Title	What is an adaptive filter that extracts and elucidates useful information from signals? : Dedicated to creating an "ultimate filter" to unravel highly complex phenomena
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Author	田井中, 麻都佳(Tainaka, Madoka)
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Associate Professor Masahiro Yukawa featured in this issue, whose field of research focuses on an ultimate adaptive filter capable of freely extracting desired information from signals.

What is an adaptive filter that extracts and elucidates useful information from signals?

Dedicated to creating an "ultimate filter" to unravel highly complex phenomena

Our society is brimming with truly diverse signals (information), such as visual images, sounds, radio waves, brain waves and stock price fluctuations, to name a few. The primary role of signal processing is to convert these signals into numerical form and extract only a desired piece of information for identifying the characteristics of a given phenomenon or using it to make a projection. By taking a mathematical approach and making complex signals obtained from diverse phenomena in the universe easily usable, Associate Professor Masahiro Yukawa is intent on establishing a mathematical system useful for extracting needed information.

Signal processing – the backbone of electronics industry

"Suppose our modern world loses signal processing, we will suddenly find our life totally inconvenient and boring – no TVs, no mobile phones, no digital cameras and no airplanes flying in the sky. MRI, the medical equipment, is also a product of signal processing. Popular topics of our conversation of late, such as drones, androids and big data analysis, are also impossible without signal processing. In short, signal processing is something essential to our modern life just like air," mentions Dr. Yukawa.

For example, the microphone converts cellular phone sound into and the image sensor converts images captured by a digital camera into electrical signals, respectively. By replacing these electrical signals with numeric sequences, they come to be mathematically processed and become objects of the so-called signal processing.

"What I have actually focused my effort on is adaptive processing of acoustic and radio communication signals. One example is the echo canceler. In videoconference or cell-phone conversations, your voice may echo back to yourself belatedly via the other side's microphone, which is often annoying. The echo canceler is designed to cut the echoed voice only. Because your echoed voice is not necessary, signal processing performs subtraction and allows only the other side's voice to be delivered. Likewise, in the case of radio communication, adaptive signal processing deals with multiple communication data, which simultaneously arrive in the base station, separate and deliver them to individual users. What is indispensable to such signal processing is the "adaptive filter."

The role of adaptive filter is to estimate a function from data

Just like a coffee filter, the adaptive filter extracts, through a mathematical operation called "filtering", an exactly needed piece of information.

"Speaking of sounds, the role of the adaptive filter is to estimate the function f capable of extracting the required sound x from the observed sounds y. Putting it another way, we simply have to seek the function f because we need to estimate x from y," explains Dr. Yukawa.

As the term "adaptive" suggests, however, we, operators, must work – flexibly adapting the filter function to the constantly changing environments. In other words, the adaptive filter's performance depends largely on our ability to express, in real time, a function made as closer as possible to the required information while minimizing computational complexity.

Here's a major problem: most of actual

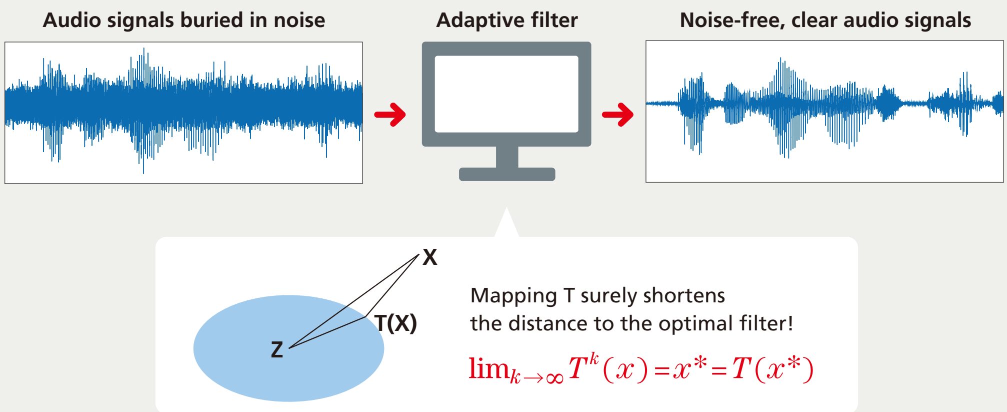

Fig. 1 Adaptive filter: its application example and basic principle
Functioning like a coffee filter for removing disagreeable taste elements from coffee, the adaptive filter can be used to extract clear audio signals by removing noises. The basic algorithm for updating a filter coefficient is based on a kind of nonexpansive mapping known as metric projection. When mapping T is a weighted average of a "nonexpansive mapping with fixed points" and the "identity mapping," it is known that the filter converges to a fixed point x* as T is operated repeatedly (Mann fixed-point theorem).

