Local Voting Protocol for the Adaptation of Airplane's "Feathers" in a Turbulence Flow

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Outline

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Introduction

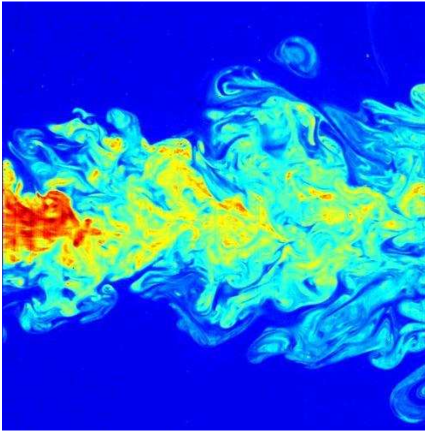
Miniaturization and increased performance of calculators, sensors and actuators are opening up the new possibilities of an intelligent control for complex mechatronic systems in conditions of turbulence and on transition intervals of times.

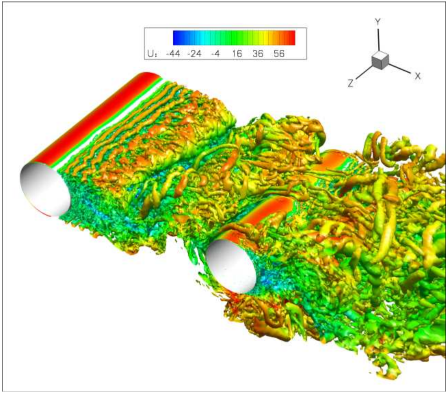
Control of Transition Processes

- Non-Equilibrium Processes
  - Structure of state space changes with time
  - Traditional methods give bad results
- New approachers are required

Due to the limited possibilities of practical implementation,
the adaptive control is explored slightly when the structure of the state space is time-varying.

Control in Turbulence





Complexity of Algorithms

- Many problems are *NP*-hard ...

Complexity of Algorithms

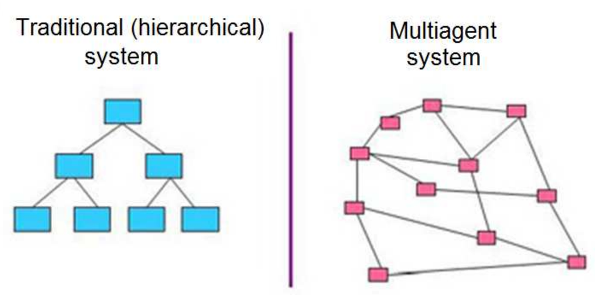
- Many problems are *NP*-hard ...
- Alternative framework:
  - use a set of $\{$sensors + actuators + comput. units$\}$ as an investigation systems with such complexity that is similar to the complexity of studied phenomena

Multi-Agent Technologies

The application of the traditional mathematical models of system motion with a large number of transducers / sensors and actuators often leads to extremely complex problems, involving extremely high-dimensional state spaces. The multi-agent technology can effectively solve many of the problems arising in this context by

- replacing the general model of interactions by a complex system containing the set of multiple local models
- and using some way of local models aggregation (clustering). Decisions in local models are being made based on locally available data

Muliagent Systems (From 1990s)



The achievements in the following areas were taken as a basis:

- Parallel Computing
- Distributed Problem Solving
- Artificial Intelligence

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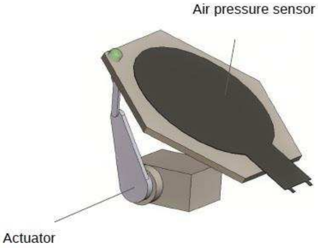
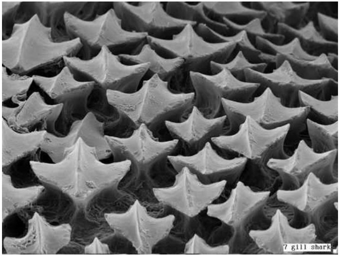
An Airplane with “Feathers”

