* CSL – NTUA : A glimpse of our Robotic activities

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Greece

* Introduction: The NTUA-CSL Team

The Team

- 3 Professors
- 2 Research Engineers (Full time)
- 2 Research Scientists (Adjunct)
- 12 Doctoral Researchers
- 8 Postgraduate Researchers
- ~20 Diploma Students

RTD effort

- Last 10 y: 40 Projects (8 M €)
- Currently: 10 Projects (5 EU + 5 National)

Relevant Facilities: Space & Support

- ~ 600 m^2 Lab space
- Embedded & Real Time Computing Platforms (QNX, RT-Linux, VRTx)
- Machining workshop (including CNC machines, 3D-Printer, etc.)





Research Areas

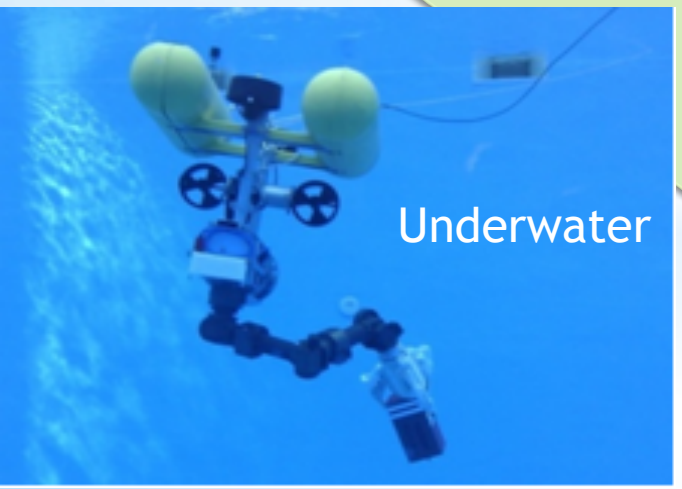
Human Oriented Robotics





Embedded Control Systems in **Robotics**









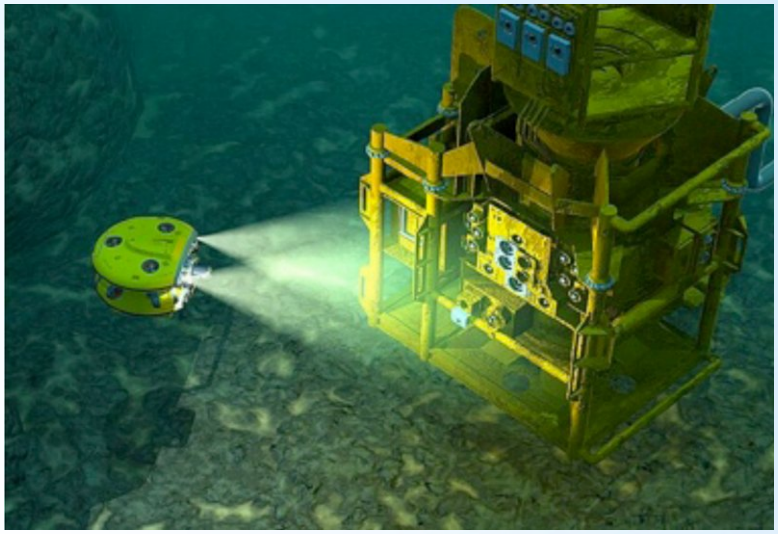
Towards Persistent Autonomy of Underwater Vehicle – Manipulator Systems:

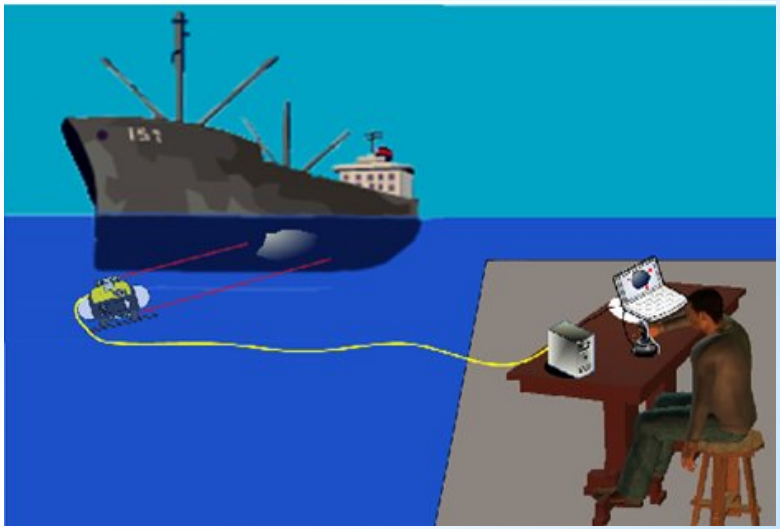
Robust Control Strategies for Efficient Positioning and Interaction

