Hybrid Intelligent System Using PSO/Bacterial Foraging and PID Controller Tuning

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Contents and Relationship

(J-X) : Journal Papers
[C-X] : Conf. Papers

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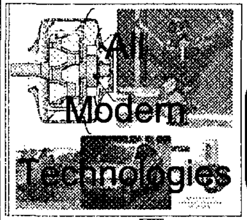
Chapter 5 Conclusion and Further Works

Background (2)



- Complex reasoning
- Learning
- Optimization
- Adaptability

Conventional methods
Ex: Optimal signal estimation

- Classical Approaches
  - Mathematical knowledge
  - Not obtain requirement conditions simultaneously

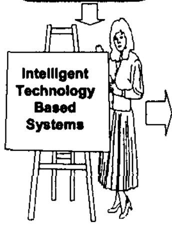
To implement these requirement conditions,

• Effective control technology

Background (3)

Mathematical Approach Based Classical Methods

Mathematical (Riccati Equation) Iacopo Riccati 1676-1754



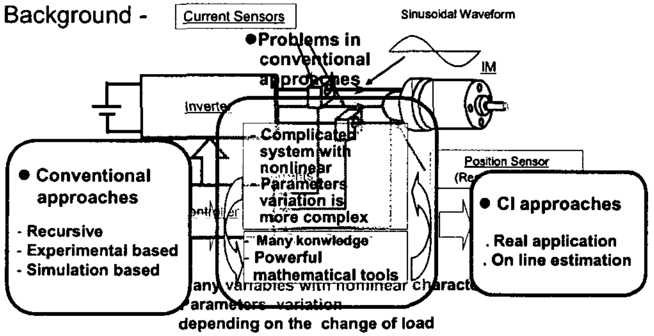
- GA Combined with PSO/BF and application to PID Tuning
- IM based Parameter Estimation (Ch. 2)
- GA-PSO based PID AVR, PI Motor Vector (Ch. 3: Sim, Exp.)
- GA-BF based PID AVR, PI Motor Vector (Ch. 4: Sim, Exp.)

- Efficiency
- Safety
- Flexibility

- Fusion or Hybrid CI
- Motivation for new technology in real system

Chapter 2 : Immune Based Parameter Estimation

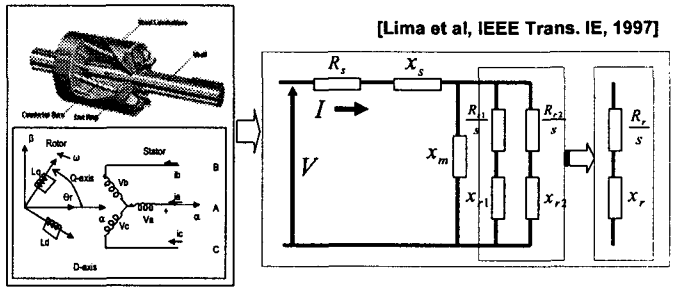
- Background -



System Model

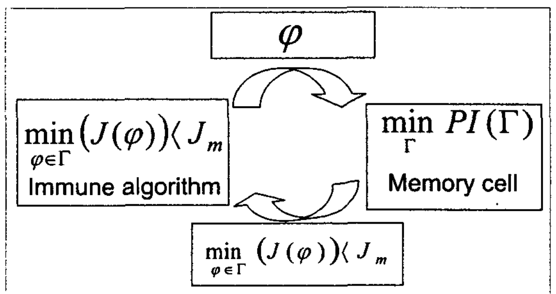
- Squirrel induction motor
- Vector control in Ch. 3

[Lima et al, IEEE Trans. IE, 1997]



Equivalent circuit of a squirrel-double induction motor

Computational structure for optimal parameter estimation using clonal selection of immune algorithm



