Extended Summary

Estimation of Comfort/Discomfort Based on EEG in Massage
by Use of Clustering according to Correlation and Incremental
Learning type NN

Tatsuya Teramae Member (Tottori University)
Daisuke Kushida Member (Tottori University)
Fumiaki Takemori Non-member (Tottori University)
Akira Kitamura Non-member (Tottori University)

Keywords: EEG, Correlation Coefficient, Incremental Learning, Estimation of Comfortable/Uncomfortable Feeling, Massage

Authors proposed the estimation method combining k-means algorithm and NN for evaluating massage. However, this estimation method has a problem that discrimination ratio is decreased to new user. There are two causes of this problem. One is that generalization of NN is bad. Another one is that clustering result by k-means algorithm has not high correlation coefficient in a class. Then, this research proposes k-means algorithm according to correlation coefficient and incremental learning for NN.

Figure 1 shows flowchart of proposed method in this paper. The proposed k-means algorithm realizes classes with correlation coefficient more than constancy certain, since the evaluation function for correlation coefficient is considered in k-means algorithm. Flow of the incremental learning method is as follow. 1) New EEG data is measured when new user feels comfort/discomfort, 2) NN is selected based on clustering result from new EEG data, 3) New EEG data is incremental in learning data set of selected NN, 4) NN is learned using learning data set incremental new EEG data.

The proposed k-means algorithm and incremental learning method are verified by EEG data. 242 EEG data (comfort:121, discomfort:121) is set existing data. 20 EEG data (comfort:10, discomfort:10) is set new data. 242 EEG data was classified into 5 classes by proposed k-means algorithm. NN is learned by EEG data in each classes. The estimation result is shown in Figure 2. The discrimination ratio for verification data in each classes is shown in black bars. The discrimination ratio is average 86.4%, max 90% in all classes. The estimation result of conventional method is shown in slash bars. The conventional method is method using normal k-means algorithm. The discrimination ratio is average 82.4%, max 85%. In result, estimated accuracy is improved 4% by proposed k-means algorithm according to correlation coefficient. The discrimination ratio for new user’s data is shown in gray bars. In result, the discrimination ratio is average 52.5% and max 60% are low. On the other hand, the discrimination ratio by NN using incremental learning is shown in white bars. The discrimination ratio is average 86%, max 90%. In result, the accuracy of NN is improved by incremental learning.

![Fig. 1. Estimation method of comfortable/uncomfortable feeling based on EEG](image)

![Fig. 2. Discrimination ratio of estimated comfort/discomfort by NN](image)
PFC design via FRIT Approach for Adaptive Output Feedback Control of Discrete-time Systems

Ikuro Mizumoto Member (Kumamoto University, ikuro@gpo.kumamoto-u.ac.jp)
Taro Takagi Non-member (Kumamoto University)
Sota Fukui Non-member (Kumamoto University)
Sirish L. Shah Non-member (University of Alberta)

Keywords: Adaptive control, Output feedback, PFC, FRIT

1. Problem Statement

Consider a closed-loop system for a single input/output discrete-time system $G$ with a controller $C(p_C)$ and a PFC $H(p_H)$, which are parameterized by $\rho = [p_C^T \quad p_H^T]^T$ as shown in Fig. 1.

The controller and the PFC with the parameter $\rho = [p_C^T \quad p_H^T]^T$ satisfy the following assumptions.

**Assumption 1** $H(p_H) = 0$ with $p_H = 0$.

**Assumption 2** $C(p_C) = \rho_{a1}$ with $p_C = [\rho_{a1}, 0, \ldots, 0]^T$.

In this case, the closed-loop system from $r$ to the augmented output $y_a(p)$ with a controller $C(p_C)$ and a PFC $H(p_H)$ can be expressed by

$$G_{ac}(\rho) = \frac{(G + H(p_H))C(p_C)}{1 + (G + H(p_H))C(p_C)}$$

Here, we assume that one can obtain an input/output data set $\{u_0(k), y_0(k)\}$ for appropriate controller and PFC with parameters $\rho_0 = [p_{C0}^T \quad p_{H0}^T]^T$. Under this statement, the objective here is to obtain a PFC which renders the augmented system with the PFC ASPR.

To this end, we first consider a desired SPR system:

$$y_{SPR} = G_{SPR}r$$

and then consider to find a parameter $\rho = [p_C^T \quad p_H^T]^T$ which minimizes the error between SPR model output $y_{SPR}$ and the obtained augmented system’s output $y_a(p, k)$. That is, to find a parameter $\rho = [p_C^T \quad p_H^T]^T$ which minimize the following performance function:

$$J(\rho, k) = \sum_{k=0}^{N} (y_a(p, k) - y_{SPR}(k))^2$$

![Fig. 1. Closed-loop system](image)

is objective. However, this performance function cannot be obtained directly, because the plant model $G$ is unknown. Therefore we adopt FRIT approach to the parameter tuning.

2. Design of PFC

In order to achieve the objective of PFC design by using an input/output data set $\{u_0(k), y_0(k)\}$, here FRIT approach is considered. The following relation is satisfied for any parameter $\rho = [p_C^T \quad p_H^T]^T$:

$$C(p_C)(r^* \rho, k) - y_{ao}(\rho, k)) = u_0(k)$$

where $y_{ao}(\rho, k)$ is the augmented output with the PFC output $H(p_H)u_0(k)$:

$$y_{ao}(\rho, k) = y_0(k) + H(p_H)u_0(k)$$

**Assumption 3** There exists an ideal parameter vector $\rho_d = [p_{Cd}^T \quad p_{Hd}^T]^T$ with $p_{Cd} = [K^*, 0, \ldots, 0]$ such that the obtained closed-loop system with the controller $C(p_{Cd}) = K^*$ and the PFC $H(p_{Hd})$ can be expressed by the given SPR model $G_{SPR}$. That is,

$$G_{SPR} = \frac{(G + H(p_{Hd}))K^*}{1 + (G + H(p_{Hd}))K^*}$$

We define a virtual output $\tilde{y}(\rho, k)$ for the system with a controller and a PFC with a parameter $\rho$ as follows by using the input/output data set $\{u_0(k), y_0(k)\}$.

$$\tilde{y}(\rho, k) = G_{SPR}(C(p_C)^{-1}u_0(k) + y_0(k) + H(p_H)u_0(k)) - H(p_H)u_0(k), \quad \tilde{p}_C = [\rho_{d1}, 0, \ldots, 0]^T$$

Then, consider minimizing the following performance function:

$$J_F(\tilde{\rho}, k) = \sum_{k=0}^{N} (\tilde{y}(\tilde{\rho}, k) - y_{0}(k))^2$$

The obtained optimal $\rho_d$ by this FRIT approach can be expected to guarantee the minimization of the performance function given in (3).
Linear Multivariable Controller Tuning Using Measured Frequency Response Data

Zi-Jiang Yang  Member  (Ibaraki University, yoh@mx.ibaraki.ac.jp)

Keywords: Data-based control design, Frequency response, Controller tuning, DFT, PID controller

In many practical control applications for industrial processes, a mathematical description of the plant is not available, and the controller has to be designed on the basis of input-output measurements. This problem has attracted the attention of control engineers for several decades. Data-driven controller tuning approaches try to avoid the intermediate step of model identification so that the controller can be obtained directly from the data. The procedures typically estimate the controller parameters by minimizing a control criterion. In recent years, a resurgence of interest of data-driven controller tuning approaches has been witnessed in the literature.

Most of the recent methods in the literature are based on the time-domain data. And in these works, the performance and stability are not transparent before exact implementation of the designed controller.

On the other hand, if the DFTs of input-output data are obtained, we can obtain the frequency response measurements of the plant under study. By virtue of the frequency response plots, particularly Bode plots, some knowledge of the plant can be exploited in an early phase without the necessity of identifying a parametric model. Also, the stability of the closed-loop can be checked by the Bode plots or small gain theorem in the frequency-domain for linear systems. A control engineer can assess the plant properties, and determines the frequency shaping functions by investigating the visualized frequency response data. Therefore, the tuning process is considered to be more transparent in the frequency-domain.

Motivated by these discussions, in this paper, we propose a direct tuning method of linear multivariable model reference controllers based on frequency response measurements. The plant is stimulated by some appropriate block-pulse excitation signals, and the frequency response measurements are obtained by DFTs. Then a linearly parameterized controller is obtained by minimizing a frequency-shaped model reference control criterion at selected frequency points in the frequency-domain. The method usually does not need iterative experiments.

The proposed method is applied to a two input two output system:

\[
\begin{bmatrix}
    y_1(t) \\
    y_2(t)
\end{bmatrix}
= G_c(s)
\begin{bmatrix}
    u_1(t) \\
    u_2(t)
\end{bmatrix}
= \begin{bmatrix}
    G_{c11}(s) & G_{c12}(s) \\
    G_{c21}(s) & G_{c22}(s)
\end{bmatrix}
\begin{bmatrix}
    u_1(t) \\
    u_2(t)
\end{bmatrix}
\]  \hspace{1cm} (1)

where

\[
G_{c11}(s) = \frac{1}{10s + 1} e^{-4s}, \quad G_{c12}(s) = \frac{0.75}{15s + 1} e^{-3s}
\]

\[
G_{c21}(s) = \frac{-0.75}{30s + 1} e^{-6s}, \quad G_{c22}(s) = \frac{1}{20s + 1} e^{-5s}
\]

\hspace{1cm} (2)

It is clarified that a linear multivariable controller can be obtained by stimulating the system by some appropriate block-pulse excitation signals without the necessity of sufficient prior knowledge on the system. The resultant controller parameters are obtained as:

\[
\hat{C}_c(s) = \hat{C}_p + \hat{C}_i + \hat{C}_d \frac{s}{\gamma s + 1}, \quad \gamma = 4 \quad \cdots \cdots \cdots \cdots \cdots (3)
\]

\[
\hat{C}_p = \begin{bmatrix}
    1.0473 & -0.1790 \\
    0.3464 & 0.3435
\end{bmatrix}, \quad \hat{C}_i = \begin{bmatrix}
    0.0703 & -0.0134 \\
    0.0527 & 0.0174
\end{bmatrix}
\]

\[
\hat{C}_d = \begin{bmatrix}
    -0.5406 & 0.5120 \\
    0.9108 & -1.4537
\end{bmatrix}
\]  \hspace{1cm} (4)

And the Control performance is illustrated in the following figure, where \( r_1 \) and \( r_2 \) are the setpoint signals of \( y_1 \) and \( y_2 \) respectively.

![Control performance of the tuned controller.](image)
An Application of Fictitious Reference Iterative Tuning to State Feedback Control

Yoshihiro Matsui Member (Tokyo National College of Technology, matsui@tokyo-ct.ac.jp)
Shunichi Akamatsu Non-member (Tokyo National College of Technology)
Tomohiko Kimura Member (Tokyo National College of Technology, t-kimura@tokyo-ct.ac.jp)
Kazushi Nakano Member (The University of Electro-Communications, nakano@ee.uec.ac.jp)
Kazunori Sakurama Non-member (Tottori University)

Keywords: state feedback control, inverted pendulum, unstable system, gain tuning, FRIT, stability analysis

In this paper, an application method of Fictitious Reference Iterative Tuning (FRIT) to single-input multivariable systems is proposed.

To apply the FRIT to single-input multivariable systems, the systems are assumed as single-input single-output systems with output matrix \( c^T \), that is \( c^T(sI - A)^{-1}b \).