Introduction

Design, Implementation and Real Time Application of Robust Control Schemes for the Autonomous/Semi-Autonomous Operation of Underwater Robotic Vehicles

- Persistent Autonomy for AUVs and the role of Motion/Force Control
- On line State & Parameter Estimation of Underwater Vehicles
- Semi – Autonomous Motion Control Schemes for Inspection Tasks
- Robust Servo Control:
  - ✓ Sonar & Model – Based for Surveillance
  - ✓ Visual & Model Free for Inspection/ Interaction Tasks
- Model Predictive Control Schemes for Inspection Tasks
- Underwater Vehicle – Manipulator Control Schemes for Interaction Tasks





Robust Sonar Servo Control for Surveillance

Robust Wall-Following Control (RWFC) Problem: *Assume that the underwater vehicle is initially placed in front of a perpendicular wall (e.g., a submerged structure). The control objective is to fix the distance x and the angle ψ from the wall as well as the depth z to some desired constant values x_d, ψ_d, z_d and maintain a desired constant velocity $\dot{y}_d$ parallel to the wall.*

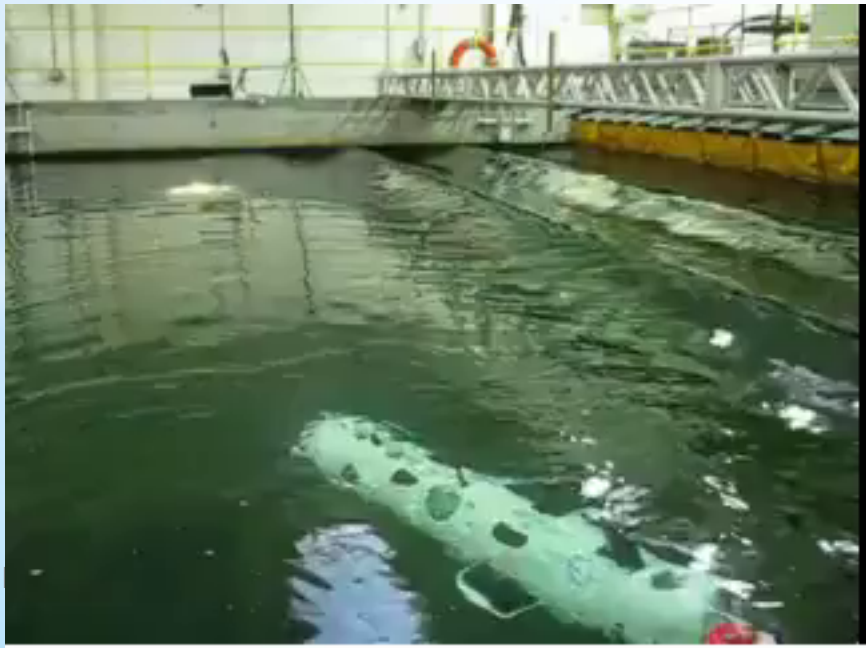
Control scheme:

Kinematic controller

$$u_d = -k_x e_x \cos\psi + v_{yd} \sin\psi$$
$$v_d = k_x e_x \sin\psi + v_{yd} \cos\psi$$
$$w_d = -k_z e_z$$
$$r_d = -k_\psi e_\psi$$

Dynamic controller

$$X = -k_u e_u - e_x \cos\psi + m_u \dot{u}_d - m_v v r - X_u u - X_{|u|u} |u| u - X_{robust}$$
$$Y = -k_v e_v + e_x \sin\psi + m_v \dot{v}_d + m_u u r - Y_v v - Y_{|v|v} |v| v - Y_{robust}$$
$$Z = -k_w e_w - e_z + m_w \dot{w}_d - Z_w w - Z_{|w|w} |w| w - Z_{robust}$$
$$N = -k_r e_r - e_\psi + m_r \dot{r}_d - (m_u - m_v) uv - N_r r - N_{|r|r} |r| r - N_{robust}$$





Robust Model - Free Motion Control

Kinematic controller

$$u_d = -k_x \frac{e_x(t)}{\rho_x(t)} \cos\psi - k_y \frac{e_y(t)}{\rho_y(t)} \sin\psi$$

$$v_d = k_x \frac{e_x(t)}{\rho_x(t)} \sin\psi - k_y \frac{e_y(t)}{\rho_y(t)} \cos\psi$$

$$w_d = -k_z \frac{e_z(t)}{\rho_z(t)}$$

$$r_d = k_o \frac{e_o(t)}{\rho_o(t)}$$

Performance functions:
$\rho_x(t)$, $\rho_y(t)$, $\rho_z(t)$, $\rho_o(t)$
Control gains: k_x, k_y, k_z, k_o