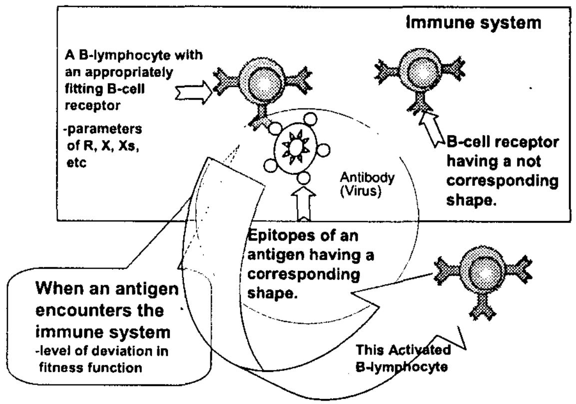
[Kim, WSEAS Trans. Sys. 2004]
[Kim, LNCS 2004]

Computational Structure

All clonal selection process

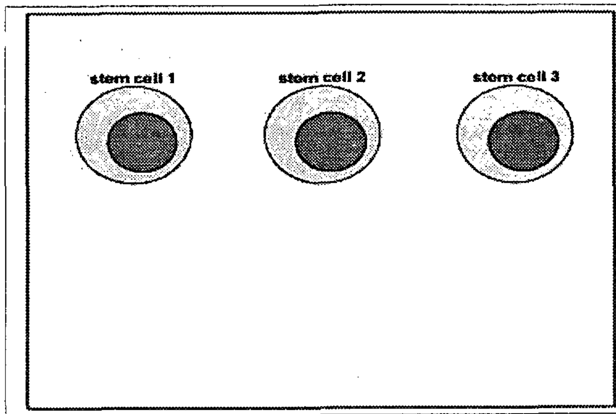
- Step 1: Early differentiation process
- Step 2: Reaction and activation step
- Step 3: Clonal expansion and fine-tuning
- Step 4: Clonal expansion
  - Plasma cell (Antibody-secreting B-lymphocytes)
  - Memory cell (Anamnestic response)

Computational Structure: Clonal Selection Step 2

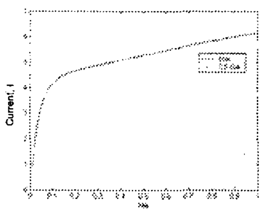


This process is known as clonal selection

Clonal Selection (Animation)

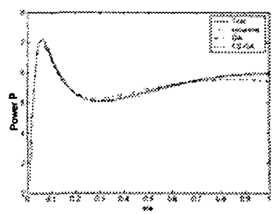


Experimental Results



Variation of I (s) by CS-GA and true values (Error=0.001%)

CS (Clonal selection)



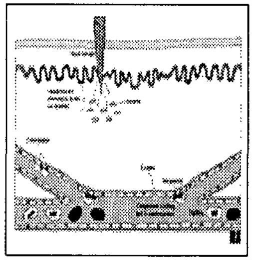
Variation of P (s) by CS-GA (Error=0.010%), GA (Error=0.230%), recursive (0.012%), and true values

Parameter Estimated by Immune Algorithm

Item	R_{r1}	R_{r2}	X_{r1}	X_{r2}	X_s	R_s	X_m
Recursive	0.078	0.0129	0.0164	0.121	0.1167	0.0073	4.29
GA	0.063	0.0138	0.010	0.122	0.1260	0.0074	4.21
CS-GA	0.0755	0.0135	0.009	0.1168	0.1195	0.0064	4.34

Summary

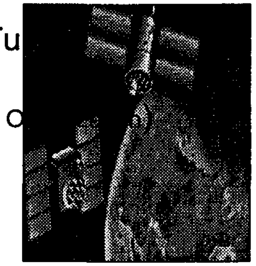
Induction Motor
Parameter estimation



- Using clonal selection of Immune algorithm
- Nonlinear parameter estimation of three-phase induction motor
- Good parameter estimation results
- Converge in a relatively fast way (around 100 generations)