The initial data sets \( u_i \) and \( x_i \) acquired from a closed-loop system with an initial stable gain \( f_i^T \) are used for model matching by the FRIT so that the sum of square error between the actual plant output data \( y_i = c^T x_i \) and the reference model output data \( y_M \) is minimized in time domain as shown in Fig. 1. Therefore the state feedback gain \( f^T \) and the time constant \( \tau \) of the reference model \( M(\tau, s) \) are tuned using only the initial data sets \( u_i \) and \( x_i \) by Eqs.(1) ~ (3) without any additional experimental data.

\[
\rho = (f^T, \tau) \tag{1}
\]
\[
\rho^* = \arg \min_{\rho} J(\rho) \tag{2}
\]
\[
J(\rho) = \sum_{k=0}^{N-1} \varepsilon_2(k) = \sum_{k=0}^{N-1} \left[ y_M(k) - c^T x_i(k) \right]^2 \tag{3}
\]

Since the control performance of the closed-loop system with the state feedback gain tuned by the method depends on the choice of the output matrix \( c^T \), the data sets \( u_i \) and \( x_i \) are also used in frequency domain to estimate the frequency characteristics of the plant and to determine the output matrix \( c^T \) for the improvement of the control performance of the closed-loop system.

The method was applied to the state feedback gain tuning for an inverted pendulum with an inertia rotor shown in Fig. 2.

It was shown that the state feedback gain was tuned by the proposed method so that the disturbance responses of the closed-loop system with the gain were improved significantly as shown in Fig. 3, where the state variables are \( x_1 = \theta_1 \), \( x_2 = \dot{\theta}_1 \), \( x_3 = \theta_2 \) and \( x_4 = \dot{\theta}_2 \).
Design of a Self-Tuning Controller using Multiple Local Linear Models for Nonlinear Systems

Shinichi Imai  Member  (Hiroshima National College of Maritime Technology, imai@hiroshima-cmt.ac.jp)
Toru Yamamoto  Senior Member  (Hiroshima University, yama@hiroshima-u.ac.jp)

Keywords: Local Linear Models, Self-Tuning Control, Pole-Assignment Control, Nonlinear Systems

Almost real-world plants are represented by nonlinear systems. Therefore, it is important to consider control schemes to cope with such systems. In this paper, a control method for nonlinear systems is newly proposed. Some local linear models on typical equilibrium points are first designed, followed by linear controllers corresponding to these models. The distances between the query and these local models are calculated, and the weights are computed in proportion to the distances. These weights are put for local controllers, and the controller corresponding to the query can be designed. According to the proposed scheme, the good control performance can be easily obtained. The effectiveness of the control scheme is illustrated by some simulation examples.

This paper therefore proposes to consider the stability and characteristics of control systems for nonlinear models and to utilize the pole placement control, with which control system design is possible, in order to build multiple local linear models, obtain individual parameters for each of these local linear models, and switch parameters for the equilibrium points. This method features more appropriate parameter tuning than nonlinear models, since parameters are determined for multiple individual local linear models.

Simulation that applies the newly proposed scheme to a nonlinear system is performed, and the effectiveness is consequently considered. The nonlinear system that applies is as follows:

\[ y(t) = 0.4y(t-1) - 0.99y(t-2) + 0.3u(t-1) - 0.1u(t-2) + 0.1y(t-1)u(t-1) + 0.05y(t-2)u(t-2) + \xi(t) \]  

Where \( \xi(t) \) denotes the white Gaussian noise, which has zero mean and variance 0.01\(^2\). The reference signal \( r(t) \) is given as follows:

\[ r(t) = \begin{cases} -1.0 & (0 \leq t < 100) \\ 1.0 & (100 \leq t < 200) \\ 6.0 & (200 \leq t < 300) \\ 3.0 & (300 \leq t < 400) \end{cases} \]  

Fig. 1. Control result using the newly proposed control scheme in the case of bilinear model.

The local linear model is given in the following manner.

\[ -4.0 \leq u_1 < 2.0 \]  
\[ 2.0 \leq u_2 < 3.4 \]  
\[ 3.4 \leq u_3 < 4.0 \]  

The number of divisions used here was 3. This paper does not consider the method for dividing local linear models, since that is considered to be an issue to be dealt with in the future. Furthermore, various parameters included in the proposed method were set as \( n_y = 2, n_u = 1, k_m = 0 \).

The control result for the proposed method is shown in Figure 1. Referring to Figure 1, the weight from Figure 1 is shown in Figure 2. Local model parameters are varied appropriately according to the characteristics of the system to obtain favorable control results with the proposed method, as seen from the results shown in Figure 2.

A method involving the building of multiple local linear models and obtaining parameters for each local linear model, in order to switch parameters according to equilibrium points, has been proposed in this paper. With the method presented here, on the other hand, there is no concept of learning time and since the parameters are calculated from multiple local models, it is possible to make it available online. Such advantages are effective for application on actual systems. Furthermore, it was verified through a numerical simulation that favorable control results are obtained by switching a parameter appropriately according to the characteristics of the system for a nonlinear system.
Multi-rate Control System for Improvement in Intersample Response Based on State-space Representation

Takao Sato Member (University of Hyogo, tsato@eng.u-hyogo.ac.jp)
Yoshiki Hattori Non-member (University of Hyogo, es10042@steng.u-hyogo.ac.jp)
Nozomu Araki Non-member (University of Hyogo, araki@eng.u-hyogo.ac.jp)
Yasuo Konishi Non-member (University of Hyogo, konishi@eng.u-hyogo.ac.jp)

Keywords: multi-rate control system, steady state, sample response, intersample response, state-space representation.

The decision of sampling and hold intervals is an important issue in the design of sampled-data control systems, in which a continuous-time plant is controlled using a digital computer in discrete time, and the selection of intervals greatly influences the control quality. However, it is not easy to set these intervals arbitrarily because of hardware constraints. This paper proposes a new method for the design of a multi-rate single-input single-output sampled-data control system under the constraint that the sampling interval of the plant output in continuous time is an integer multiple of the hold interval of the control input, which is updated in discrete time. In the design of the multi-rate control system, the intersample plant output can possibly oscillate even if the sampled plant output converges to its reference input. In conventional design methods, to improve intersample ripples, both the sample and the intersample responses are simultaneously designed, and then, the original sample response might be deteriorated even though the intersample response is improved. In this study, a multi-rate control law, which stabilizes a closed-loop system, is extended on the basis of state-space representation, and the multi-rate control system is redesigned such that the steady-state intersample response is improved independently of the sample response. As a result, the sample response is maintained and the intersample response is improved in the steady state. Numerical examples demonstrate the effectiveness of the proposed method.

The proposed method is applied to HDD head control, and the simulation results are shown in Fig.1 and Fig.2. Fig.1 shows the head position using the conventional method, and it can be seen that the sample response converges to its reference input but the intersample response oscillates. However, Fig.2 shows that the intersample ripples can be eliminated and the sample response is maintained using the proposed method.

Fig. 1. HDD head position using multi-rate control

Fig. 2. HDD head position using extended multi-rate control
Design of an Implicit GMV-PID Controller Using Closed Loop Data

Shin Wakitani Student Member (Hiroshima University, wakitani-shin@hiroshima-u.ac.jp)
Kei Hosokawa Non-member (Hiroshima University, hosokawakei@hiroshima-u.ac.jp)
Toru Yamamoto Senior Member (Hiroshima University, yama@hiroshima-u.ac.jp)

Keywords: PID Control, Generalized Minimum Variance Control, Implicit Method, Closed Loop Data

PID control strategies have been applied for a lot of process systems because the control structure is simple and the physical meanings of PID parameters are clear. Some schemes which adjust PID parameters have been proposed, however, in most of these methods, control parameters are computed based on the system model.

On the other hand, model-free methods represented by VRFT (Virtual Reference Feedback Tuning) or FRIT (Fictitious Reference Iterative Tuning) have attracted much attention in last few years. According to these methods, the control parameters can be tuned by using only one set of experimental data.

In this work, a new design scheme of implicit PID controllers using a set of experimental data is proposed. The proposed scheme is based on the GMVC (Generalized Minimum Variance Control) and control parameters are calculated without system parameters, and then these control parameters are approximately replaced by PID parameters. In addition, the proposed controller has a user-specified parameter \( \lambda \), and the tracking property and the stability of the control system can be adjusted by choosing the suitable value of \( \lambda \).

The effectiveness of the proposed control scheme is verified on a temperature control system. The experimental equipment is shown in Fig.1. First the PID control whose PID parameters are computed by the CHR (Chien, Hrones, Reswick) method is employed and the control result is shown in Fig.2. Next the proposed method is applied, and the control results are shown in Fig.3 and Fig.4, where the user-specified parameter \( \lambda \) is set to 0 and 0.01, respectively. These figures show that the control performance is drastically improved by using the proposed method. Moreover, it is clear that the control performance is influenced by \( \lambda \). It is necessary to choose the user-specified parameter \( \lambda \) in consideration of the control performance. This is our future work.

Fig. 1. Appearance of the temperature control equipment.

Fig. 2. Experimental result by using the CHR method.

Fig. 3. Experimental result by using the proposed method where \( \lambda \) is equal to 0.

Fig. 4. Experimental result by using the proposed method where \( \lambda \) is equal to 0.01.
Application of Two Degree-of-Freedom Generalized Predictive Control to Temperature Control Experiment of an Aluminum Plate

Akira Yanou Non-member (Okayama University, yanou@suri.sys.okayama-u.ac.jp)
Satoshi Okazaki Non-member (Okayama University, okazakis@suri.sys.okayama-u.ac.jp)
Junki Nishizaki Non-member (Okayama University, nishizaki@suri.sys.okayama-u.ac.jp)
Shiro Masuda Member (Tokyo Metropolitan University, smasuda@sd.tmu.ac.jp)
Mamoru Minami Non-member (Okayama University, minami@suri.sys.okayama-u.ac.jp)
Seiji Saito Non-member (Chugoku Polytechnic College Shimane, s7.saitou@ehdo.go.jp)

Keywords: generalized predictive control, two degree-of-freedom, process control

This paper explores an application of two degree-of-freedom generalized predictive control (GPC) (1) to temperature control of an aluminum plate. Two degree-of-freedom GPC has the feature that its controller reveals an effect of integral compensation only if there is modeling error or disturbance. Therefore performance degradation due to an integral compensation, such as excessive control effort or slow response, can be expected to avoid. In this paper, this feature is defined as two degree-of-freedom system because the characteristics of output response with and without modeling error and disturbance can be designed independently, that is, on one hand the characteristic of output response without modeling error and disturbance is designed by minimization of objective function which includes control input and tracking error, on the other hand the characteristic of output response with modeling error and disturbance is designed by a gain of integral compensator. In order to verify the validity of proposed method, this paper explores numerical simulation and experiment for an aluminum plate thermal process with proposed method.

Two Degree-of-Freedom GPC

Consider a single-input single-output stable system,

\[ A[z^{-1}]y(t) = z^{-k}B[z^{-1}]u(t) \]  \hspace{1cm} (1)

In order to make system output \( y(t) \) track reference signal \( r \), the control input \( u(t) \) of two degree-of-freedom GPC is given as follow,

\[ u(t) = H_0(z^{-1})r - F_0(z^{-1})y(t) + Gz(t) \]  \hspace{1cm} (2)

Where \( H_0(z^{-1}) \) and \( F_0(z^{-1}) \) are designed by GPC strategy and optimal servo system concept. \( G \) is design parameter for gain of integral compensation \( z(t) \). The integral compensation \( z(t) \) is calculated so that \( z(t) \neq 0 \) (that is, the integral compensation appears) only if there is modeling error or disturbance. In other words, \( z(t) \) is always zero if there is neither modeling error nor disturbance.