Dynamic controller

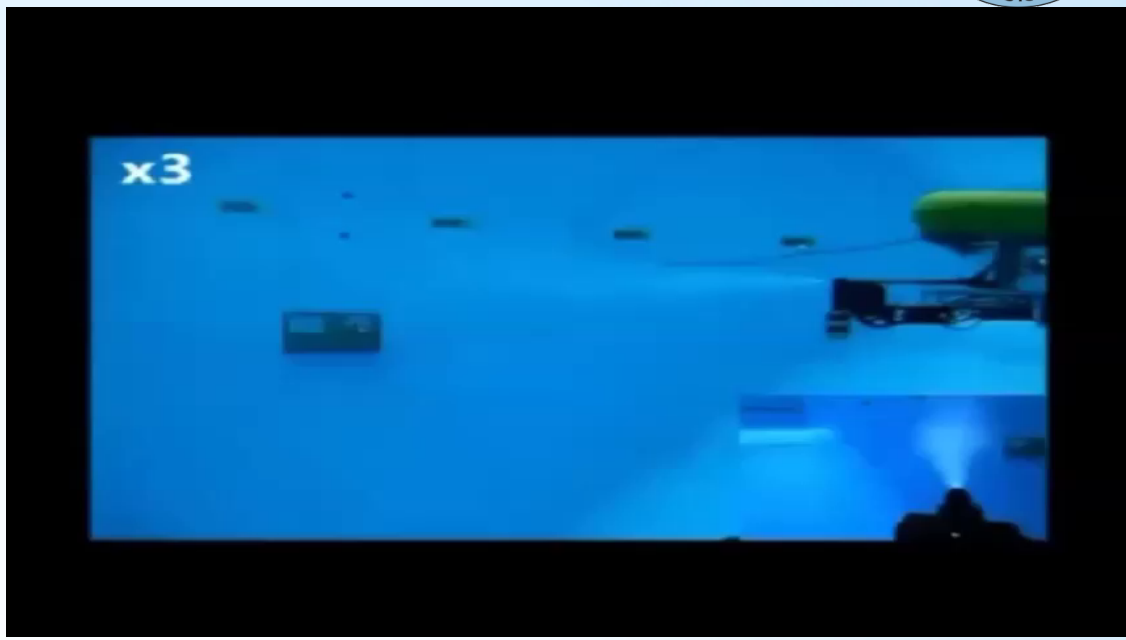
$$X = -k_u \frac{u(t) - u_d(t)}{\rho_u(t)}$$

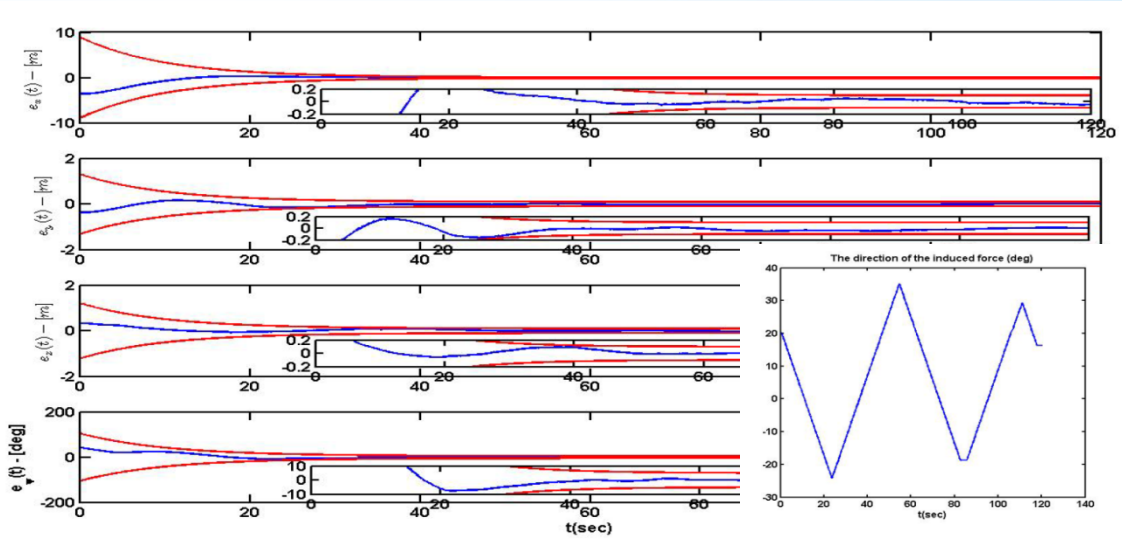
$$Y = -k_v \frac{v(t) - v_d(t)}{\rho_v(t)}$$

$$Z = -k_w \frac{w(t) - w_d(t)}{\rho_w(t)}$$

$$N = -k_r \frac{r(t) - r_d(t)}{\rho_r(t)}$$

Performance functions:
$\rho_u(t)$, $\rho_v(t)$, $\rho_w(t)$, $\rho_r(t)$
Control gains: k_u, k_v, k_w, k_r