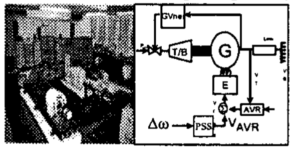
Chapter 3 :

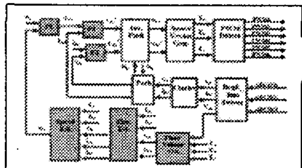
Intelligent PID Controller Tu
Using GA-PSO
(Genetic Algorithm-Particle Swarm O



Background (1)

AVR (Automatic Voltage Regulator)





- Controller: PID
- Problem: Tuning

- Controller: PID
- Problem: Tuning

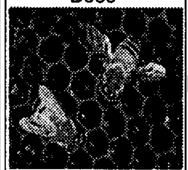
Energy consumption : over 50%

Advanced tuning technology

- **GA-PSO control for AVR**
- **Motor vector control**
- **Comparison (GA, PSO, IMM, BF)**
- **Motivation for development of new CI and engineering application**

Background (2)

Bees

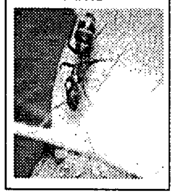


Termites

- **The complexity and sophistication for Self-Organization is carried out with no leader**

- **Social insects can be applied to the field of Intelligent System Design**
- **The modeling of social insects by means of *Self-Organization* can help design artificial distributed problem solving devices.**

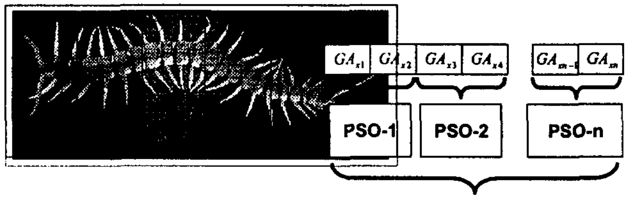
Ants



- **Problem solving benefits include:**
  - **Flexible**
  - **Robust**
  - **Decentralized**
  - **Self-Organized**

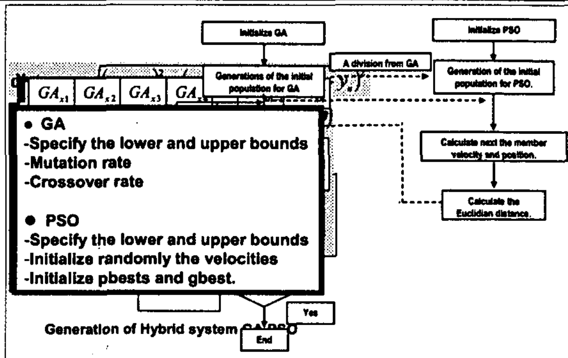
- **Particle Swarm Intelligent Based System Study**

Implementation of Hybrid system



- Enhance GA
- Reduce the computation time
- Improving the learning efficiency

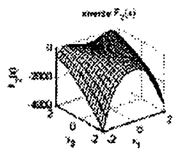
Computional Procedure of Hybrid GA-PSO



The GA-PSO Algorithm

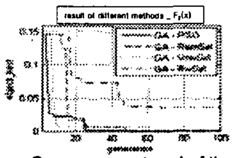
[Kim et al, IEEE ICI 2005]
[Kim et al, IFSA 2005]

Rosenbrock Function :

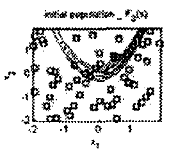


The contour of Rosenbrock function.

•RemSel (Remainder stochastic Sample with replacement Selection)
•UnivSel (stochastic Universal sampling Selection)
•RwSel (Roulette wheel Selection)

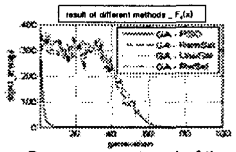


Convergence trend of the best values of GA, GA-PSO.