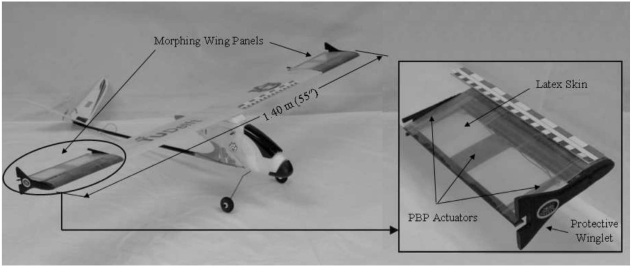


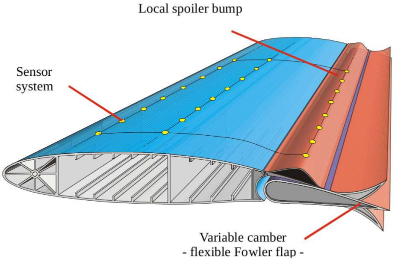
Owl Feathers

Shark Scales

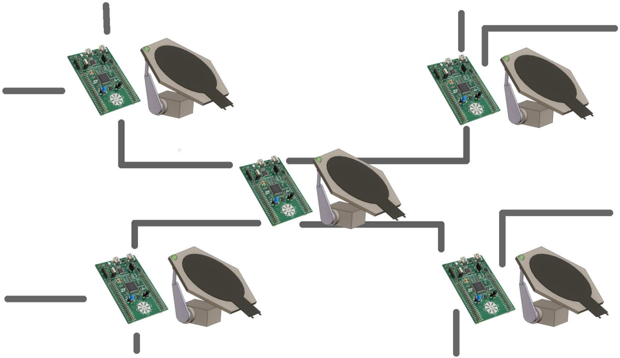


Adaptive Wing Form

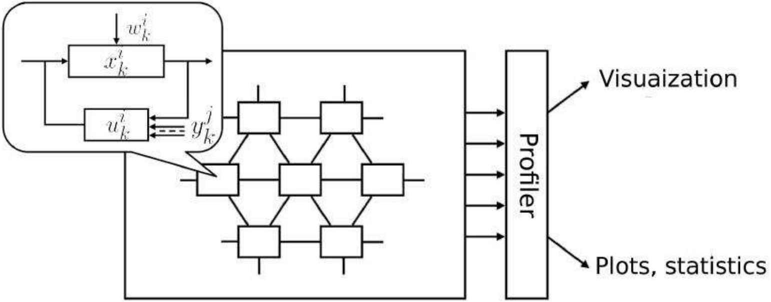




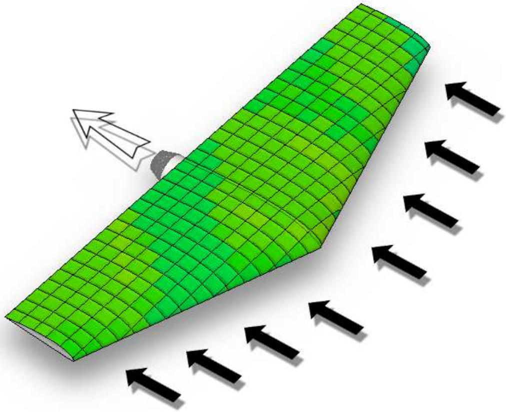
System Architecture



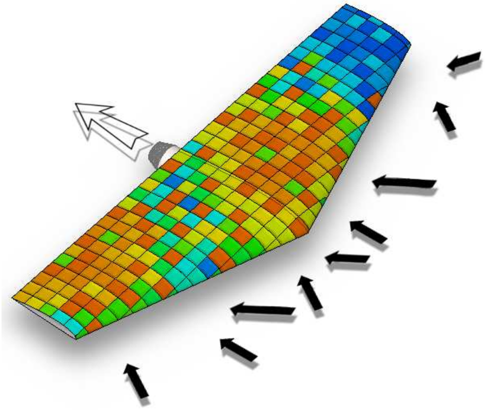
Architecture of Experimental Stand



Airplane with “Feathers” in Laminar Wind Flow



Turbulent Flow



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Local Voting Protocol

Let x_k^i be the integrated pressure deviation for "feather" a^i
Agents' dynamics:

$$x_{k+1}^i = f(x_k^i, u_k^i),\ i \in N = \{1, \ldots, n\}$$

Observations:

$$y_k^i = x_k^i + \xi_k^i$$

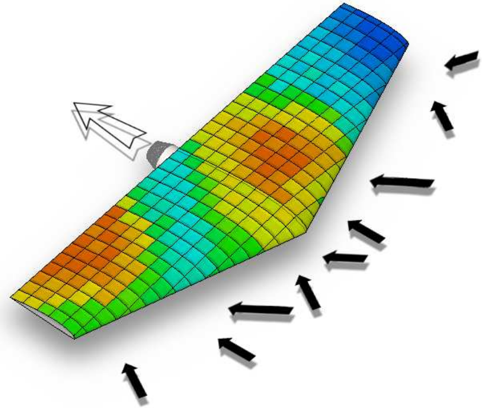
Local Voting Protocol:

$$u_t^i = \alpha \sum_{j \in N_k^i} b_k^{i,j} (y_k^j - y_k^i)$$

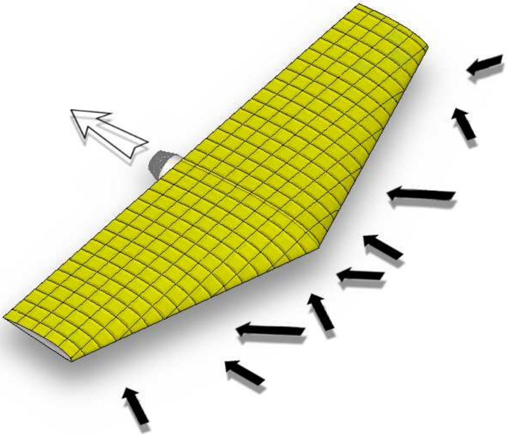
Consistent behavior (consensus):

$$x_k^i \approx x_k^j,\ i,j \in N$$

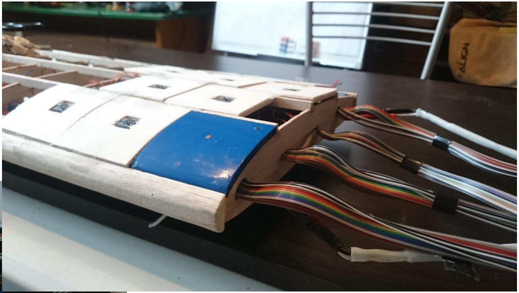
Clustering of “Feathers”