Numerical and Experimental Results

From aluminum plate thermal process, its model as single-input single-output system is derived as,

\[ A[z^{-1}] = 1 - 3.02z^{-1} + 3.452z^{-2} - 1.849z^{-3} + 0.4615z^{-4} - 0.0428z^{-5} \]

\[ B[z^{-1}] = 0.0486 - 0.118z^{-1} + 0.1017z^{-2} - 0.0364z^{-3} + 0.0046z^{-4} \]

Where \( k_{an} = 1 \). The control parameters are set to \( N_1 = 1 \), \( N_2 = 1 \), \( N_3 = 0.01 \) and \( G = 0.1 \). Reference signal is \( r = 4 \). In Fig. 1 derived by numerical simulation, the proposed method reveals an effect of integral compensation when there is step-type disturbance after 500 sec. In Fig. 2 by experimental, the proposed method can track the reference signal. Moreover, the submitted paper compares to conventional GPC (2), and the effectiveness of proposed method is discussed.

References

Stabilization for Uncertain Multi-channel Markov Jump Stochastic Systems with Additive Gain Perturbations

Muneomi Sagara Member (Prefectural University of Kumamoto, sagara@pu-kumamoto.ac.jp)
Hiroaki Mukaidani Member (Hiroshima University, mukaida@hiroshima-u.ac.jp)

Keywords: Markov jump systems, multi-channel systems, additive gain perturbations, fuzzy control.

1. Introduction
In this paper, stabilization problem for a class of multi-channel Markov jump stochastic systems with additive gain perturbations is addressed. A sufficient condition for the existence of the controller is derived in term of matrix inequality. In the sequel, the mode-independent strategy set is considered.

2. Problem Formulation
Consider the linear stochastic difference equation governed by Markovian jumps defined by

$$
x(k+1) = [A(r_k) + \Delta A(r_k, k)]x(k) + \sum_{j=1}^{N} [B_j(r_k) + \Delta B_j(r_k, k)]u_j(k) + A_i(r_k) \Delta x(k), w(k), \quad x(0) = x^0, \ldots, (1)$$

where $x(k) \in \mathbb{R}^n$ represents the state vector, $u_j(k) \in \mathbb{R}^l$, $j = 1, \ldots, N$ represent the $j$-th control inputs. $w(k) \in \mathbb{R}$ is a one-dimensional stochastic process defined in the filtered probability space. $r_k$ is a Markov chain taking values in a state space $\mathcal{S} = \{1, 2, \ldots, s\}$. Let us introduce the matrices $A(r_k) = A(i), A_i(r_k) = A_i(i)$ and $B_j(r_k) = B_j(i)$, where $r_k = i, i = 1, \ldots, s$. Here the matrices mentioned above have appropriate dimensions. The Markov chain $r_k$ has the transition probabilities given by

$$P_r\{r_{k+1} = j \mid r_k = i\} = p_{ij}, \quad p_{ij} > 0, \quad \sum_{j=1}^{s} p_{ij} = 1.$$  \hspace{1cm} (2)

On the other hand, the deterministic uncertainties are given below.

$$\Delta A(r_k, k) : = D_a(r_k)F_a(r_k, k)E_a(r_k), \ldots, (3a)$$

$$\Delta B_j(r_k, k) : = D_{b_j}(r_k)F_{b_j}(r_k, k)E_{b_j}(r_k), \ldots, (3b)$$

where $[F_a(r_k, k)] \leq 1$ and $[F_{b_j}(r_k, k)] \leq 1$.

It is assumed that the strategy has the following form.

$$u_j(k) = u_j(r_k, k) = [K_j(r_k) + \Delta K_j(r_k, k)]x(k) = [K_j(r_k) + D_{f_j}(r_k)F_{f_j}(r_k, k)E_{f_j}(r_k, k)]x(k), \ldots, (4)$$

where $[F_{f_j}(r_k, k)] \leq 1$.

On the other hand, the cost performance for each strategy subset is defined by

$$J(x_0, r_0, u_1, \ldots, u_N) = \sum_{j=1}^{N} \gamma_j J_j(x_0, r_0, u_j, \ldots) \hspace{1cm} (5)$$

where $\sum_{j=1}^{N} \gamma_j = 1, 0 < \gamma_j < 1, J_j(x_0, r_0, u_j) = E \sum_{k=0}^{\infty} \left[ x_k^T(k)Q_j(r_k)x_j(k) + u_j^2(r_k, k)R_j(r_k) \mid x_0, r_0 \right]$.

The aim of this paper is to find the Pareto strategy set that minimizes the cost (5).

3. Main Result
The following theorem indicates the mean square stability of the stochastic system.

**Theorem 1** A stochastic system described by (1) with the following control law (7) is mean square stable if the LMI (6) holds.

$$u(k) = [u_1(k) \cdots u_N(k)] = [Y X^{-1} + D_jF_j(k)E_jx(k)] \cdots \cdots \hspace{1cm} (7)$$

Then we have the cost bound.

$$J(x_0, r_0, u_1, \ldots, u_N) = E[x_T(0)X^{-1}x(0) \mid r_0 = i].$$ \hspace{1cm} (8)

It should be noted that the mode-independent additive gain controller can stabilize the stochastic system even though the systems modes cannot be observed.

In order to ensure easy implementation and simple design, fuzzy control is considered as the additive gain perturbation.
Machine-learning-based Controller Design for Discrete-valued Input Systems

Eiji Konaka Member (Meijo University, konaka@meijo-u.ac.jp)

**Keywords:** discrete-valued input system, machine learning, approximate nearest neighbor method, support vector machine

Switching and ON/OFF controls are effective control techniques for control systems equipped with low-resolution actuators. They can be modeled as control systems that restrict the control input to discrete values. In this class of systems, the controller classifies input/output sequence and output reference into a discrete control value.

On the basis of this concept, a controller design method based on a machine-learning technique is discussed in this paper. Machine-learning-based methods have the following advantages:

- No internal model of the plant is required. That is, these methods are “model-free.” Only the input and output sequences are needed.
- They can be applied to nonlinear plants.
- A nonlinear controller can be designed automatically by using them.

Learning data is composed of the current situation (previous input sequence and previous output sequence) and the output evolution. The corresponding teaching data is the applied input. The relation between learning and teaching data is learned by using certain supervised machine learning methods (Figure 1).

Specifically, different machine learning methods, such as the approximate nearest neighbor (ANN) method and the support vector machine (SVM) method are used in this study.

The ANN method that combines the k nearest neighbor (kNN) method and locality sensitive hashing (LSH) method is used. The kNN method is known as the simplest deterministic supervised learning method. However, this method requires substantial computation for a large database. The recently developed LSH method is a promising solution for computation-related problem of the kNN method.

The SVM method is also a deterministic supervised learning method. Unlike the kNN method, the SVM method requires a training procedure that is formulated as a quadratic programming problem. However, SVM method can realize quick classification.

A trained classifier is a controller that connects the current situation with a suitable control input that can drive the current output to the desired one.

The effectiveness of the proposed method is verified for discrete-valued input systems via certain simulations and experiments. Figure 2 shows a control result for a DC servomotor. The output is the angle of the motor. The horizontal axis represents the sampling index. The sampling interval is 10 [ms].

This result shows that the output can follow the reference when the proposed method is used. It should be noted that the larger the output error is, the larger is the magnitude of the input. This result also shows that a pulse-width modulation (PWM)-like controller for an unknown plant can be designed automatically using only the input/output sequence with the help of the proposed method.

![Fig. 1. Supervised learning for discrete-valued controller](image1)

![Fig. 2. DC servomotor control result (SVM method)](image2)
Design of Performance Driven Self-Tuning PID Control Systems and Its Application for DC-DC Converters

Yoshihiro Ohnishi Member (Ehime University)
Takahiro Ikemoto Non-member (Kure National College of Technology)
Toru Yamamoto Senior Member (Hiroshima University)

Keywords: control performance assessment, self-tuning control, PID control

PID control schemes based on the classical control theory, have been widely used for various process control systems for a long time. However, since such many industrial processes have time varying properties and changing operating regimes it is difficult to find a suitable set of PID parameters that will provide optimal process performance under all conditions. One solution for dealing with such systems is to implement self-tuning (STC) or adaptive control. The basic structure of STC consists of the following steps. First, the property of the controlled system is identified by an on-line identification method such as recursive least squares. Next, the control parameters are calculated from the estimated parameters by using any one of the several PI(D) controller design algorithms. Finally, the control input is generated by the newly computed control parameters. Clearly adaptation or auto-tuning should only be carried out only when the control performance deteriorates. It is not difficult to get an on-line measure of controller performance. Many control performance assessment methods have been proposed and many instrument and control vendors have software that allows one to obtain a performance index. One of the first performance monitoring index was based on the minimum variance control benchmark based method proposed by Harris. The performance index in this case can be defined as the ratio of minimum variance of the closed loop output and the current actual output variance. This index can then be expressed as the value between 0 and 1. The index near 1 means good control performance, and near 0 means poor performance that may need retuning of control parameters. This paper deals with the design, implementation and evaluation of an adaptive PID controller which is driven by current control performance. The calculations of the PID parameters are based on the generalized minimum variance control (GMVC) algorithm. The current control performance is obtained in an online manner over a user-specified time-window with some overlap. The retuning of PID parameters are only carried out when controller performance deteriorates below a user-specified threshold. The algorithm of the proposed scheme is shown as Fig.1. The least squares identification algorithm is employed for the purpose of system identification. Experimental evaluations on the voltage control of the DC-DC converter demonstrates the practicality and utility of this idea. Fig.2 shows the trajectory of the performance index by using the proposed scheme. The performance index is recovered after system changing.
Modeling of Nonlinear Systems using Genetic Algorithm

Kayoko Hayashi  Non-member (Graduate School of Engineering, Hiroshima University)
Toru Yamamoto  Senior Member (Div. of Electrical, Systems and Mathematical Engineering, Hiroshima University)
Kazuo Kawada  Member (Graduate School of Education, Hiroshima University)

Keywords: System Identification, Evolutionary Computation, Modeling Genetic Algorithm, Nonlinear System

1. Introduction

System is controlled by the controller, the controller is designed that system output y sucks around desired value r. Generally, the controller is designed by the model based on the system property. However, it is difficult to characterize system because many real systems have nonlinearity. In this paper, a newly method of modeling for nonlinear systems is proposed. This scheme is determined system structure and system parameters using genetic algorithm (GA). And to show the effectiveness of the proposed scheme, some numerical simulation results are illustrated.