□ - GA - PSO
◇ - GA - UnivSel

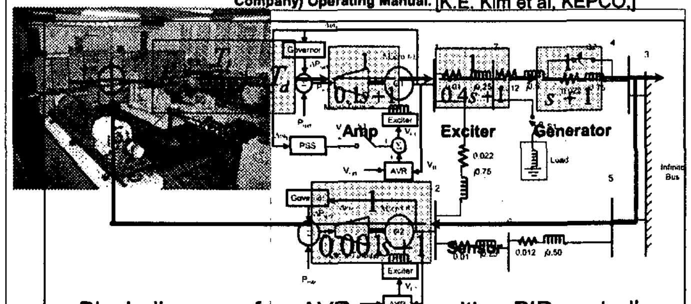
Population of change from 0 to 50.



Convergence trend of the average values of both methods.

Application for Thermal Power Plant System

REF. KEPCO (Korea Electric Power Company) Operating Manual. [K.E. Kim et al, KEPCO.]



Block diagram of an AVR system with a PID controller

Performance Index of GA-PSO based PID Tuning

[W. K. Ho, IEE Proc. 1998]

$$\min F(k_p,k_i,k_d)=\frac{e^{-\beta}\cdot t_s/\max(t)}{(1-e^{-\beta})\cdot|1-t_r/\max(t)|}+e^{-\beta}\cdot Mo+ess$$

$$=\frac{e^{-\beta}\cdot(t_s+\alpha_1\cdot|1-t_r/\max(t)\cdot Mo|)}{(1-e^{-\beta})\cdot|1-t_r/\max(t)|}+ess$$

$$=\frac{e^{-\beta}\cdot(t_s/\max(t)+\alpha\cdot Mo)}{\alpha}+ess$$

$$\alpha=(1-e^{-\beta})\cdot|1-t_r/\max(t)|$$

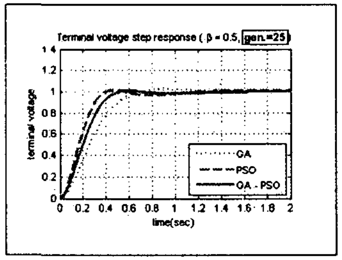
k_p,k_i,k_d : PID parameters, β : weighting factor,
Mo : overshoot, t_s : settling time (2%),
ess : steady-state error, t_r : desired settling time.

Performance of the GA-PSO for PID Controller Tuning

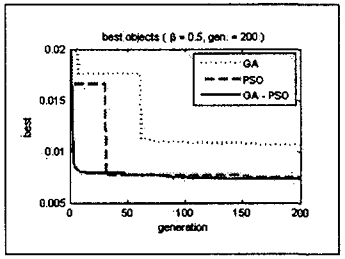
Best parameter values using GA-PSO controller

β	Number of generations	kp	ki	kd	Mo (%)	ess	ts	tr	Min $F(k_p,k_i,k_d)$
0.5	25	0.6204	0.4929	0.2232	0.97	0.0097	0.4570	0.2973	0.0030
1	25	0.6584	0.5819	0.2548	1.71	0.0166	0.4000	0.2651	0.0072
1.5	25	0.6801	0.6260	0.2681	1.97	0.0186	0.3770	0.2523	0.0079

Performance of the GA-PSO for PID Controller Tuning

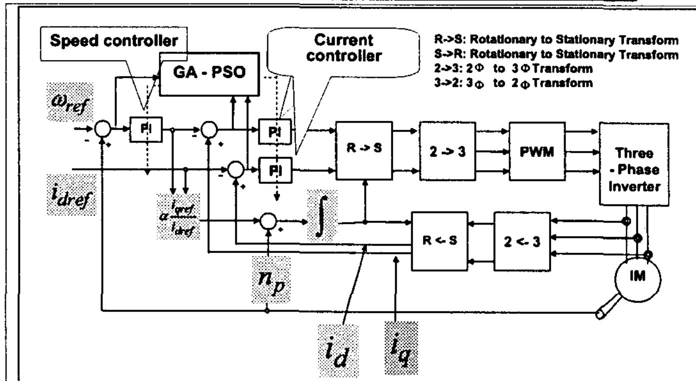


Comparison of Terminal voltage step response of an AVR system ($\beta=0.5$ generations=25).