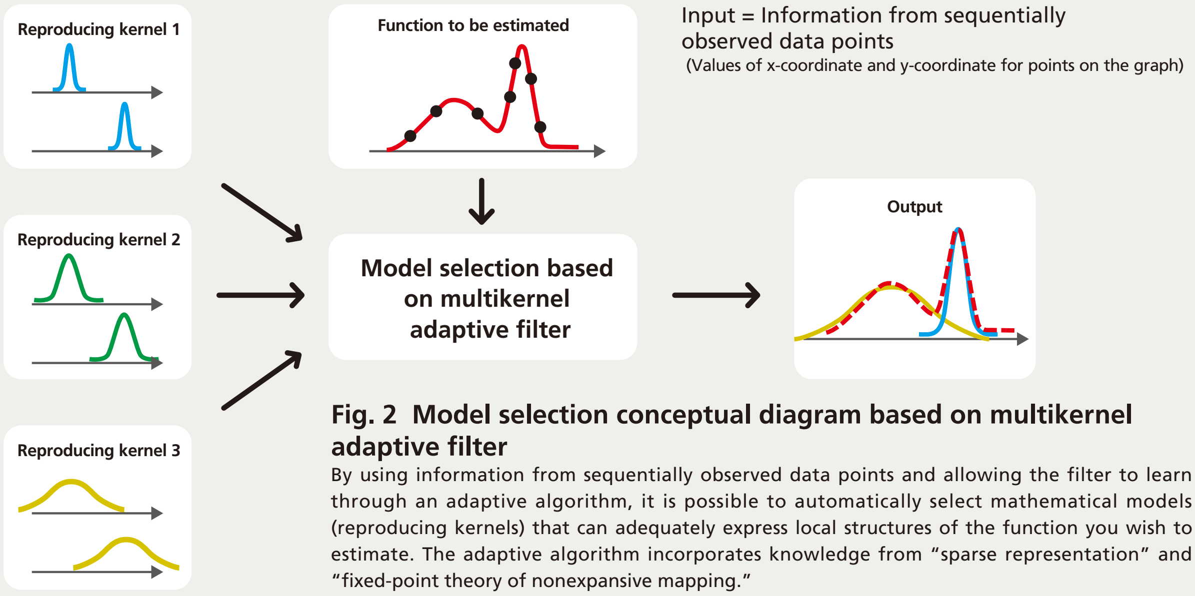

Fig. 2 Model selection conceptual diagram based on multikernel adaptive filter

By using information from sequentially observed data points and allowing the filter to learn through an adaptive algorithm, it is possible to automatically select mathematical models (reproducing kernels) that can adequately express local structures of the function you wish to estimate. The adaptive algorithm incorporates knowledge from "sparse representation" and "fixed-point theory of nonexpansive mapping."

phenomena are of nonlinearity, which is difficult in general to be handled mathematically. Nonlinearity means not being linear. In short, with these phenomena, input and output are not proportional to each other. Attempting to deal with nonlinear data causes the amount of computation to suddenly increase, making it difficult to extract the needed information speedily.

"Volterra filter and neural network are typical approaches to handling nonlinear data. But the former involves enormous volumes of computation while the latter has the drawback of ending up with a local minimum. To address these problems, I decided to adopt what is known as the "kernel adaptive filter" based on the kernel method.

The kernel method allows data to be mapped onto a feature space of higher dimensions (for example, from two dimensions to three dimensions), thereby converting a group of data into an easier-to-handle group. This technique is widely used for facial recognition and other pattern recognition as well as big data analysis. Formerly it was used in batch processing, a method to process batches of collected data all at once. In recent times, it is increasingly in use for online scenarios in which new data are collected and processed from moment to moment.

"I would omit explanation of reproducing kernel because it is too technical and difficult. But the benefit of reproducing kernel exists in that it can evaluate a function value as an "inner product." A simple example of an inner product is the sum of all products that have been obtained by multiplying two vector elements in series. The inner product makes it possible to express correlations between two vectors. Once these correlations can be expressed with an inner product, we can now use our knowledge of linear models to the fullest," Dr. Yukawa states emphatically.

In short, you can say that the greatest advantage of this method is that it allows us to use the easy-to-compute linear theory in dealing with usually difficult-to-handle nonlinear data.

Extracting exactly needed information in real time

Dr. Yukawa has developed the "multikernel adaptive filter," based on the kernel adaptive filter and making the most of the latest developments in convex optimization.

"To put it in a general image, the filter I developed approximates a function's waveform by adding up bell-shaped curves known as Gaussian kernels. We prepare in advance a number of Gaussian kernels – wide and low curves, narrow and high curves, etc. – then arrange coefficients, which determine their heights, in matrices. Finally, we estimate the function by adding up a smaller number of peaks."

"The key point here is to include a mechanism designed to automatically identify peaks that fit the function you wish to estimate while nullifying coefficients for most of the other peaks. Sparse matrices refer to those matrices that contain many zeros. Neat arrangement of information (in sparse matrices) enables optimal model selection."

This allowed us to adjust Gaussian kernel widths to nonlinear function forms adaptively and automatically and respond freely to function forms even when they may change with a lapse of time. Highly accurate estimate is thus possible with a smaller number of peaks.

"By using this technique, for example, we can make highly accurate, real-time predictions of future power outputs in solar power generation on the basis of power output data of the past," he adds.

The "fixed-point theory for nonexpansive mapping" is the mathematical foundation for Dr. Yukawa's study.

"A fixed point refers to a point that does not move even when mapping T is operated, that is, x such that Tx = x. Also, nonexpansivity refers to the characteristic which the operation of a mapping does not expand the distance between two points. Today, it is becoming increasingly known that solutions to problems – in various fields of science and engineering – can be expressed as fixed points of a mapping. Actually, the use of a nonexpansive mapping makes it easy to design fixed points, or algorithms to seek the solution of a problem. The multikernel adaptive filter estimates unknown functions by expressing ever-changing functions as fixed points of a mapping which is created using data that flow in from moment to moment," he remarks.

Dr. Yukawa expresses his desire to create an "ultimate filter" in the future — the ultimate filter capable of dealing with any complex phenomena. After 2015 set in, Dr. Yukawa is making a name for himself internationally as three of his papers were already accepted for publication in the journals of IEEE (The Institute of Electrical and Electronics Engineers, Inc.) and he was picked out as an Associate Editor for the world premium journal in the field of signal processing. He continues to focus on fundamental mathematical systems underlying the currently highlighted research themes such as distributed signal processing, big data analysis and deep learning while taking a side glance at them.

(Reporter & text writer : Madoka Tainaka)