Kostas J. Kyriakopoulos

Underwater Vehicle Manipulator System (UVMS): *Modeling*

Kinematic equations :

$$\begin{bmatrix} \dot{\eta}_1 \\ \dot{\eta}_2 \end{bmatrix} = \begin{bmatrix} J_{v1}(\eta_2) & 0 \\ 0 & J_{v2}(\eta_2) \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$

Body-fixed System Velocity

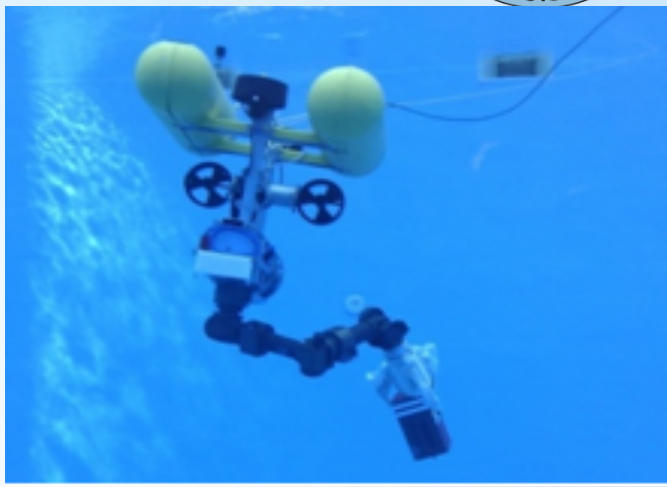
$$v = \begin{bmatrix} v_1^T & v_2^T \end{bmatrix}^T \in \mathbb{R}^6 \quad \begin{cases} v_1 = \begin{bmatrix} u & v & w \end{bmatrix}^T \\ v_2 = \begin{bmatrix} p & q & r \end{bmatrix}^T \end{cases}$$

$$\begin{bmatrix} \dot{p}_{e1} \\ \dot{p}_{e2} \end{bmatrix} = \dot{p}_e = J_W(\eta_2, q_m) \cdot \zeta \qquad \zeta = \begin{bmatrix} v^T & \dot{q}_m^T \end{bmatrix}^T \in \mathbb{R}^{n_m+6}$$

Body-fixed AUV Velocity

$$\begin{bmatrix} {}^0v_E \\ {}^0\omega_E \end{bmatrix} = \begin{bmatrix} J_{m1} \\ J_{m2} \end{bmatrix} \cdot \dot{q} = J_m \cdot \dot{q}$$

Manipulator Geometric Jacobian



Dynamic equations of UVMS:

$$M(q_m) \cdot \dot{\zeta} + C(\zeta, q_m) \cdot \zeta + D(\zeta, q_m) \cdot \zeta + g(\eta_2, q_m) = \tau$$

$M(q_m) \in \mathbb{R}^{(n_m+6)\times(n_m+6)}$: inertia matrix including added mass

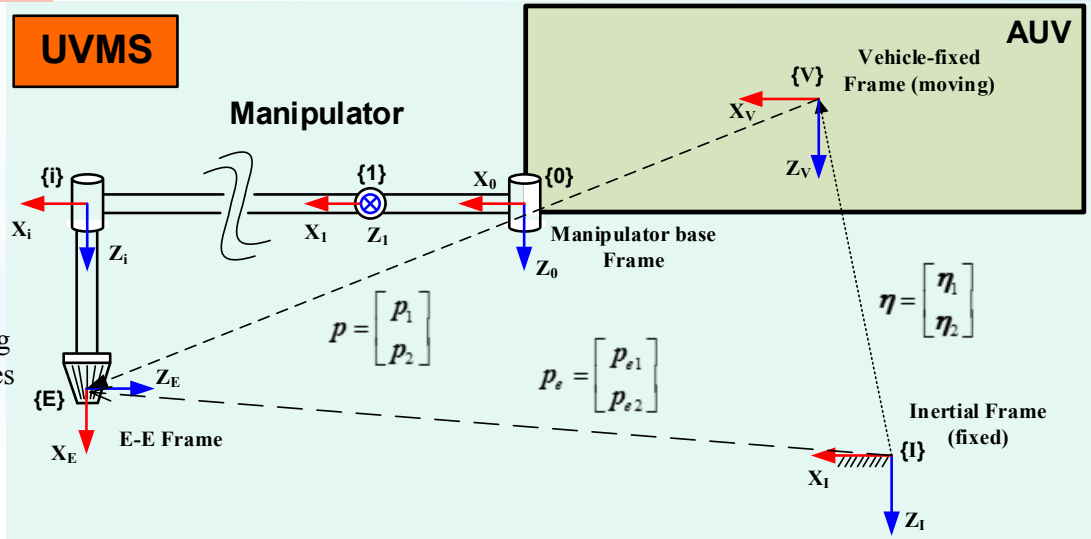
$C(\zeta, q_m) \in \mathbb{R}^{(n_m+6)\times(n_m+6)}$: matrix of Coriolis and centripetal terms including added mass