Comparison of the best objects values of each methods ($\beta=0.5$, generations=200).

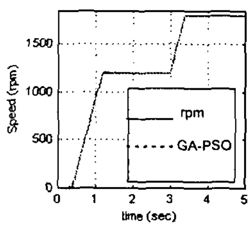
Application for Motor Vector PI Control



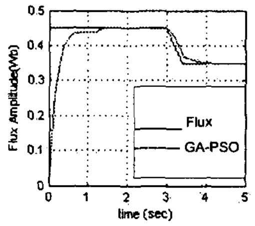
Block diagram of indirect vector PI controller using GA-PSO.

[Kim et al, LNCS, KES2005]

Simulation Results (1)

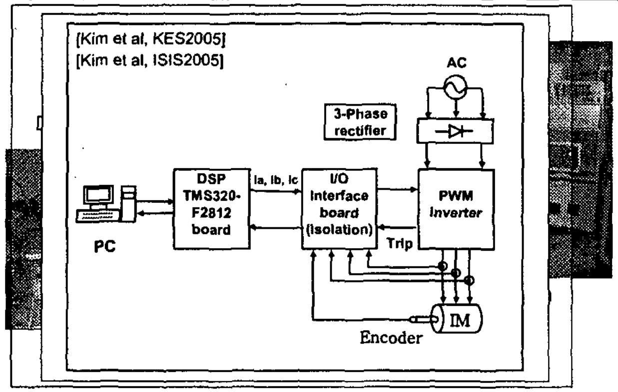


Speed tracking of indirect vector PI controller.

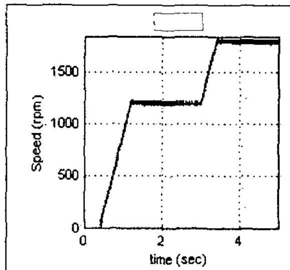


Flux amplitude tracking of indirect vector PI controller.

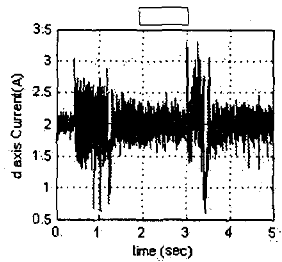
GA-PSO Based DSP Vector PI Control



Experimental Results (3)



Speed tracking in experiments of indirect vector PI controller



d-axis current tracking in experiments of Indirect vector PI controller.

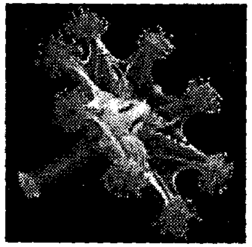
Summary

- Suggest GA-PSO for improving learning and reducing computing time
- Obtain good tuning approach in AVR systems
- Satisfied the speed and current control requirements for good torque and efficiency
- Reduce loss with motor vector PI controller tuning (Efficiency, Torque, Speed)
- Have possibility of wide range of data

Chapter 4 :

Intelligent PID Controller Tuning Using Hybrid System Based on GA (Genetic Algorithm) and BF (Bacteria Foraging)

[Kim, IWEB2005]
[Kim, KES2005]



Background

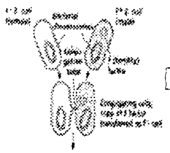
Robust Intelligent PID tuning for The dynamically Changing Environments

Strategy for Life
- Learning
- Optimization

Dynamic equation for the characteristics of learning and optimization

- Find the best intelligent approach depending on system
- Apply to engineering problem (Ex. Tuning)

Behavior Characteristics of Bacteria Foraging



The char. of bacterial foraging

- Natural selection,
- Tends to eliminate bacterias with poor foraging strategies
- Favor the propagation of genes of those BF that successful foraging strategies
- More likely to apply reproductive success to have an optimal solution for their life

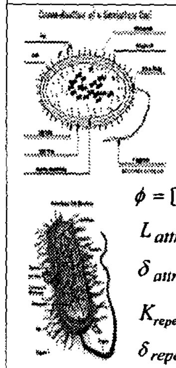
Foraging scenarios

- Modeled as an optimization process

Application to Eng.

