The 21st Century COE Program for Research and Education on Complex Functional Mechanical Systems

— New Front of Mechanical Engineering Inspired by Science of Complexity —

Kyoto University

Graduate School of Engineering

- Department of Mechanical Engineering and Science
- Department of Micro Engineering
- Department of Aeronautics & Astronautics

Graduate School of Informatics

- Dept. of Applied Analysis and Complex Dynamical Systems

COE Leader

Prof. Kazuo Tsuchiya (2003-2006)
(Dept. of Aeronautics & Astronautics)

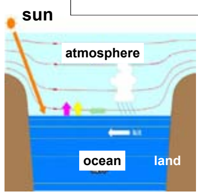
Prof. Tetsuo Sawaragi (2007)
(Dept. of Mechanical Eng. and Sci.)

Mission and Scope of the Program

Phenomenological Analysis and Modeling → Complex Systems Mechanical Engineering ← Control and Functional Synthesis

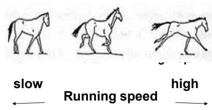
Complex Functional Mechanical Systems

macroscopic phenomena of complex systems consisting of microscopic elements, mostly via nonlinear, large-scale interactions



Atomosphere and Ocean Systems

…



Robot Systems

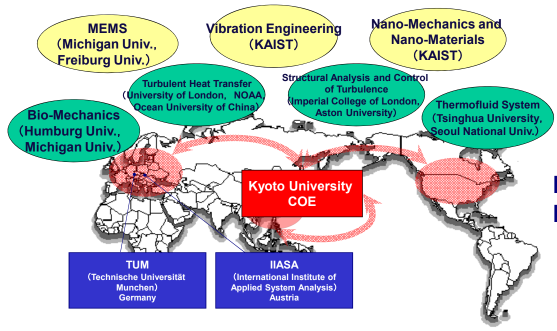
Modeling and analysis of universal laws governing the dynamic behaviors of natural and artificial complex mechanical systems

To elucidate and formulate control principles which make possible the practical application of complex systems

Roadmaps of the Research Topics

	Spatial Complexity	Temporal Complexity
Phenomenological Analysis and Modeling	Analysis of Heat Diffusion and Wave Propagation on Fractal Structures Analysis of Behaviors of Mechanical Materials with Complex Structures	Analysis of Turbulent Transport Phenomena and Modeling of Atmosphere-Ocean System
Control and Functional Synthesis	Turbulence Control by Chaos Theory	Adaptive Pattern Formations of Locomotive Behaviors and Human-Guided Collaboration

Network of International Collaborations



Educational Phylosophies of the COE

- Renewing Knowledge Vision of Mechanical Engineering
- Educational Research and Development for Promoting Basic Research
- Mechanical Engineering as an Empirical Science supported by qualified Pragmatism

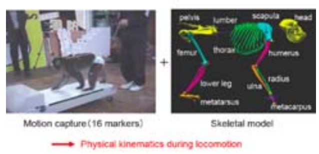
Education Program for Young Researchers

- Joint Interdisciplinary research program
- Fellowship program
- Public education program

Complex System Control and Design

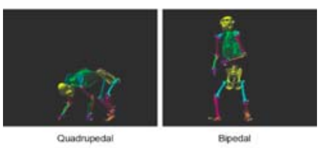
Reconstruction of Locomotive Behaviors

Reconstruct locomotor behavior of Japanese monkey based on obtained skeletal model

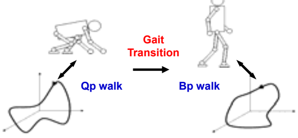


Physical Kinematics

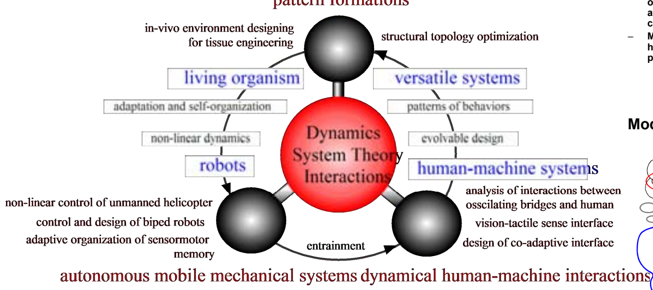
Reconstructed physical kinematics from obtained motion capture data and skeletal model