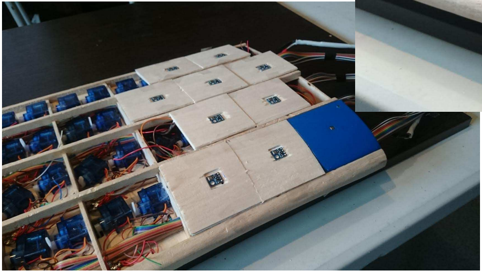


"Alignment" of Pressures in Turbulent Wind Flow



Experimental Stand (in Progress)





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Conclusions and Future Work

Miniaturization of control plants and high frequency control actions do not allow to validate the motion model with the traditional high degree of accuracy.

This fact emphasizes the key problem:

- development of adaptive control in presence of significant uncertainties and external disturbances when we have only finite time interval for the adaptation process.

Acknowledgements

- Russian Science Foundation (project 16-19-00057 "Model Predictive Adaptive Control with Time-Varying State Space Structure and Applications in Network Control of Motion and Automatic Medical Tools")
- Saint Petersburg State University (travel grant)

What is an actual structure of complex systems?

Complex systems:

$X(t)$ is a state vector, $W = \begin{pmatrix} u \\ w \end{pmatrix}$ is an external disturbances

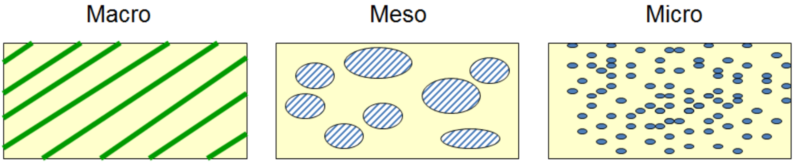
Dynamic equations:

$$\dot{x}_i = g_i(X, W),\ i = 1, 2, \ldots, n,\ X \in \mathbb{R}^n \tag{1}$$

or

$$\dot{x}_\gamma = g_\gamma(X, W),\ X = \{x_\gamma\},\ \gamma \in [0, 1] \tag{2}$$

Levels of Model Description, Self-organization



In open thermodynamic systems, synergistic processes often form new dynamic structures at the mesoscopic level. These processes are associated with an internal control feedback, which, together with an external control, leads to the discretization of state space and time of non-equilibrium systems.

Cluster Flow

Let W be structured, and structure s_k changes in time instances $T_0, T_1, T_2, \ldots$
Clustering of state space:

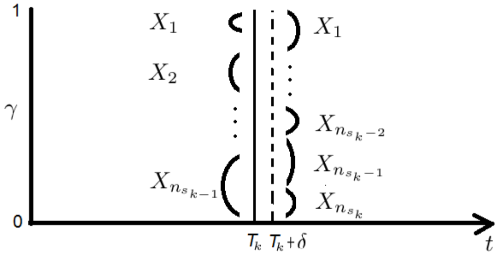
$$\mathscr{X}_{s_k} = \{X_1, X_2, \ldots, X_{n_{s_k}}\} : \; X = \cup_{i=1,2,\ldots,n_{s_k}} X_i, \; X_i \subset X \tag{3}$$

Dynamic Equations:

$$\dot{\bar{x}}_i = \bar{g}_i(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_{n_{s_k}}, u, w, \theta_{s_k}), \; i = 1, 2, \ldots, n_{s_k}, \tag{4}$$

where $\bar{x}_i$ is a set of integrated x_γ on cluster X_i,
θ_{s_k} is a finite set of "current" parameters

State Space Structure Changing



$$\delta << \zeta = \min_k |T_{k+1} - T_k|$$

System Identification Issues

Measurements:

$$Y(t) = \int_{t-\Delta}^{t} \int_{\mathbb{M}} f(X, W) dX dt' = \int_{t-\Delta}^{t} \bar{f}_k(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_{n_{s_k}}, u, w, \theta_{s_k}) dt' \quad (5)$$

After disretization and simplifications, we have:

$$y_i = \tilde{f}_k(x_i, u_i, w_i, \theta(s_k)) + \xi_i \quad (6)$$

where $y_i = Y(t_i)$, $t_i \in [T_k, T_{k+1}]$, $\tilde{f}_k(\cdot)$ are functions of

$$x_i = col(\bar{x}_1(t_i), \bar{x}_2(t_i), \ldots, \bar{x}_{n_{s_k}}(t_i)),\ u_i = u(t_i),\ w_i = w(t_i),\ \theta_{s_k},$$

$\xi_i = \xi_i' + \xi_i(s_k)''$ is a standard error (noise),
ξ_i' is a random noise, $\xi_i(s_k)''$ is a systematic errors

Thank you for your attention!