transformation which reveals sparsity hidden in discrete samples of FPC signals. The proposed transformation is *tight* in the sense that the dimension of the transformed domain does not exceed the number of samples. Then, by utilizing the newly revealed sparsity, we successfully translate the estimation of FPC signals into a convex optimization problem.

Meanwhile, estimation of piecewise continuous systems over multi-dimensional space has also been a challenging problem in, e.g., identification of hybrid systems involving both discrete and continuous dynamics. In such scenarios, similarly to the case of FPC signals, the system can be expressed as, in a certain multi-dimensional region, a finite linear combination of known continuous functions. We refer to such a class of systems as FPC systems over multi-dimensional space. Due to the multi-dimensional domain, the estimation of FPC systems is even more challenging than the estimation of FPC signals on real line.

The second goal of this thesis is to generalize the proposed approach for the estimation of FPC systems over multi-dimensional space. More precisely, we design a linear transformation which reveals sparsity for output values of FPC systems. This proposed transformation preserves the tightness in the sense stated above. We also demonstrate how the newly revealed sparsity can be exploited for the estimation of FPC systems over multi-dimensional space.

Moreover, this thesis also considers the adaptive estimation of a special class of piecewise continuous systems, that is, the cascade of clipping systems and finite impulse response (FIR) systems. This problem has become increasingly important due to nonlinearity introduced by actuators in acoustic devices and mechanical systems. We focus on the particular characteristic that non-smooth points of the clipping system are only a few, and the response of the clipping system is odd-symmetric. By leveraging this feature, we present an efficient algorithm for adaptive alternating estimation of clipping systems and FIR systems.

As a related application, in this thesis, we also treat the problem of nonlinear acoustic echo cancellation. More precisely, for nonlinear echo paths containing relatively large-size loudspeakers, we show how the sparsity of room impulse response vectors can be exploited for the estimation of echo path.