2. System Modeling using Evolutionary Computation

2.1 Problem Statement

The ideal model must be compactly and exactly and its parameters and the model structure are estimated easily. From these points, The NARMAX (Nonlinear-ARMAX) is employed. The NARMAX model is described as follows:

\[ \hat{y} = \theta^T \psi(t) \]

where

\[ \theta = [ c_1 \ c_2 \ \cdots \ c_{l-1} \ c_l ] \]

\[ \phi = [ x_1(t) \ x_2(t) \ \cdots \ x_{l-1}(t) \ x_l(t) ]^T \]

\[ \theta, \omega \text{ and } l \text{ are the model parameters, the model structure and the number of model term, respectively.} \]

2.2 Modeling Algorithm using GA

It is important to determine the model structure and its time-delay when control object is identified. In this scheme, these elements are estimated by simple GA (SGA). Moreover, the model length can have variable-length gene by using GA, so the model length is adjusted to suitable. The model structure and time-delay are coded as Table 1. The element of model structure consists of 0, 1, u and y and system nonlinearity is given these combination. The generated individuals are evaluated by following equation (3):

\[ f := \frac{1}{1 + \sum_{i=1}^{N} |y(t) - \hat{y}(t)|} - \omega \cdot \frac{l}{100} \]

Table 1. Encoding in bit strings

<table>
<thead>
<tr>
<th>structure</th>
<th>time-delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>0</td>
</tr>
<tr>
<td>01</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>u</td>
</tr>
<tr>
<td>11</td>
<td>y</td>
</tr>
</tbody>
</table>

N and l are the number of step and the model length, and \( \omega \) is penalty parameter. The crossover is divided into two phases because model length and order of each term is variable. In step.1, after selected parents at random are given crossover point, the terms since crossover point are switched around. In step.2, crossover is performed for every terms of the model.

3. Simulation Examples

In order to evaluate the effectiveness of the newly proposed scheme, following Hammerstein model system is considered.

\[ y(t) = 0.6y(t - 1) - 0.1y(t - 2) + 1.2x(t - 1) + 0.1x(t - 2) + \xi(k) \]

\[ x(t) = 0.5u(t) - 1.5u^2(t) + 0.5u^3(t) \]

where \( \xi(k) \) denotes zero mean and covariance 0.01. The proposed scheme is employed. The obtained mathematical model is as follows:

\[ \hat{y}(t) = 0.51693y(t - 1) - 0.054252y(t - 2) + 0.0027669y(t - 3) + 1.80196u(t - 1) - 0.89987u^2(t - 1) - 0.60005u^3(t - 1) + 0.00043422y(t - 1)y(t - 2) - 0.076492. \]

In comparison with equation (4) and obtained model, these static property are shown in Fig. 1. As a result, the static property of the obtained model approximates these of original model.

4. Conclusions

In this paper, the newly modeling scheme using GA has been proposed. Then, we have illustrated a numerical result to show the effectiveness. We must consider adaptation to the actual system in the near future.

Fig. 1. The comparison the static property.
Development of a Nonlinear Soft-Sensor Using a GMDH Network for a Refinery Crude Distillation Tower

Kenzo Fujii Non-member (Idemitsu Kosan Co. Ltd., kenzo.fj@mopera.net)
Toru Yamamoto Senior Member (Hiroshima University, yama@hiroshima-u.ac.jp)

Keywords: GMDH networks, modeling, foaming prediction, refinery crude distillation tower, nonlinear systems

The liberalization and internationalization of refinery and petrochemical process industries has caused global competition, and the further decreasing of production costs has become a notable problem in such industries. Therefore, the key point in the near future will be how to manufacture high-quality products at low cost using useful production technologies. In order to overcome such problems, some advanced control technologies, (e.g., model predictive control (MPC) and dynamic matrix control (DMC)), have been developed in the last two decades. However, if the process can be highly stabilized by such control methods, the operating target or the operating mode is moved to a target where profit can be further expected. Therefore, there are many cases where processes are operated at critical points which are considerably close to the stable limit. Moreover, the crude oil is optimally switched corresponding to the production market, and as a result the stable margin cannot be secured in the operation because properties of the ADT drastically change due to the switching of crude oil. That is, the operation in the ADT falls into unstable states, and the steady production of products cannot be maintained since abnormal phenomena such as foaming and flooding are generated in the ADT unit. The characteristics and factors of these phenomena have not yet been clarified, and it has also been difficult to forecast them due to nonlinearities.

The main objective in this paper is to establish a monitoring method for such irregular phenomena in the ADT by using GMDH (Group Method of Data Handling) which is shown in Fig. 1. An important feature of GMDH is composed of some N-Adaline that the input-output relation can be described by a mathematical model as shown in Fig. 2. According to the conventional GMDH method, the least squares method is usually utilized in determining the weight coefficients (system parameters). However, in order to improve the accuracy of estimation, it is desirable that the error criterion in the GMDH method is not limited to the squared errors and is freely designed. Therefore, instead of the linear least squares method, the nonlinear least squares method is employed in this paper. In the ADT unit to be considered in this paper, it is hoped to obtain the forecast value with high accuracy around the area of the regression. In this light, the evaluation is based on the minimum area (i.e., the absolute value is more suitable than the evaluation on the least squares method). The Levenberg-Marquardt (LM) method is introduced as a nonlinear least squares method in this paper. There is no study, to the best of our knowledge, that employs the LM method in adjusting the weight coefficients in the GMDH network.

The behaviour of the proposed monitoring system is examined in the ADT unit. The proposed GMDH network model was employed, which has the objective function based on minimization of the summation of the absolute value of the prediction errors. By setting $\alpha$ as 0.55, the absolute values of the prediction errors can be approximately computed. The prediction result is shown in Fig. 3. The number of layers was 7 and the contribution ratio was 0.6206. It is therefore clear that the highest prediction accuracy can be obtained by the proposed GMDH network model. In particular, the prediction data corresponding to about 6 of the measured data is drastically improved.
Extended Summary

System Identification in $H^\infty$ for Multiple Sets of Data

Hideyuki Tanaka Non-member (Hiroshima University)

Keywords: $H^\infty$ worst-case identification, subspace system identification, multiple sets of data, robust control

1. Introduction
In designing robust control systems, it is well known that we need not only a nominal model, but also an uncertainty model. The progress in robust control theories has brought a renewed interest in the estimation of uncertainty sets from data. Set membership identification for robust control has been extensively studied, and $H^\infty$ identification is one of the most investigated methods.

The literature of $H^\infty$ identification is now already very extensive. However, as far as the author knows, there are few researches on modeling under multiple sets of data. There are motivations for uncertainty modeling under multiple sets of data. For example, if a nonlinear system is given, and if we can locally operate the system at different operating points, we have multiple sets of data from identification experiments. As another example, we can consider a parameter-dependent system.

In this paper, we study identification in $H^\infty$ for multiple sets of data. We develop an algorithm for giving a model set under multiple sets of data in the frequency domain, by using subspace identification methods and linear matrix inequalities (LMIs).

2. Modeling from Multiple Sets of Data
We carry out identification experiments for $P^{(i)}(z) \ (i=1,\ldots, M)$, generating data independently: $y^{(i)}_t = P^{(i)}(z)u^{(i)}_t + v^{(i)}_t$, \hspace{1cm} (1)

where $u^{(i)}_t \in \mathbb{R}^d$ and $y^{(i)}_t \in \mathbb{R}^p$ respectively the input and output for the $i$-th plant $P^{(i)}(z)$, and where $v^{(i)}_t$ expresses the noise satisfying $E\{u^{(i)}_t(v^{(i)}_t)^\top\} = 0$. We assume that $u^{(i)}_t$ and $v^{(i)}_t$ are zero-mean weakly stationary processes, and that there is no feedback from the output $y^{(i)}_t$ to the input $u^{(i)}_t$. We moreover suppose that $v^{(i)}_t$ and $v^{(j)}_t$ are mutually independent for $i \neq j$, since they are stochastic noises in different experiments.

Define $w^{(i)}_t = [u^{(i)}_t(v^{(i)}_t)^\top]^\top$, and describe the spectral density function of $w^{(i)}_t$ as $\Phi^{(i)}(\omega)$. We moreover suppose that multiple sets of measurements of the spectral density functions $\Phi^{(i)}(z_k) \ (i=1,\ldots, M)$ are available at finite frequency points $z_k = e^{j\omega_k}$ ($\omega_k = 2k\pi/2N, k=0,\ldots,N$).

We write a model of the input $w^{(i)}_t$ and the output $y^{(i)}_t$: $y^{(i)}_t = \hat{P}(z)u^{(i)}_t + e^{(i)}_t \ (i=1,\ldots, M), \hspace{1cm} (2)$

where $\hat{P}(z)$ is a nominal model and $e^{(i)}_t$ is the error. Taking the prior knowledge of noises into account, we have $e^{(i)}_t = \Delta(z)u^{(i)}_t + d^{(i)}_t$, \hspace{1cm} (3)

for $k = 0, \pm 1, \ldots, \Delta(z)$ expresses an uncertainty, and where $d^{(i)}_t$ is a noise model. From (2) and (3), we have a model $y^{(i)}_t = P_\Delta(z)u^{(i)}_t + d^{(i)}_t \ (i=1,\ldots, M)$, where $P_\Delta(z) = \hat{P}(z) + \Delta(z)$. In this paper, we find a nominal model $\hat{P}(z)$ and an uncertain model $\Delta(z)$.

3. Numerical Simulation
Assume that the true plants $P^{(i)}(z)$ are given by $P^{(i)}(z) = \frac{c(z-b_1)(z-b_2)(z-b_3)}{(z-a_1)(z-a_2)(z-a_3)}$, where $a_k \ (k=2,3), b_k \ (k=1,2,3)$ and $c$ are constants, and where $a_1(\rho)$ is also a constant dependent on $\rho$. Each identification experiment is carried out for the frozen $\rho_t \ (i=1,\ldots, 5)$. We suppose that frequency domain data $\Phi^{(i)}(z_k)$ are available under the noises $v^{(i)}_t$.

We have state space realization of $\hat{P}(z)$ with a model set $\mathcal{M}$ in (4). In Fig.1, the dotted circles indicate that the model set $\mathcal{M}$ includes $\hat{P}(z)$ and $P^{(i)}(z)$.

![Fig. 1. Nyquist plots of $P^{(i)}(z)$ and $\hat{P}(z)$.](image)

---
Extended Summary

Image Watermarking Scheme for Specifying False Positive Probability and Bit-pattern Embedding

Kohei Sayama Non-member (Hiroshima University, sayamakouhei@hiroshima-u.ac.jp)
Masayoshi Nakamoto Member (Hiroshima University, masy@hiroshima-u.ac.jp)
Mitsuji Muneyasu Member (Kansai University, muneyasu@kansai-u.ac.jp)
Shuichi Ohno Non-member (Hiroshima University, ohno@hiroshima-u.ac.jp)

Keywords: image watermarking, discrete wavelet transform (DWT), false positive probability, correlation-based detector, bit-pattern, PSNR

1. Introduction
This paper treats a discrete wavelet transform (DWT)-based image watermarking with considering the false positive probability and bit-pattern embedding. We propose an iterative embedding algorithm of watermarking signals which are $K$ sets pseudo-random numbers generated by a secret key. In the detection, $K$ correlations between the watermarked DWT coefficients and watermark signals are computed by using the secret key. $L$ correlations are made available for the judgment of the watermark presence with specified false positive probability, and the other $K-L$ correlations are corresponding to the multi-bit signal. The advantages of the proposed method are that not only to be able to specify the false positive probability in the watermark detection but also to able to embed the bit-pattern signal into the host image.