$D(\zeta, q_m) \in \mathbb{R}^{(n_m+6)\times(n_m+6)}$: matrix of dissipative effects

$g(\eta_2, q_m) \in \mathbb{R}^{n_m+6}$: vector of gravity and buoyancy effects

$\tau \in \mathbb{R}^{n_m+6}$:vector of propulsion force/moment acting on the vehicle as well as joint torques

$\zeta = \begin{bmatrix} v^T & \dot{q}_m^T \end{bmatrix}^T \in \mathbb{R}^{n_m+6}$:body-fixed system velocity vector

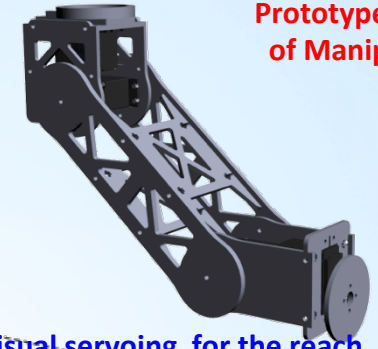


case study 1

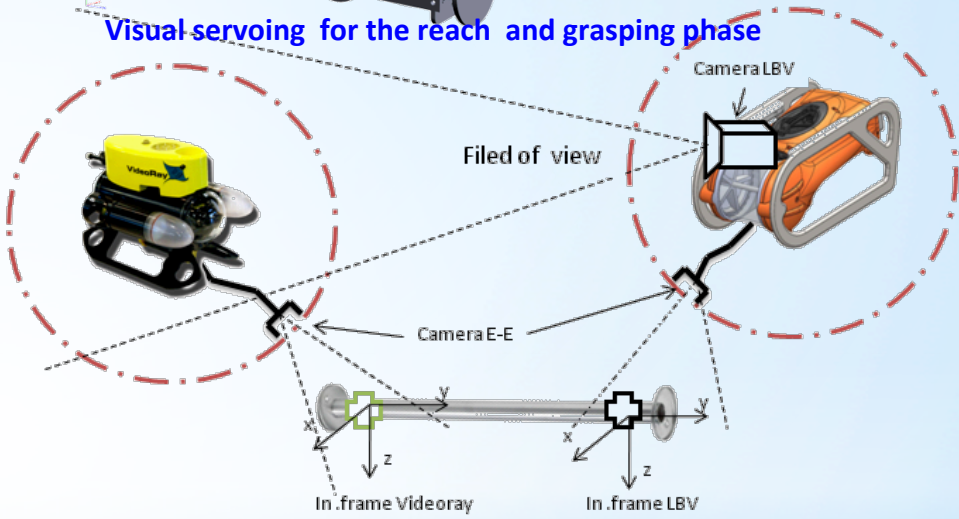
weighting factor of the objective function: w=0.9

UVMS: Future plan

Prototype Design of Manipulator



Visual servoing for the reach and grasping phase



UVMS cooperation:

1- cooperative reach and grasping task

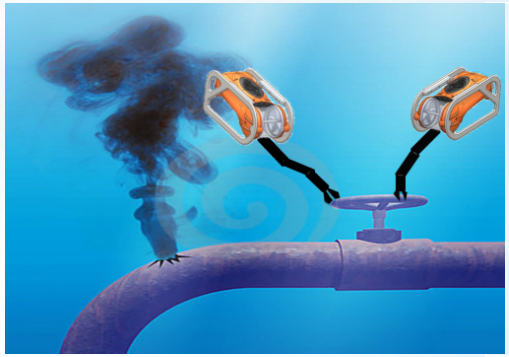
A Cooperative Visual servo leader follower scheme:

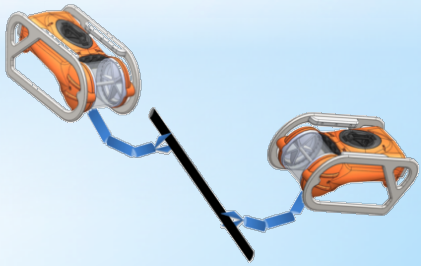
1- Visibility Constraints (object in FOV and leader in FOV of follower)
2- reach to a suitable point (edge) of the object
3- Suitable distance of AUV from target
4- Collision avoiding between UVMS
5- Collision avoiding between UVMS and object
6-Arm joint limits
7- disturbances

2- Cooperative transport of a rigid object to a desired position.