Gait transition from Qp to Bp locomotion



Research Topics of the Group



Design Theory for Dynamical Systems with Semiosis

Flexible adaptability / Rich variabilities → Soft and Dynamical Systems

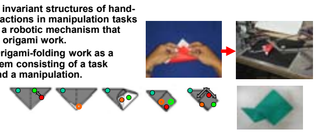
- to use the natural dynamics that each of the system components originally has to create structures and functions
- how the component recognize the environment and how the context determines the behaviors of the component

‖

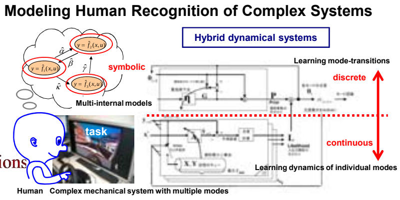
Shift from "Design for Manufacture" to "Design for Narture"

Development of "Origami" Folding Robot

- Identify the invariant structures of hand-object interactions in manipulation tasks and design a robotic mechanism that can make a origami work.
- Modeling Origami-folding work as a hybrid system consisting of a task planning and a manipulation.

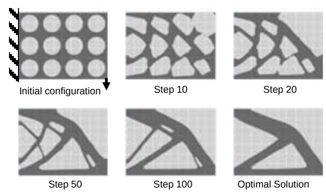


Modeling Human Recognition of Complex Systems



- Modeling dynamical characteristics of a human user's recognition within a human-machine system.
- Constructive approach to Interface design based upon understanding the development of human recognition skills.

Topology Optimization Based on the Level Set Method

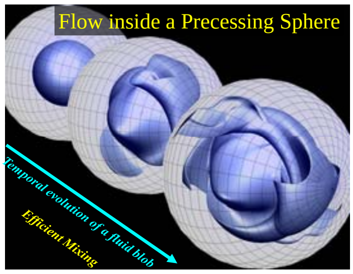


Complex Fluid Mechanics Research

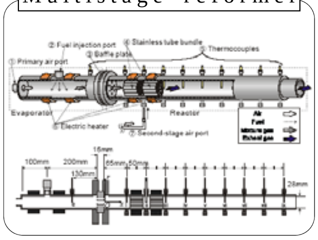
Main members: S. Komori (Leader), K. Aoki, T. Inamuro, S. Kida, T. Makino, M. Nagata, K. Nakabe, K. Ono, and H. Yoshida

Scalar transfer across the air-water interface in a wind-wave tank

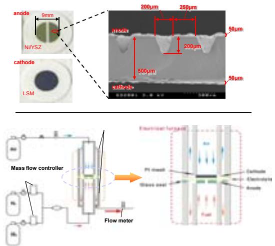
Flow inside a Precessing Sphere



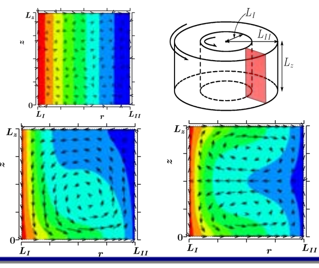
Multistage reformer



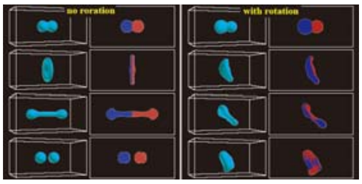
Mesoscale structure of SOFC

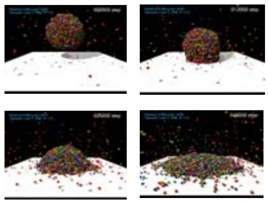


Instability and bifurcation of rarified fluid



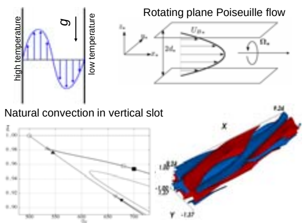
Simulation of droplet collision dynamics by the lattice Boltzmann method (LBM)