- Apply this optimization process to engineering fields.

Dynamic Equation of Bacteria Foraging



$$P_c(\phi) = \sum_{i=1}^{N} P_{cc}^i = \sum_{i=1}^{N}\left[-L_{attract}\exp\left(-\delta_{attract}\sum_{j=1}^{n}(\phi_j-\phi_j^i)^2\right)\right] + \sum_{i=1}^{N}\left[-K_{repellant}\exp\left(-\delta_{repellant}\sum_{j=1}^{n}(\phi_j-\phi_j^i)^2\right)\right]$$

$\phi = [\phi_1, ..., \phi_p]^T$: Point on the optimization domain,

$L_{attract}$: Depth of the attractant released by the cell

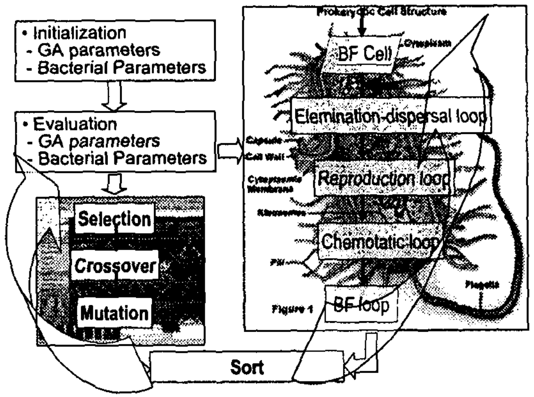
$\delta_{attract}$: Measure of the width of the attractant

$K_{repel} = L_{attra}$: Height of the repellant effect magnitude

$\delta_{repellant}$: Measure of the width of the repellant

[Passino, IEEE Mag., 2002]

Computation procedure of GA-BF Algorithm

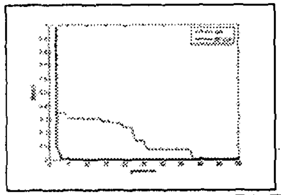


Initial condition of test function and variation of parameters obtained by simulation

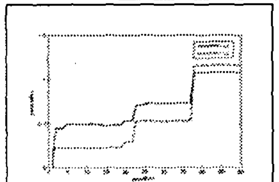
Test Function	Range		Genetic Algorithm Parameters				Bacteria Foraging Parameters			
	$x_i^{(L)}$	$x_i^{(U)}$		G	Mu	Cr	CS	Step size	Ns	S
$F_1(x) = \sum_{i=1}^{3} x_i^2$	-5.12	5.11	20	300	0.9	0.1	1000	1e-007	3	10
$F_2(x) = 100(x_1^2 - x_2)^2 + (1 - x_1)^2$	-2.04	2.047	20	600	0.9	0.1	1000	1e-007	3	10
$F_3 = \sum_{i=1}^{5} [x_i]$	-5.12	5.12	20	180	0.9	0.1	1000	1e-007	3	10
$F_4 = \sum_{i=1}^{30} ix_i^4 + N(0,1)$	-1.28	1.27	20	300	0.9	0.1	1000	1e-007	3	10

CS : chemotactic steps, S : the number of critical reaction
Ns : The length of the lifetime in the bacteria.