- Arm joint limits
- Manipulability must to be within specified range
- Vision visibility
- Moving of the vehicle when only it is needed (task priority)
- Energy consumptions
- Minimum common information set to be shared
- Using the underwater communication technologies: USBL / vision
- Acceptable communication bandwidth
- Disturbances

Cooperative manipulation tasks UVMS







*NeuroRobotics

From Brain Machine Interfaces to

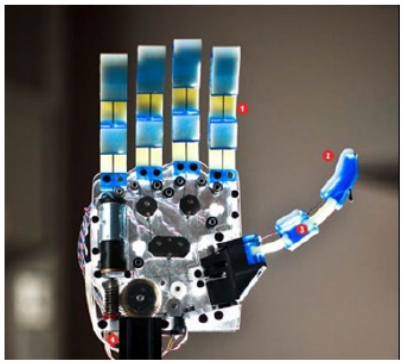
Human Robot Interaction Applications

Neuro-Robotics

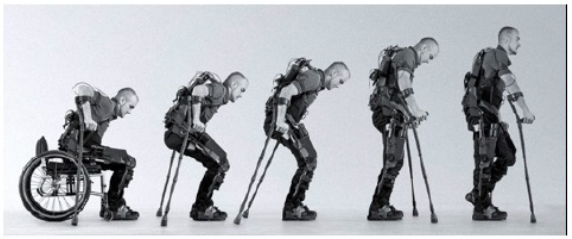
- At the interface of neuroscience and robotics, neuro-robotics is the science and technology of embodied autonomous neural systems
  - ✓ From brain-inspired algorithms to computational models of biological networks to be embodied in actuated machines: robots (manipulators), prosthetic systems (exoskeletons)

NeuroRobotics



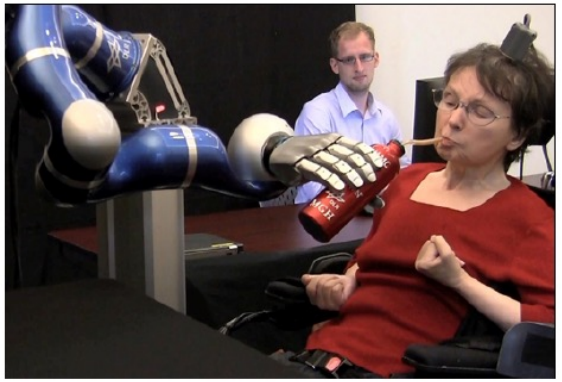


Duality: Human & Robotic Devices



The Experimental Science of Embodiment





A Mixture of Neuroscience & Robotics

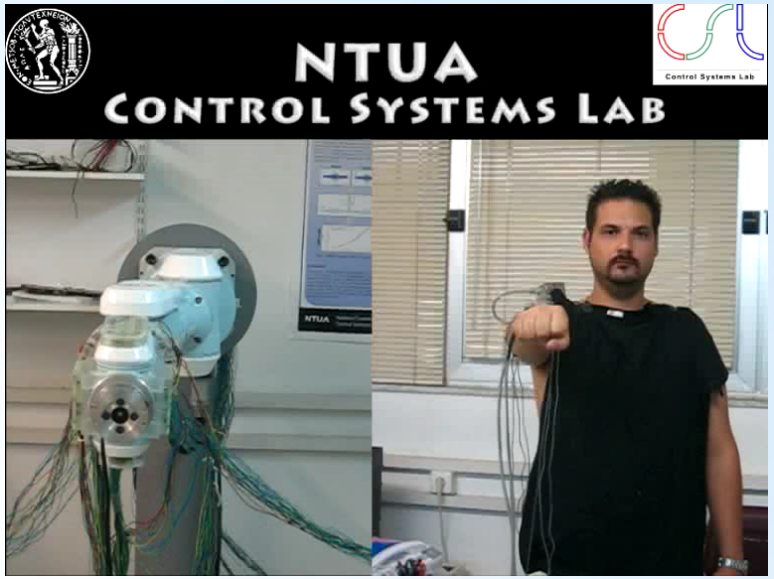
Brain Machine Interfaces:
EMG Based Teleoperation of Arm Hand Systems

We developed EMG based Interfaces:

* That have been used for **continuous** and **smooth control** of robot artifacts
* Are considered to be **robust to time-varying characteristics of EMG signals** (e.g., fatigue, switching models online).
* Use **sophisticated machine learning techniques** that **outperform** previously used methods.

These interfaces can be used for:

* EMG based teleoperation of robot arm hand systems
* EMG control of exoskeletons (rehabilitation)
* Advanced myoelectric prostheses.





FP6-2002-IST-001917 “NEUROBOTICS: The fusion of NEUROscience and roBOTICS for augmenting human capabilities”, 2004 – 7