Molecular simulation of impingement a nano-scale droplet on solid surface

Transition from laminar to turbulence in parallel shear flow

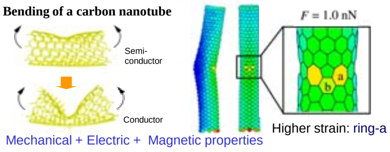


Properties of Materials with Complex Structure

Materials Science in Mechanical Engineering

Quantum mechanics of materials

Deformation and properties

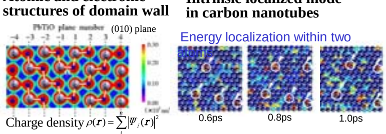


Mechanical + Electric + Magnetic properties

Structures and properties

Atomic and electronic structures of domain wall

Intrinsic localized mode in carbon nanotubes



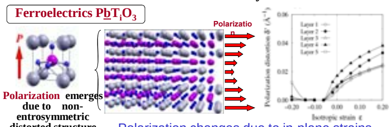
Charge density $\rho(\mathbf{r}) = \sum |\Psi_i(\mathbf{r})|^2$

Ab initio calculation

Change in distribution of total energy

Strain effects on surface ferroelectricity

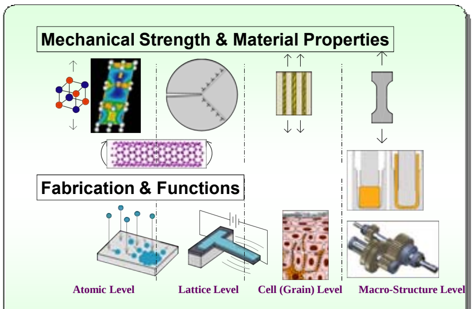
Ferroelectrics $PbTiO_3$



Polarization emerges due to non-entrosymmetric distorted structure

Polarization changes due to in-plane strains.

The study targeted here is centered on the modeling of materials system made up with "elemental formation of internal structures" and through "interactions of the elements" in the "Complex Science".

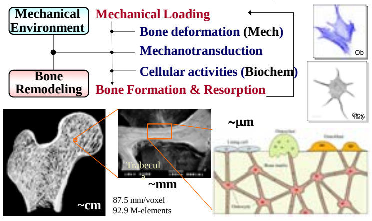


Mechanical behaviors of materials are highly dependent on the structure with **multiscale hierarchy**.

Our goal is to establish a common basis for dealing with "complexity" by reconsidering mechanical behaviors and functions of materials/structures from multi-physical aspects.

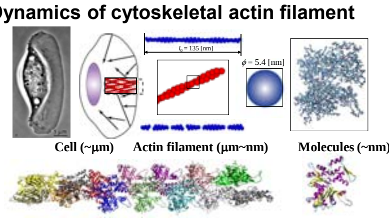
Adaptive materials and structure:

Bone functional adaptation by remodeling



Computer simulation of cancellous bone remodeling in Human proximal femur considering osteocyte network system

Dynamics of cytoskeletal actin filament



Multiscale modeling and simulation of cell crawling driven by dynamics of cytoskeletal actin filament from molecules to cell

Applied Analysis and Complex Dynamical Systems

The Scope of Our Research

We aim at establishing *the theory of Complex Dynamical Systems* from both science and engineering through this COE program. To this end, we select our research topics as;

1. **fractal and probability,**
2. **brain science,**
3. **analysis of chaos,**
4. **computational engineering,**
5. **signal processing based on control theory**

Keywords

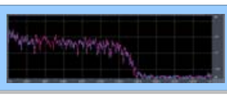
fractal, fractal geometry, chaos, probability,
brain science, signal processing, non-linear physics, fluid dynamics, inverse problems, numerical analysis, computational engineering, fracture mechanics, applied analysis, control theory

A signal processing example is shown on the right:

Digital Signal Processing based on Control Theory

It is widely believed that the audible range is limited to 0-20kHz. Anything beyond is sharply cut via a low-pass filter. This is based on the well-known *Whittaker-Shannon sampling theorem*. This however has the following problems

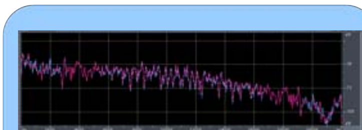
- **The Shannon formula is *non-causal*, it is not readily applicable to sound reconstruction/recovery.**
- **It is also argued that the Nyquist frequency 22.05kHz may *NOT have a sufficient margin against the audible range*.**



FFT of a digital audio signal of MD (mini disc) with 66kbps

To remedy these problems, we propose a new theory based on *sampled-data control*, which guarantees a digital filter (named *YY filter*) that optimally recovers the *analog performance*. The theory have been applied to audio signal processing, image/video processing, signal compression, hearing aids, etc.

DA converter with YY filter implemented on TI C6713 DSP



FFT of reconstructed audio signal by YY filter.