2. Proposed Method
First, the $K$ sets pseudo-random numbers are generated by the key as shown in Fig. 1. $L$ sets are used for the detection of the watermark presence, and the others ($K-L$ sets) are used for the multibit. This random numbers are embedded into the DWT coefficients of the host image by using the following expression ($k = 1, 2, \cdots , K$):

\[
\hat{Y}^{(1)}(i,j) = \hat{Y}^{(0)}(i,j) + \alpha x_1(i,j)
\]
\[
\vdots
\]
\[
\hat{Y}^{(L)}(i,j) = \hat{Y}^{(L-1)}(i,j) + \alpha x_L(i,j)
\]

where $Y^{(k)}(i,j)$ is $(i,j)$ element of the $k$-time embedding DWT coefficient. $\alpha$ is a parameter that is decided by the strength of the watermark and it can be calculated by the specified PSNR. $x_k(i,j)$ is $(i,j)$ element of the $k$-th pseudo-random number. We obtain $\hat{Y}^{(K)}(i,j)$ after the multibit is embedded into $\hat{Y}^{(L)}(i,j)$. The watermarked image can be obtained by the IDWT of $\hat{Y}^{(K)}(i,j)$. Also, the bit-pattern are embedded as

\[
\hat{Y}^{(L+1)}(i,j) = \hat{Y}^{(L)}(i,j) \pm \alpha x_1(i,j)
\]
\[
\vdots
\]
\[
\hat{Y}^{(K)}(i,j) = \hat{Y}^{(K-1)}(i,j) \pm \alpha x_K(i,j)
\]

where the each bit (0 or 1) is corresponding to the sign of $\alpha x_k(i,j)$.

In the detection, we calculate the $K$ correlations between the watermarked DWT coefficients and watermark signal generated by the key which is used in the embedding process. From the correlations, we can detect the watermark presence and recover the bit-pattern.

3. Experimental Results
Let us use two host images Mandrill and Lenna whose sizes are both $M = N = 512$. Figure 2 shows the detection result of the watermark signal in Mandrill, and the 500th watermark is corresponding to the correct one. Other watermarks are generated by the incorrect keys. Similarly, the bit-pattern embedded into digital image can be detected only by the correct key. In addition, we confirmed that this method has comparison against JPEG compression, scaling down and cropping by some experimental results in Mandrill and Lenna.

![Fig. 1. Random number generator](image1.png)

![Fig. 2. Detection result of the watermark signal](image2.png)
A Study on the Improvement of Dynamic Loudspeaker Nonlinear Distortion

Takamasa Inuzuka  Student Member  (Tokyo Metropolitan University)
Misawa Kasahara  Member  (Tokyo Metropolitan College of Industrial Technology)
Yasuchika Mori  Senior Member  (Tokyo Metropolitan University)

Keywords: dynamic loudspeaker, disturbance observer, nonlinear distortion

Recently, the distortion caused by signal transduction has been significantly reduced because of development of digital signal processing technology so that sound quality has improved dramatically. However, speaker system located at the end of the so and reproduction has not changed since the basic principle of the invention, the nonlinear distortion occurs mostly have been concerned about the deterioration of sound quality. It is important to eliminate this distortion in high fidelity music playback. In order to reduce the nonlinear distortion, we propose a system using disturbance observer and consider in this method.

Constituting disturbance observer is to estimate the disturbance as part of the state, under this theory, replacing the nonlinear distortion of loudspeaker systems as a disturbance to estimate it.

As shown in equ.(1) to define the extended system including the disturbance and its route of penetrate.

\[
\begin{bmatrix}
\dot{x}_a(t) \\
\dot{x}_b(t) \\
\dot{d}(t)
\end{bmatrix} =
\begin{bmatrix}
A_{11} & A_{12} & D_1 \\
A_{21} & A_{22} & D_2 \\
0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
x_a(t) \\
x_b(t) \\
d(t)
\end{bmatrix} +
\begin{bmatrix}
B_1 \\
B_2 \\
0
\end{bmatrix} u(t) \cdots \cdots (1)
\]

By designing an observer for this system, it is possible to estimate the equivalent non-linear distortion. Then, by feeding back the estimated nonlinear distortion, nonlinear distortion can be suppressed to the speaker.

Select the Mirror filter to compare the responses,(the conventional method). This method is a nonlinear inverse filter to simulate the dynamics of the speaker, a predistorter to compensate the nonlinear distortion.

Simulation conditions, when there is no variation in the nonlinear parameters, assuming the case of.

Fig. 1, 2 shows the simulation results.

Fig. 1 shows the response time for each output (the circle line is linear output, the dotted line is nonlinear output, the dashed line is the output from the conventional method, the solid line is the output from the proposed method.)

The nonlinear distortion can be reduced with both techniques. However, the proposed method, the error is observed with linear output. It is considered that due to the speed of convergence and the observed delays in the theory of the observer.

Fig. 2 shows the time response which the model error has occurred.

In the conventional method is to use a nonlinear term of the speaker system directly, if parameter is not been precisely defined, would lead directly to the deterioration of the response. In the proposed method, Even if it is not been precisely defined parameters, nonlinear distortion can be removed properly.

In this paper, by constructing the proposed method for speaker systems, can reduce the strain showed that the nonlinear robust to parameter errors. However, the observer may be slow convergence when the amplitude and frequency changes. In addition, the proposed method are affected by measurement noise. In the future, to solve the above issues, perform the actual verification.
Evaluation of Brain Activity Related to Speech and Handwriting Using NIRS

Hirotoshi Asano  Member  (Aoyama Gakuin University)
Hiroaki Suzuki  Non-member  (Aoyama Gakuin University)
Hideto Ide  Member  (Aoyama Gakuin University)

Keywords : Near-Infrared Spectroscopy, Speaking, Writing

1. Introduction
In recent years, aging population and low birthrate is progressing quickly in Japan. The elderly ratio to all the population will reach to 40.5% in 2055. And one per 2.5 people become elderly people aged 65 and over. In the case of the serious person requiring care who lost especially the intention communicative function, a non-care worker is asked for the objective judgment to physical and mental pain. Therefore, development of the technology of the objective evaluation for intention transfer is an important subject. It aimed at smooth communication support of a person requiring care and a care worker in this research. Action was presumed from the signal of brain activity when performing operation of handwriting and speech using NIRS. If it becomes possible to presume action based on the signal of brain activity, it is applicable to detection and transfer of the intention of a person requiring care. This experiment was conducted by electromagnetism shield room (Fig. 1). The room temperature of 26.0±1.0 [℃], the illumination 200 [lx], and the interior of a room is calm. NIRS (Shimadzu FOIRE-3000) was installed. It equipped with the head holder and the measurement probe by making a subject’s frontal lobe into a measured region. Head holder wearing made the probe (R9) of the probe number 9 correspond to Fpz based on the international 10-20 method, and it equipped with it. The number of the channels to measure is 32ch. In a holder, the probe for irradiation and the probe for detection lights are arranged by turns at 30 [mm] intervals. In order to measure brain activity while handwriting and speech, the speech was carried out in Task A, handwriting in Task B, it was made to occur in Rest. Moreover, in Task C, it wrote with the talk. In order to remove ΔOxyHb(s) other than the target operation, difference with ΔOxyHb when it writes talking from ΔOxyHb when writing it as the time of talking was taken. And action was presumed from brain activity of speech and handwriting using NN (Fig. 2). As for the subject’s “A, C, F, G” presumed rate, the subjects’ B and E presumed rate brought a result of 100% of a presumed rate by the subject H 75.0% 62.5% (Fig. 3). This result has suggested a possibility that the difference between speech and handwriting can be presumed by this presumed method.

Fig. 1.  Experiment system

Fig. 2.  Presumption model

Fig. 3.  Result of presumption
Fuzzy Inference Based Obstacle Avoidance Control of Electric Powered Wheelchair Considering Driving Risk

Atsushi Kiso  Student Member  (Chiba Institute of Technology)
Hiroki Murakami  Non-member  (Yoshinokogyosho Corp.)
Hirokazu Seki  Member  (Chiba Institute of Technology)

Keywords: support for elderly people and disabled people, electric powered wheelchair, ultrasonic sensor, obstacle avoidance control, driving risk, fuzzy algorithm

This paper focuses on joystick operation types of an electric powered wheelchair and its advanced motion control system. A rider operates a joystick by himself/herself and a driving torque is generated according to a joystick operation. Fig.1 shows a photograph of an electric powered wheelchair developed by YAMAHA Co. called “JWI”.

This paper proposes a novel obstacle avoidance driving control scheme for electric powered wheelchairs on the basis of fuzzy inference. Some basic driving experiments will be conducted using an experimental wheelchair.

Fig.2 shows the proposed fuzzy algorithm based driving control system. The suitable driving direction $\theta_d$ and the driving risk $r$ are determined on the basis of the fuzzy algorithm (A) (B).

Fig.3 (a) shows an example of a driving test course. Fig.3 (b) shows the driving trajectory result. The joystick operation is only a forward direction in this experiment. Nevertheless the wheelchair could avoid obstacles as shown in Fig.3 (b).

Fig.4 shows the driving experimental results. The proposed control system generates the suitable driving risk $r$ according to the obstacle and the suitable velocities of the right and left wheels could be generated when $r$ is large. The proposed control system could realize a driving safety considering a human’s intent and obstacles.

---

Fig. 1. Electric powered wheelchair.

Fig. 2. Proposed fuzzy algorithm based driving control system.

Fig. 3. Test course and driving trajectory.

Fig. 4. Driving experimental results.
An Attempt of Fan Beam Microwave CT System which Determines the Straight Transmission Path by Time Domain Measurement of Demodulated DC Voltage

Mutsumi Tamura Member (Niigata University, tamura@procom.jp)
Takahiro Ogawa Non-member (Niigata University, ogawa@melinc.co.jp)
Yuuki Takeuchi Non-member (Niigata University, t08f429h@mail.cc.niigata-u.ac.jp)
Michio Miyakawa Member (Niigata University, miyakawa@eng.niigata-u.ac.jp)

Keywords: chirp pulse, microwave CT, dynamic range, delay time

We have developed demodulated direct current voltage-based microwave CT (DC-MCT) which is composed on the basis of Chirp-Pulse Microwave CT (CP-MCT). DC-MCT was used time domain measurement technique to determine the shortest propagation path between the transmitting-and receiving-antennas. By using standard signal generator with the low phase noise and phase synchronization of signal source, the reconstructed amplitude-and phase-images can be obtained. A phase image is not obtained in CP-MCT using the analog signal source. The frequency of the signal source was modulated in 256 points at 4MHz steps from 2GHz to 3GHz in DC-MCT. After reading the measured DC data at each frequency, a Fourier transform was performed to discriminate the propagation path. Figure 1 shows (a) Demodulated DC voltage and (b) Time domain spectrum. Time domain spectrum which gives the maximum amplitude value by demodulated DC voltage was showed delay time of 55.664ns.

In this study, we modified the imaging process to shorten the measurement time, as shown in Figure 2. The overshoot characteristics caused by the low pass filter deteriorates the performance of the proposed high speed imaging method using the modified imaging process. To avoid the influence of the stability time of the standard signal generator, we fixed the transmit frequency of the standard signal generator and measured the demodulated direct current voltages received by all antennas. After the data acquisition of all antennas at the transmit frequency, we measured the received signal at the next transmit frequency. The modified imaging process succeeded to shorten the measurement time to one eighth that of the previous imaging process.