P. Artemiadis’ Ph.D Thesis. Now Ass. Prof. at **Arizona State Univ.**

URL: http://www.contro
Kostas J. Kyriakopoulos

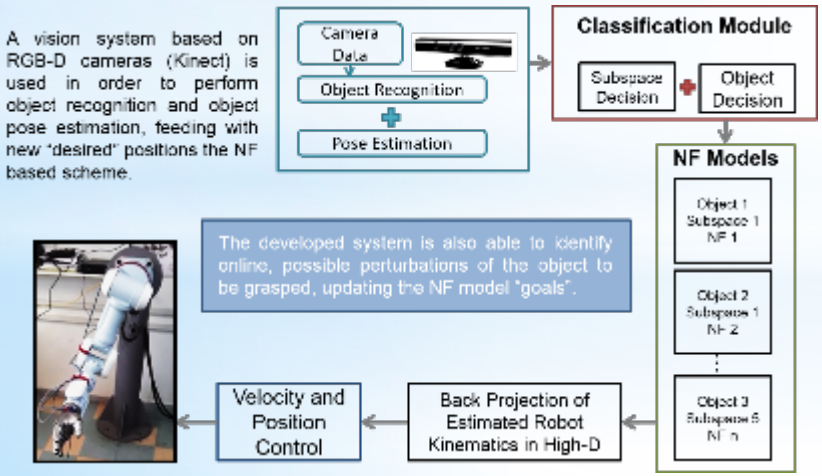
Human Robot Interaction Applications:
Mapping Human to Anthropomorphic Robot Motion & Closed-Loop Anthropomorphic Grasp Planning

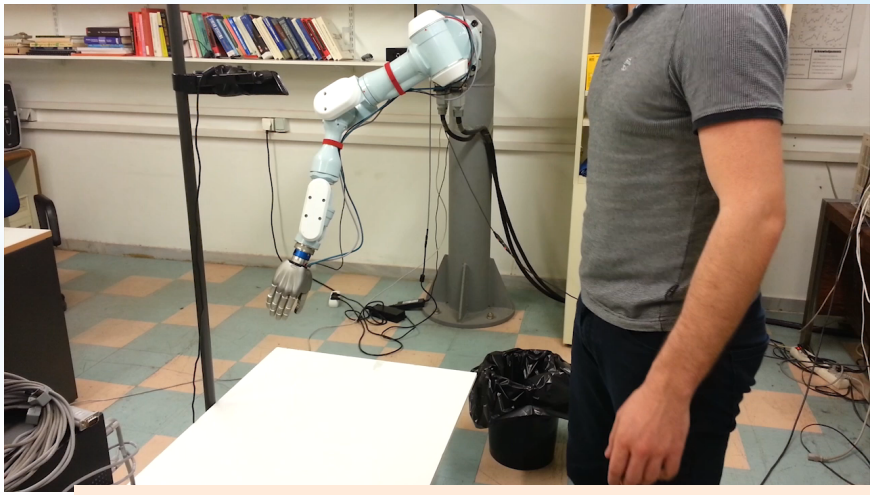
M. Liarokapi's Ph.D Thesis. Now PostDoc at Yale

A **closed-loop scheme** that produces **adaptive robot behavior** similar to humans by switching to different grasping primitives based on **online feedback from a vision system** based on Kinect (Microsoft).

Advanced mapping schemes that transform **human motion to anthropomorphic robot motion** for arm hand systems.



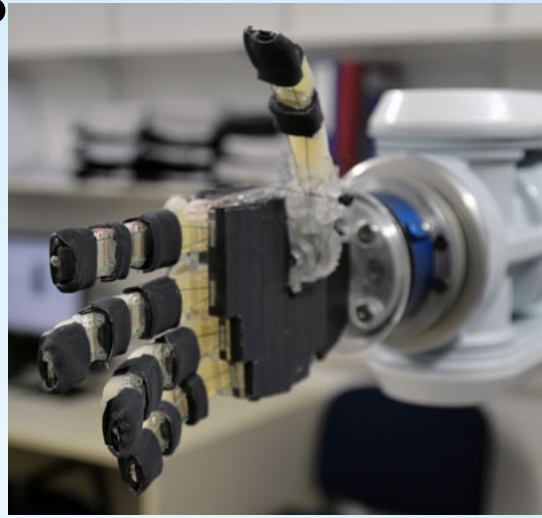




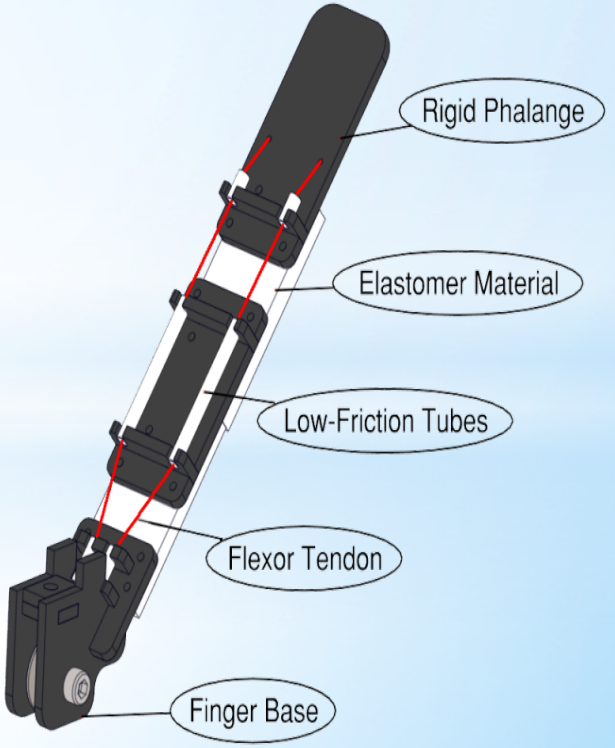
"THE: The Hand Embodied", EU, FP7-248587 -2010-Cognitive Systems and Robotics