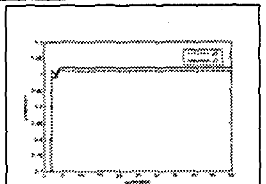
Experimental Results



Characteristics of GA and GA-BF by test function

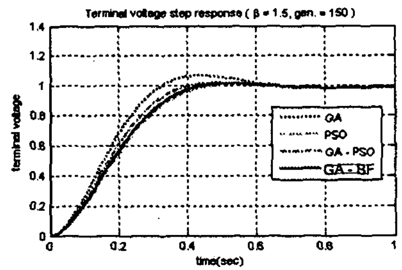


Characteristics of GA by test function



Characteristics of GA-BF by test function

Intelligent Tuning of AVR system [Kim, KES2005]



Terminal voltage step response of an AVR system in different controllers

Comparison of PID Parameter in Each Optimal Algorithm (Using performance in Ch.3)

β	Item	k_p	k_i	k_d	Mo	ess	t_s	t_r	F(kp, Ki, Kd) in Ch3
1.5	GA	0.8282	0.7143	0.3010	6.7122	0.0112	0.5950	0.2156	0.0135
	PSO	0.6445	0.5043	0.2348	0.8399	0.0084	0.4300	0.2827	0.0076
	GA-PSO	0.6794	0.6167	0.2681	1.8540	0.0178	0.8000	0.2526	0.0071
	GA-BF	0.6728	0.4787	0.2299	1.97	0.0014	0.4180	0.2795	0.0073

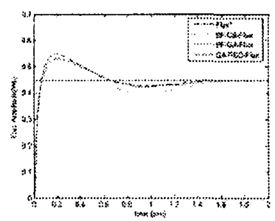
Gen.=150

Comparison of PID parameter in each optimal algorithm

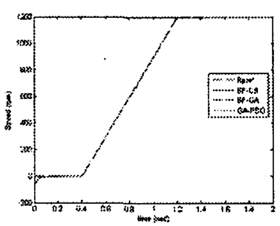
Item	GA-BF	GA	Immune Algorithm
Kp	29.901	29.992	29.739
Ti	0.25813	0.0001	0.39477
Td	30	28.3819	27.277
ITSE	0.000568	0.000668	0.0006352

Performance index: ITSE (Integration Time Squared Error)

Comparison of in Each Approach (Simulation)



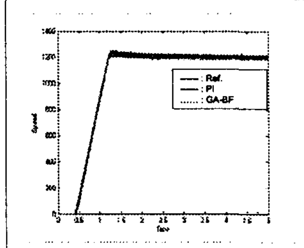
Flux variation



Speed variation

Comparison of Each Approach (Experiment)

[Kim, LNCS, KES2005, ISIS2005]



Speed variation

Error of GA-BF based vector PI controller

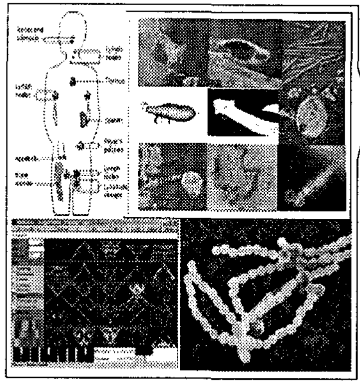
Method	ISE (Integral Square Error)
Back stepping	1.7371×10^{-6}
GA-BF	1.4251×10^{-6}

Summary

- GA-BF approach for improvement of learning and optimization in GA
- GA-BF has better response on various test functions
- Satisfactory PID *controller tuning* in AVR, *motor vector* control systems
- Potentially useful in many practically important engineering optimization problems

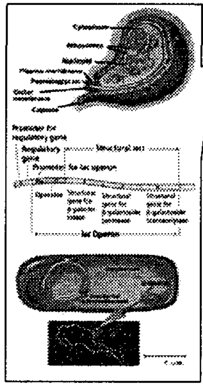
Chapter 5
Conclusions

Trend



- Many kinds of biological *information processing* (BIP) approaches
  - various feasible computational ideas
  - Engineering fields
- Evolutionary computation based approaches
  - Increased attention
  - Many problems which could not be solved
  - Conventional problem solving techniques.