In the experiment of the imaging, a 0.6% saline solution was used as a bolus, and 38mm and 50mm diameter cylindrical phantoms were used as objects. Both 38mm and 50mm diameter phantoms were filled with water. Figure 3 shows the amplitude-and phase-images by 72 projection data. The amplitude imaging showed the correct phantom image but the phase imaging showed the area of black color in the center of the phantom like a doughnut. In the phase imaging, 50mm diameter phantom does not reconstruct successfully. However, outside dimensions showed about 50mm diameter. 38mm diameter phantom was reconstructed successfully.

For the purpose of improving the resolution, the distance between 38mm-and 50mm-diameter phantoms were measured, the distance of 7mm was showed at the amplitude-and phase-resolutions. However, at a distance of 5mm, two phantoms seem to discriminate. This is considered the effect of low phase noise and phase synchronization of signal source.

In addition, for the purpose of improvement of receiver dynamic range, receiver dynamic range which is determined by a maximum DC voltage value was indicated 40dB. Further, receiver dynamic range improved about 2dB by pursuing a time domain spectrum which gives a max value of amplitude. It was showed the possibility to improve receiver dynamic range.

At the result, this paper shows usefulness of new method for microwave imaging.
Self-calibration of Hand-eye Coordinate Systems by Five Observations of an Uncalibrated Mark

Yukiyasu Domae Non-member (Mitsubishi Electric Corp.)
Shinjiro Kawato Non-member (Mitsubishi Electric Corp.)
Haruhisa Okuda Member (Mitsubishi Electric Corp.)
Kazuhiko Sumi Non-member (Aoyama Gakuin Univ.)
Yasuo Kitaaki Non-member (Mitsubishi Electric Corp.)
Shun’ichi Kaneko Member (Graduate School of Hokkaido Univ.)

Keywords: self-calibration, hand-eye, an uncalibrated mark, five observations

Fig.1 shows the hand-eye calibration problem. We propose a hand-eye calibration method by using an uncalibrated mark. Main advantage of the method is easy to use. Conventional calibration methods use multiple marks or many observations. But the multiple marks is hard to capture by vision sensors on robots. The many observations require long time operation. To lessen the burden, we propose a easy-to-use method which uses only an uncalibrated mark and needs only five observations. The method has two points; 1) A Rotation matrix and a translation vector is independently computed. 2) Each observation is integrated as much as possible. In our main paper, we show problem settings, formulation of the method, observation conditions in detail.

Fig.2 shows our system for evaluation tests. Fig.3 shows an example of observations by our proposed method. In our evaluation tests, the proposed method achieves a 27% decline in the operation time in comparison to a conventional method.

Fig. 1. Eye-in-Hand coordinate systems. A problem is how to compute $R_h$ and $t_h$. Our method computes them by using an uncalibrated mark and only five observations. It is easy to use.

Fig. 2. An experimental system.

Fig. 3. Five observations by the experimental system.
Feature Extraction of Motion from Time-series Data by using Attractors

Takuma Akiduki Non-member (Toyohashi University of Technology, akiduki@is.me.tut.ac.jp)
Zhong Zhang Member (Toyohashi University of Technology, zhang@is.me.tut.ac.jp)
Takashi Imamura Non-member (Toyohashi University of Technology, ima@is.me.tut.ac.jp)
Tetsuo Miyake Non-member (Toyohashi University of Technology, miyake@is.me.tut.ac.jp)

Keywords: Attractor, nonlinear dynamical systems, inertial sensor

This paper discusses the problem of human motion analysis from inertial sensor data (e.g., accelerometers and gyroscopes), which are the time-series data obtained from human motions. The human motion can be divided into some simple movements, such as arm or leg swings. Divided those simple movements are fundamentally periodic, and they can be modeled by dynamical systems using periodic attractors. On the other hand, more complex motion like a walking can be represented by a sequence of simple movements. To analyze the time-series data from the human motion, we propose a feature extraction method by using attractors, which is shown in Fig. 1. In this approach, the time-series data of motions are abstracted through the attractor representation. Furthermore, a symbol space, which is a map to characterize the human motion, is designed from the attractors.

Firstly, we introduce a design method of a dynamical system, which encodes time-series data in a motion pattern as an attractor. Consider a matrix

\[ X_t = \begin{bmatrix} x_t \end{bmatrix} \in \mathbb{R}^{n \times T}, \]

for a human motion \( M_i \), which is a cyclic having a period. Then the matrix \( X_t \) draws a closed curve \( A_t \) into \( n \)-dimensional state space. To design the dynamical system with the \( A_t \) as an attractor, it is considered that the discrete time dynamics as the following differential equation:

\[
x_{t+1} = x_t + f_i(x_t), \quad f_i(x_t) = \Theta_i \phi(x_t),
\]

\[ \cdots \cdot (1) \]

Where, \( f_i(\cdot) \) is a vector field in \( x \)-space, and it has an attractor on \( A_t \). According to the vector field design proposed by Okada et al., \( \phi \) is the polynomial function, and the matrix \( \Theta_i \) is the coefficients of the function in Eq. (1). Using the design procedure, the parameters of the dynamics, \( \Theta_i (i = 1, \ldots, m) \), are obtained for \( m \) motions. Through the principal component analysis (PCA) for the set of the parameters \( \Theta_i \), the symbol space is designed.

Secondly, we demonstrate an example of our approach using a simple movement of arm. The movement of arm swing was included four patterns, and these patterns were changed every 10 [sec], which was varying both the amplitude and the velocity such as: \( M_0 \) (rest state) → \( M_1 \) (little, slow) → \( M_2 \) (little, quick) → \( M_3 \) (full, slow) → \( M_4 \) (full, quick). These motions were measured by two accelerometers (ATR Promotions Inc., WAA-006) on subject’s wrists respectively. Figure 2 (a) shows the measured time-series data after PCA, and (b) shows the results of cluster analysis (QTC), which include five major clusters \( X_i (i = 0, \ldots, 4) \) corresponding to the motions \( M_i (i = 0, \ldots, 4) \). On the other hand, the motion characteristics of each \( M_i \) are expressed as the shape of trajectory \( \bar{A}_i \) in Fig. 3 (a). Moreover the designed symbol space shown in Fig. 3 (b), the features of dynamics of human motion are described in the placement of the points.

In conclusion, we proposed the method for feature extraction of motion using dynamical systems. Our approach is unique in the way it represents human movements as the attractors, and symbolizes the movement characteristics of human motion by using the attractors.

---

Fig. 1. Proposed method for analyzing human motion by using attractors in nonlinear dynamical systems

Fig. 2. Results of both PCA and QTC for the motion data of the arm swing

Fig. 3. Results of feature extraction from motion data, where (a) shows formed attractors, and (b) shows the designed symbol space for feature extraction of the arm swing
Production Density Diffusion Equation Propagation and Production

Kenji Shirai  Member (Niigata University of International and Information Studies, shirai@nuis.ac.jp)
Yoshinori Amano  Non-member (Kyohnan Elecs.co.,LTD, y.aman@kyohnan-elecs.co.jp)

Keywords: production density, diffusion equation, Ginzburg-Landau free energy, potential energy

This study, in the manufacturing sector in the process of producing a product ordered from the earlier order, the product elements that are sorted to produce between processes, that is, composed of units that the production of parts to form a complete product of one an idea that is. When we call the production flow to transition elements in the next step in the process of product manufactured one, the production flow is considered to be displaced in the direction of the unit production density. Density and production, as captured from different perspectives, also said production costs per unit of production. However, it is assumed that contributed to the production cost of manufacturing 100 percent. They may not correspond to the physical propagation conditions after each step of the production density, the equations governing the manufacturing process, which is intended to be represented by a single diffusion equation.

\[ J(x,t) dt - J(x + dx, t) dt = [S_i(x, t + dt) - S_i(x, t)] Rd x \]

Here, \( J \) is the production flow.

At this time, production flow is defined as the displacement in the direction of the density of the production unit of production, in other words, the density is proportional to the cost of production than required for production can also be thought of as the production cost per unit of production, the following equation: can be formulated as follows.

\[ \frac{\partial S_i(x,t)}{\partial t} = D \frac{\partial^2 S_i(x,t)}{\partial x^2} \]

In addition, the product can be produced in due time, the contract amount to flow from the destination to source sales order. In other words, by completing the preparation of the plan, you will get some sort of revenue. By applying the concept of energy levels in statistical mechanics of this fact, the production density function, in other words, in statistical mechanics “field” that if you use the world of manufacturing and production term . If the free energy in this production (potential) entity that consumes is nothing but the entropy production. That is, productivity is defined as the entropy production has to be.

Normally, when we increase the number of production units, the product nears completion at year-end number of units completed and will aim to be delivered to the contractor from the turnover order. However, if you stop at any number of units, that will increase production density over time. Thus, the diffusion does not proceed from that would be irreversible. In other words, the congestion will occur in production. This fact and to report the results of analysis based on real data.

Fig. 1, inter-process network (for production) capacity in the network (static production capacity) to \( R \), the networks and processes, the next step and one step is completed means that the sequential process is going to move and move on.

Fig. 2, data (a), (b), considering it is a singularity, when the density tends to increase profitability, subject to completion of production, then, is to fall, idling productions (1), (2) through the rising again, it is found that heralds the end of production. However, idling (1), (2) the duration of is believed to represent the behavior of any near-term.
A Fast SSCF Adaptive Algorithm and Its Application to Adaptive Equalizer

Masaki Kobayashi  Member  (Graduate school of Engineering, Chubu University)
Yasunori Nagasaka  Non-member  (Graduate school of Engineering, Chubu University)
Yasutomo Kinugasa  Non-member  (Matsue National College of Technology)
Naoto Sasaoka  Non-member  (Graduate school of Engineering, Tottori University)
Yoshio Itoh  Non-member  (Graduate school of Engineering, Tottori University)

Keywords: signal processing, digital control, adaptive equalizer, noise free, robust

The problem of the series type adaptive filter using LMS algorithm is the bias error of the tap gain caused by the noise. In this paper we propose a noise free fast SSCF (Square Sum of Correlation Function) adaptive algorithm with white input signal and its application to the adaptive equalizer. The comparison of the convergence speed to LMS and SSCF adaptive algorithm is presented.

Fig. 1 shows the structure of a series type adaptive system such as the adaptive equalizer.

In Fig. 1 $H(z)$ and $\xi(n)$ represent the transfer function of the unknown system and the noise. The adaptive algorithm of the tap gain $a$ of ADF $A(z)$ is given by

\[
a(l+1)=a(l)-\beta H^T Q
\]

\[
a=[a_0, a_1, \cdots, a_{N-1}]^T
\]

\[
Q=[q_0, q_1, \cdots, q_{N-1}]^T
\]

\[
H=\sum_{i=0}^{N-1} w_i w_i^T
\]

\[
q_k=\sum_{n=0}^{N-1} x(n-k) e(n) x(n-N) y\{n-N-(i-k)\}
\]

\[
w_k=[x(n-N)y(n-N+k), \cdots, x(n-N)y(n-2N+k)]^T
\]

\[
............................. (1)
\]

where $N$ represents the degree of ADF $A(z)$ with loop gain $\beta$ given by $0<\beta<2$.

Inverse matrix of the Hessian $H$ can be obtained at most by computational complexity $N^2$ since Hessian $H$ can be expressed in the form of the product of the trigonometric matrix.

Fig. 2 shows the comparison of the convergence speed to LMS and SSCF adaptive algorithm. The unknown system $H(z)$ was set as the transfer function of a basic model of a wireless transmission line. The convergence performance of SSCF and LMS show the most high-speed case.

Fig. 3 shows the comparison of the convergence performance at the white noise $\xi(n)$ added. It is understood that the excellent characteristic compared to LMS and SSCF is obtained.
Perceptive Curves Detection by Global Edge Tracing

Takamitsu Takagi  Non-member  (Gifu University)
Fumihiko Saitoh  Member  (Gifu University)

Keywords : Perceptive curve, Curves detection, Perceptual grouping factor, Edge tracing

1. Introduction

Human beings have the ability to perceive continuous curves from a binary image that includes discontinuous curves and noises. To achieve this capability, global detection is required. Hough transform based on a voting process is known as the global detection method. However, a shape model for detection is necessary beforehand in this method, therefore it is difficult to adopt for detection of indefinite curves.

In the past, we have proposed a perceptive curves detection method. Its method treats all figure pixels as a dot. And adjacency relation is created by Delaunay triangulation. After that all Delaunay edges are processed by following three steps: selecting as the start edge, searching the appropriate partial curve, and accumulating the evaluation value. At that time accumulated evaluation graph is obtained. Finally edges, they have accumulated evaluation value that is higher than or equal to the threshold, are extracted as perceptive curves.

However, previously reported method has a problem that interruption and branching are included in the detected curves. This paper proposes a post process to improve its problem by edge tracing.

2. Proposed Method

In proposed method, accumulated evaluation graph is obtained in advance by previously proposed method. The process after this is shown in fig. 1.

Firstly, the edge, having maximum value in the graph is selected as the start edge $P_1P_2$. It is assumed that tracing of $i$-th dots $P_i$ has finished. Secondly, from the end of dot sequence $P$, $b$ number of dots are copied to $Q$. And connect an adjacent dot in sequence from the end of sequence $Q$. This searching is conducted while sequence $Q$ satisfies that its length is less than or equal to $N_b$. By expression that based on the continuous factor and accumulated evaluation value, sequence $Q$ is evaluated with each connecting one dot. When the sequence $Q$ that has the maximum evaluation value is searched, dot $Q_{b+1}$ is registered to the end of sequence $P$ as dot $P_{i+1}$.

Above tracing is conducted until it loops or $Q_{b+1}$ does not exist.

If length of the sequence $P$ is greater than or equal to $L_{min}$, it is memorized as a perceptive curve. Otherwise, it is treated as noise. Next, the edges that are similar to sequence $P$ are removed.

3. Experiment and Result

Figure 2 shows examples of detection results by proposed method. Perceptive curves are detected without interruption and branching. Table 1 shows that the averages of rank order by subjective assessment for two kinds of noise images. The rank of the proposed method is the highest in other methods. It is found that the method is nearest to perception.

Table 1. Average of rank order by subjective assessment.

<table>
<thead>
<tr>
<th>Noise name</th>
<th>Voting method</th>
<th>GA method</th>
<th>Previously reported method</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise I</td>
<td>3.37</td>
<td>3.28</td>
<td>2.19</td>
<td>1.16</td>
</tr>
<tr>
<td>Noise II</td>
<td>3.28</td>
<td>3.37</td>
<td>2.10</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Fig. 1. Tracing process.
A Real-time Reinforcement Learning Control System with $H_\infty$ Tracking Performance Compensator

Shogo Uchiyama  Non-member  (Yamaguchi University, p005vk@yamaguchi-u.ac.jp)
Masanao Obayashi  Member  (Yamaguchi University, m.obayas@yamaguchi-u.ac.jp)
Takashi Kuremoto  Non-member  (Yamaguchi University, wu@yamaguchi-u.ac.jp)
Kunikazu Kobayashi  Member  (Yamaguchi University, koba@yamaguchi-u.ac.jp)

**Keywords**: reinforcement learning, robust control, $H_\infty$ control, robust reinforcement learning, real-time

1. Introduction

In this paper, we propose a “Real-time Reinforcement Learning Control System (RRLCS)” through combining reinforcement learning to treat unknown nonlinear systems with robust control theory to guarantee the robustness and stability of the system control. Concretely, Actor-Critic method which is a kind of reinforcement learning, is combined with $H_\infty$ Tracking Compensator (HTC) to construct RRLCS.

A $n$th-order nonlinear system is considered as

$$x^{(n)} = f(x) + g(x)u + d,$$

where $x = [x_1, x_2, \ldots, x_n]^T$ is a state vector of the system, $f$ is an unknown bounded function, $g$ is an unknown bounded positive continuous function, $u$ is the control input to the system, $d$ is the bounded disturbance. The object of the control system is to make the state vector $x$ of the system track the reference signal $r = [r_1, r_2, \ldots, r_n]^T$, in other words, the control signal $u$ is designed to make the tracking error $e = r - x$ be $0$.

We designed the control signal $u$ as follow,

$$u = u_a + u_h,$$

where $u_a$ is output of the Actor and $u_h$ is output of the HTC. We aim that the Actor becomes the optimal controller in meaning of getting the great tracking performance through behavior results of controller HTC. As the structure of the Actor, we adopt an Auto-Structuring Fuzzy Neural Network (ASFNN), allocate it in parallel with HTC. In initial control steps, the HTC takes mainly control because the Actor has not learned. After initial control steps, the Actor constructs optimal controller by learning.

We show effectiveness of the proposed system (RRLCS), comparing RRLCS with those of the conventional Adaptive Fuzzy Control with $H_\infty$ tracking compensator (AFC) and Auto-Structuring Fuzzy Neural Control System (ASFNCS) through the computer simulation of controlling an inverted pendulum system.

The control results are shown in Table 1, Fig.1 and Fig.2. From Fig.1, error of the proposed system (RRLCS) is smaller than conventional methods AFC and ASFNCS, because that from inner figure of Fig.1, the overshoot of the proposed system is smaller than others and it rapidly converges on reference signal. The reason why our proposed method is superior to others is that the proposed system realizes the optimal controller by the cooperation of the HTC with better $H_\infty$ tracking performance at the incipient control and the Actor with high ability of learning at the middle and the late stage. These are found out as follows. From Fig.2 the HTC works at the initial stage for the control of the pendulum, while, the Actor observes the control result of HTC during about first 2 seconds and then it works well. In a quantitative point of view, from Table 1, error areas and steady state errors of the angle of the proposed system are the lowest, followed by ASFNCS, AFC in that order. These show our proposed method is superior to conventional methods.

<table>
<thead>
<tr>
<th></th>
<th>RRLCS</th>
<th>AFC</th>
<th>ASFNCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error areas of the angle</td>
<td>$6.3 \times 10^{-3}$</td>
<td>$1.3 \times 10^{-2}$</td>
<td>$7.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Steady state errors of the angle</td>
<td>$7.7 \times 10^{-5}$</td>
<td>$1.9 \times 10^{-3}$</td>
<td>$2.7 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

Fig. 1. Comparison of the tracking errors of the angle among three methods, and inner figure is the enlarged tracking errors of the angle at the initial state, i.e. in the range of $[0.0, 10.0]$.

Fig. 2. The outputs of the Actor and HTC of the proposed system.
Recognition of Short Time - Paired Activities
— An Algorithm for a Smart Reminder System —

Hapugahage Thilak Chaminda  Non-member  (The University of Aizu, d8111104@u-aizu.ac.jp)
Vitaly Klyuev  Non-member  (The University of Aizu, vkluev@u-aizu.ac.jp)
Keitaro Naruse  Non-member  (The University of Aizu, naruse@u-aizu.ac.jp)
Minetada Osano  Member  (The University of Aizu, osano@u-aizu.ac.jp)

Keywords: Human activity recognition, Paired activities, Reminder systems, Signal processing, Wearable computing, Personal assistance

We undertake numerous activities in our daily life and for some of those we forget to complete the action as originally intended. Some common examples are closing a hot water flask after filling the water, buttoning up a suit after wearing and closing a medicine container after taking medicine from container. Significant implications of most of these actions might be: “pairing of both hands simultaneously” and “short time consumption”. In this work an attempt has been made to recognize those kinds of Paired Activities (PAs) to provide reminders, which are easy to forget.

Therefore the objective of our study is to recognize short time consuming PAs. Identified PAs will be used in the proposed Smart Reminder System in future. The specific case study of opening and closing various type of bottles in a home environment was addressed to represent short time consuming PAs. Behaviour of both hands while performing subjected activities can be shown as in Fig. 1. There were high modeling effort since the paired behaviour, shortness, different time consumption and high nonlinearity among activities in the problem domain.

Therefore a new model, which simulated the paired behaviour of both hands was proposed to model the PAs and it was called “Paired Activity Model” (PAM). PAM can be explained simply as follows:

\[
\text{Paired Activity} = \\
( ( \text{Active Hand's individual motions, Active Hand's Correlated motions with Passive Hand}), \\
( \text{Passive Hand's individual motions, Passive Hand's Correlated motions with Active Hand} )) \\
\text{............................................... (1) }
\]

In order to recognize PAs using PAM, Paired Activity Recognition Algorithm (PARA) was implemented. Data acquisition, pre-processing, unrelated activity filtering, sub frame categorizing and sub frame matching were done in the PARA respectively.

Required data acquisition was done by using wireless three axis accelerometer sensors, which were worn on the wrist areas of both hands of subject. Those raw data vectors were segmented in to same and fix sized frames in order to model the PAs. Individual and paired behaviour of hands were used to filter unrelated activities from Target Activities (TA) and recognize exact TA among other TAs. To collect individual features, time domain and frequency domain features were extracted separately for both hands using each hand’s own data vector only. In order to collect paired features, features were extracted for each hand, by coordinating other hand’s acceleration data vector also. Data classification was done by using Artificial Neural Network (ANN) algorithm. PA recognition performance of ANN was compared with Support Vector Machine (SVM) algorithm. Therefore SVM also used for categorizing the activities. In order to avoid the confusions among categorized frames by the machine learning algorithms, a threshold value was introduced and it was called Sub Frame Confusion value of a Sub Frame. That threshold value express the confusion degree among two SFs, which represent different parts of same activity.

Performance of PARA was evaluated with a specific case study of opening and closing various type of bottles in a home environment, under several typical scenarios. 8 Male and 2 female subjects, who were in different ages were involved with the experiment.

In a experiment, which was done to evaluate the user dependency of PARA, user dependence case could achieve higher accuracy level rather than the user independent case.

Another experiment was done to evaluate the performance of PARA according to the working environment. The test done in limited motion environment could achieve higher average recognition rate rather than the test done in the highly noisy motion environment.

Generally in our approach, push type non repetitive activities could be identified easily rather than the screw type repetitive activities. ANN significantly outperformed the SVM algorithm, in the real time evaluations. In the user-independent case, PARA achieved recognition rates of 96% for only target PAs and 91% for target PAs with unrelated activities. Activity reminding system will be developed in future using the proposed PAM and PARA.
A Basic Study on User Utility Maximizing Content Retrieval from Information Networks

Shinji Sugawara  Non-member  (Nagoya Institute of Technology)
Hiroyuki Ohnishi  Non-member  (Nagoya Institute of Technology)

Keywords: user utility, content retrieval, information network, distributed environment, computer simulation

In recent years, the Internet has expanded rapidly, and it has allowed many users to exchange a variety of information. And this huge amount of, and every type of information that are offered by the Internet users can be dealt by the users themselves, as it were the information stored in one huge database. In this environment, it is difficult for the users to find their target content items both because of a great number of information sources in the network and because of constant updating or removal of the content items.