Target



- As GA based Hybrid system is one of BIP *in a natural system*
- Have some characteristics

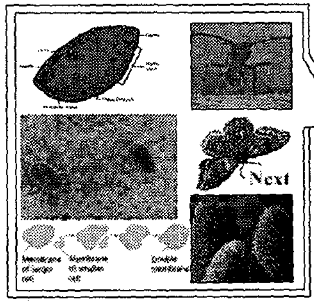
●Learning methods
●Optimization strategy

- Learning
- Optimization
- Multi-objective

- Dynamic Equation
- Analysis and Modification

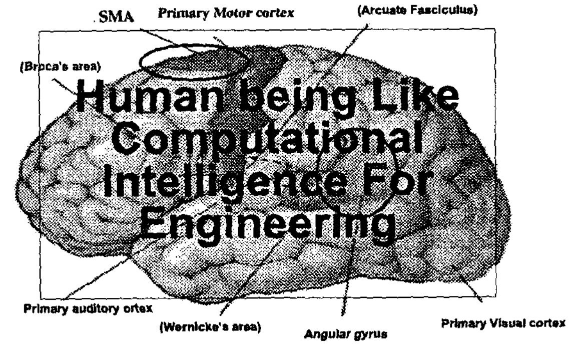
- New Fusion Technology
- Human being like CI system
- Engineering application

Further works



- **Further Works**
  - Various Evolutionary
  - Biological System
  - Bacteria Foraging
  - PSO
  - Natural, Etc.

Final Purpose



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- [J-4] Sung-Kwun Oh, Dae-Keun Lee, Witold Pedrycz, Dong-Hwa Kim, "The genetic design of hybrid fuzzy controllers," Cybernetics and Systems, Vol. 35, No. 4, pp. 1-29, 2003.
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Selected Publications (2)

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- [J-6] Dong Hwa Kim, Jae Hoon Cho, "Robust PID using Gain/Phase margin and advanced immune algorithm," WSEAS (World Science Engineering Application Society) Transaction on systems Vol. 3, No. 9, 2004, pp. 2841-2851.
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- [J-8] Dong Hwa Kim, Jae Hoon Cho, "Robust Tuning of PID Controller Using Bacterial-Foraging-Based Optimization," Journal of Advanced Computational Intelligence and Intelligent Informatics, Vol. 9 No. 6, 2005, pp. 669-676.
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- [J-11]Keun-Chang KWAK, Dong-Hwa KIM, "TSK-based Linguistic Fuzzy Model with Uncertain Model Output," IEICE TRANS. INFORMATION & SYSTEMS, VOL. E86-D, No. 1 March 20, 2005. Submitted

Selected Publications (3)

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- [J-12] Dong Hwa Kim, Jae Hoon Cho, Ajith Abraham, "*Immune algorithm based optimal learning of fuzzy neural network*," IEEE SMC, March 25, Submitted.
- [J-13] Dong Hwa Kim, *Member IEEE*, Jin Ill Park and Ajith Abraham*, *Member IEEE, Kaoro Hirota*, "Intelligent PID Controller Tuning of AVR system based on *immune* algorithm and PSO, International Journal of Electronics, May 8, 2005, Second reviewing.
- [J-14] *Dong* Hwa Kim, *Chae* Hoon Cho, "GA-PSO based vector control for indirect of three phase indiction motor," Applied Soft Computing, April 30, 2005, Second reviewing.
- [J-15] Dong Hwa Kim, "Hybrid GA-BF based intelligent PID Controller Tuning for AVR system," Applied Soft *Computing*, April 30, 2005, Second reviewing.
- [J-16] Dong Hwa Kim, "Intelligent PID controller tuning using Hybrid GA-PSO approach, Applied Soft Computing, April 30, 2005, *Second* reviewing.