We have taken up such a situation – an information accumulation environment in a large-scale network, where nobody can completely grasp and control all the contents and their locations – and we called it super distributed environment.

In order to find contents that network users want to retrieve from the network, several search methods currently exist or have been proposed. These methods, however, did not sufficiently consider the user’s satisfaction, i.e., user utility. The user utility is a standard to express how much a user is satisfied for a service. In the case of searching for a plural number of content items in the network at the same time, the user’s satisfaction is changed greatly by the searching schedule, and consequently, it is important to realize the search method that considers this point.

User utility means the user’s satisfaction with a service in general; this metric has been used in a number of studies. We focus on services that allow acquisition of content items in a network under the circumstances that user utility decreases monotonically with the increase of searching time or cost, that is, the greater the time or cost becomes, the lower user utility becomes. It has been shown by the results of subjective evaluation experiments that the relationship between waiting time of a service and its user utility can be described well by a power function or an exponential function. These functions are often used in practice to estimate utility from the waiting time.

In searching for content items, it is believed that user utility becomes the highest when the target is obtained immediately after the beginning of the search, and as the search time and cost increase, user utility decreases. Consequently, we consider user utility to be the function of the same sort, and recognize the user utility at the time when a target content item is found as the user’s satisfaction for the search.

As a basic assumption in this paper, we consider the following situation: a number of independent sources of information (afterward, we call them nodes) are scattered within a large-scale network, and a user is searching for some multiple content items which he/she wants (afterward, we call it targets) from the nodes.

In the proposed method, searching policy is decided by the estimated user utility gain and/or current user utility for each searching action, and the most favorable combination of an information source and searching content item is selected so as to enlarge the total amount of user utility of whole searching activity.

We evaluate the efficiency of the methods by computer simulations; in which, we give network topology, user utility functions, existing probabilities of searching content items in each information source etc., apply proposed methods and other methods for comparison, and compare summation of their utility gains as an estimative index. As a result, the proposed methods achieve good performance in general and about 2.45 times larger index value than an ordinary searching is observed in an extreme simulation scenario.

At the end of the paper, we discuss pros and cons of the proposed methods in all the simulation scenarios.
A Proposal of B to B Collaboration Process Model based on a Concept of Service and its Application to Energy Saving Service Business

Qi Zhang  Non-member  (Japan Advanced Institute of Science and Technology)
Michitaka Kosaka  Fellow  (Japan Advanced Institute of Science and Technology)
Kunio Shirahada  Non-member  (Japan Advanced Institute of Science and Technology)
Takashi Yabutani  Non-member  (Tomosoh Japan Ltd.)

Keywords : service, B to B collaboration process model, service field, service dominant logic, energy saving service business

1. Introduction
This paper proposes a new framework for service value co-creation in B to B collaboration based on a concept of service. Collaborators offer information or knowledge to support each other’s knowledge creation for achieving the common objectives. These activities can be considered as service behaviors. We introduce the concept of service fields to enable services more effective behaviors. Based on this concept of service field, the framework for the value co-creation process is proposed as KIKI model. Then, the collaboration can be described by 4 steps of KIKI model (Knowledge sharing related to service system, Identification of service field, Knowledge creation for new service idea, Implementation of service idea). As its application to B to B collaboration, the energy saving service business is reported to demonstrate the validity of the proposed collaboration model.

2. A Concept of Service Field and Service Value Co-creation Process Model
(1) B to B collaboration model based on a concept of service
B to B collaboration involves continual activities in knowledge creation based on consecutive service behaviors of both collaborators. Service behaviors are provided, which means that information is offered and/or support actions are given. Fig.1 shows the B to B collaboration model based on a concept of service.

(2) Concept of service field
The value of services provided to customers generally depends on the efficiency of services to achieve customer objectives. Even though services are identical, they differ in terms of how customers value the services, due to different customer characteristics in different situations (place, time, or cost). That is to say, service values depend on the contexts of service fields. According to the situation-dependent characteristics of service values, we propose the concept of service field in co-creation systems. We consider a service value to depend on the relationship between the service itself and its service field where the service was provided. Fig.2 shows a concept of service field and its application for maximizing service value.

---

Extended Summary

本文は pp.1035-1040
A Prioritization Method of Adjusting Parameters for Making Consensus on Combination of Risk-reducing Plans by Mutual Effect Analysis

Daisuke Nakajima  Student Member  (Osaka University, nakajima.daisuke@ist.osaka-u.ac.jp)
Masaki Samejima  Member  (Osaka University, samejima@ist.osaka-u.ac.jp)
Masanori Akiyoshi  Senior Member  (Hiroshima Institute of Technology, m.akiyoshi.we@it-hiroshima.ac.jp)
Ryoichi Sasaki  Non-member  (Tokyo Denki University, sasaki@im.dendai.ac.jp)

Keywords: Consensus making support, Risk-reducing plan, Parameter adjustment, Preference, Mutual effect analysis

1. Introduction
Risk managers decide combinations of risk-reducing plans to decrease the probabilities of risks according to a goal and constraints in the risk management. In order to decide the combinations, this combinatorial problem is formulated as 0-1 integer programming with parameters such as effect and cost of the risk-reducing plans. Because experts estimate various values $V_i$ on parameters in the objective function $f_i(X;V)$ and constraints $g_k(X;V_i)\leq b_i$ ($b_i>0$), the combinations $X$ as solutions are not agreed among experts. For acquiring the agreed combination, experts select a parameter to be adjusted and adjust the value of the parameter through long discussion. However, it is difficult to select the parameter to be adjusted, which requires many iterative adjustments. The goal of this research is to display parameters prioritized by possibilities of acquiring the agreed combination by adjusting the parameters.

2. Prioritization Method of Adjusting Parameters by Mutual Effect Analysis
The existing research prioritizes parameters by differences among values estimated by experts; when differences in parameters make a large effect on differences in combinations, the parameters should have high priorities of the adjustment. Effects on a difference of combinations that are called “preference $Pr_i(i)$” of risk-reducing plan $i$ are derived by the following formula:

$$Pr_i(i) = \frac{\text{Changes in } f_i(X;V) \text{ by risk-reducing plan } i}{\text{Max}_i \text{Changes in } g_k(X;V) \text{ by risk-reducing plan } i / b_i}$$

The preference $Pr_i(i)$ depends on not only parameters of the risk-reducing plan $i$ but also other parameters. We call the effect on the preference from other parameters “mutual effect”. Fig. 1 shows that adjusting parameters of risk-reducing plans increases or decreases the differences of preferences on other risk-reducing plans by mutual effects. Whether the agreed combination can be acquired by the adjustment depends on the mutual effects.

So, the proposed method analyzes the mutual effects to the disagreed combination and prioritizes parameters to be adjusted as shown in Fig. 2. When the mutual effects do not cause the disagreed combination, the existing approach based on differences of preferences can be applied. Therefore, the degree that mutual effects of risk-reducing plan $j$ do not cause the disagreed combination is evaluated by independent score $s$:

$$s_{independent} = \frac{1}{Pr_j(j) \sum |r_i(i, j)|}$$

where $r_i(i, j)$ is a change rate of preferences on risk-reducing plan $j$ in changing slightly a value of a parameter of a risk-reducing plan $i$. Parameters that represent larger independent score than an average of all independent scores are prioritized as parameters to be adjusted. The parameters that represent smaller independent score than the average are prioritized as parameters to be adjusted.

$$s_{influence} = \sum |r_i(i, j) \times Pr_j(j)|$$

3. Evaluation Experiment
The targets of the experiments are problems on the internal control and the information leakage. For consensus making on preventing information leakage, two experts adjust parameters ($p_1$ to $p_{15}$) on 15 risk-reducing plans. Two kinds of values of parameters, Case1 and Case2, are set for the experiment and parameters to be adjusted for the agreed combination are decided by computing all adjusted values. Prioritizations on Case1 by the existing method and the proposed method are shown in the following table ($p_4$ means the parameter to be adjusted):

Existing: $p_1 p_2 p_3 p_4 p_5 p_6 p_7 p_8 p_9 p_{10} p_{11} p_{12} p_{13}$
Proposed: $p_1^2 p_2 p_3 p_4 p_5 p_6 p_7 p_8 p_9 p_{10}^2 p_{11} p_{12}^2$

The proposed method can prioritize $e15$ that has little mutual effects and $p_4$ that has large mutual effects. Considering that experts discuss parameters based on the prioritization, Table 1 shows the precision rate and the recall rate in the top 5 parameters. The proposed method improves occupancy of parameters to be adjusted by 30% and decreases the adjustment time up to an hour.

Table 1. Occupancy in top 5 and adjustment time.

<table>
<thead>
<tr>
<th></th>
<th>Case1</th>
<th>Case2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>Proposed</td>
<td>Existing</td>
</tr>
<tr>
<td>Occupancy in top 5</td>
<td>40%</td>
<td>80%</td>
</tr>
<tr>
<td>Avg. of maximum adjustment time</td>
<td>174 min</td>
<td>54 min</td>
</tr>
</tbody>
</table>
Research on Using the Naturally Cold Air and the Snow for Data Center Air-conditioning, and Humidity Control

Kunikazu Tsuda  Student Member  (The University of Electro-Communications Graduate School)
Shunichi Tano  Non-member  (The University of Electro-Communications Graduate School)
Junko Ichino  Non-member  (The University of Electro-Communications Graduate School)

Keywords : Data Center, Low Energy, Air Cooling

1. Introduction
As global warming is becoming an important problem, the power consumption of data centers that are used for providing cloud computing is increasing rapidly, so the research reported here focuses on decreasing power consumption in data centers. A basic idea, a method of using the naturally cold air and the snow for dealing with that problem is proposed and experiments on the effectiveness of the method are conducted. And the effect on power consumption was verified.

2. Proposal
We propose a hybrid air-conditioning system that uses the naturally cold air and the snow for cooling data centers (Fig. 1). Recently, an experiment that uses the only snow for air-conditioning alone in Hokkaido, Japan has been executed. This is called the snow cooling. There has also been experimentally and practically applied in the storage of rice and in cooling the small-scale public hall, and it has already come to be well known. However, in Japan, there are no cases that snow cooling to data centers.

The example of using the outside air has been used for air-conditioning of the data centers has the case, but however data center air-conditioning by the combination of using the snow in summer, and using outside air in winter has not been applied before.

3. Problems of using Outside Air and Countermeasures
Although there are no examples of practical use of the snow cooling systems, for data centers in particular. One reason for that is the extremely low outside air temperature in winter (0 to −20°C) in cold region. If the moisture content of the air is constant, bringing in cold air for cooling would make the relative humidity abnormally low when the air temperature rises to room temperature. Our proposed solution to this problem is what we call the natural drip humidification method (Fig. 2), in which the return air is mixed with outside air to shorten the humidification process and reduce the power consumption.

Experiments conducted with a mock 6-racks server room to test the feasibility and effectiveness of this method showed that temperature can be controlled to within the range from of 24.2°C to 26.0°C (yellow line in Fig. 3) and that humidity can be controlled to within the range from of 35.1% to 47.7% (yellow line in Fig. 4) and that Furthermore, using outside-air for cooling can reduce power consumption by approximately 85% relative to mechanical cooling. (RA of Fig. 3 and Fig. 4 is “return air from room”. SA is “send air to room”. OA is “outside air”.)