Robot Hand Design Principles

- The bioinspired design of robot fingers reproduces the flexion/extension movements and the adaptability of human hand.
- The use of flexure joints allows the hands to adapt to various object sizes and shapes.
- Underactuation minimizes complexity and reduces cost and weight.
- Deformable materials are attached at the robot fingertips to facilitate grasp stability.
- Hands can be easily replicated with off-the-shelf materials and rapid prototyping techniques (3D printers or laser cutters).
- The design is open-source, so all files and codes are available online at our website: www.openbionics.org







Robot Hands

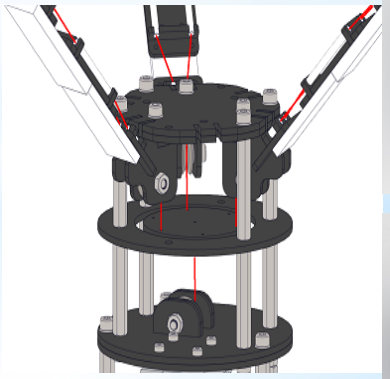
- The modularity of the design is provided by the fingers base that can accommodate up to 4 fingers, creating various.
- The disk shaped differential mechanism allows for independent finger flexion when some fingers have stopped moving due to contact with an object or the environment.
- The total cost of the hands is less than 100$ and the total weight less than 280gr.
- The design is essentially 2D so the robot hands can be easily replicated with standard machinery tools.













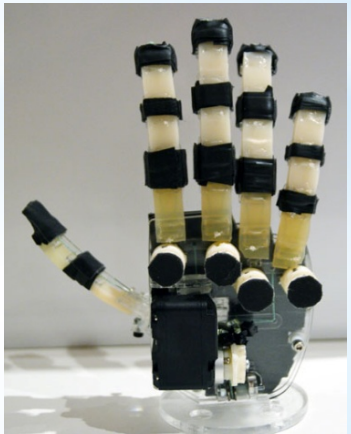


Affordable Prosthetic Hands

- An anthropomorphic design with personalized dimensions (based on an index of anthropomorphism and parametric models from human hand anthropometry studies).
- An novel differential mechanism (variant of the whiffletree) allows the user to selectively lock and unlock the fingers, facilitating the execution of 144 grasps with only 1 motor.
- The thumb mechanism allows for 9 discrete opposition configurations.
- The total cost of the hand is less than 200$ and the total weight less than 300 gr.









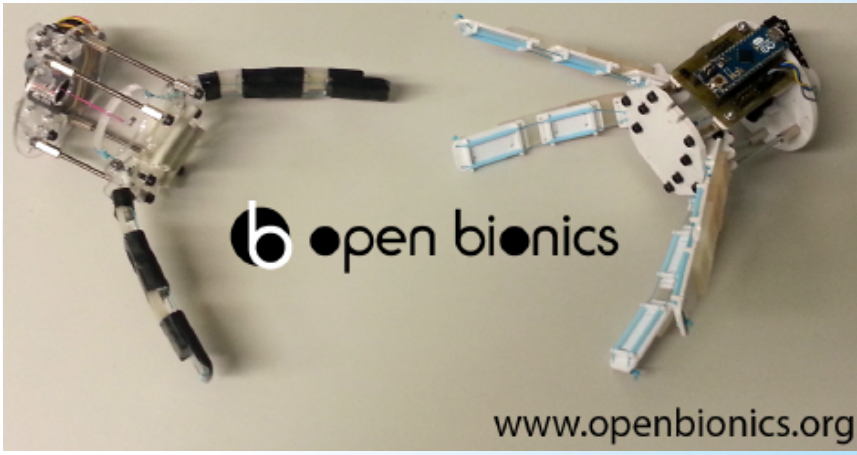
Related Activities

* **HandCorpus** (http://www.handcorpus.org):
  Open-access initiative for sharing data, tools and analyses about human and robotic hands.
  - ✓ 5 ERC/EC funded projects
  - ✓ 15 universities + 4 research institutes (EU+US)
  - ✓ CSL-NTUA: co-founder / technical coordinator

HC HAND CORPUS

* **OpenBionics** (http://www.openbionics.org):
  Development of affordable, light-weight, modular, underactuated robot hands and prosthetic devices.
  - ✓ Hits:~8200 (as of 15/03/2015)
  - ✓ CSL-NTUA: founder

OPENBIONICS





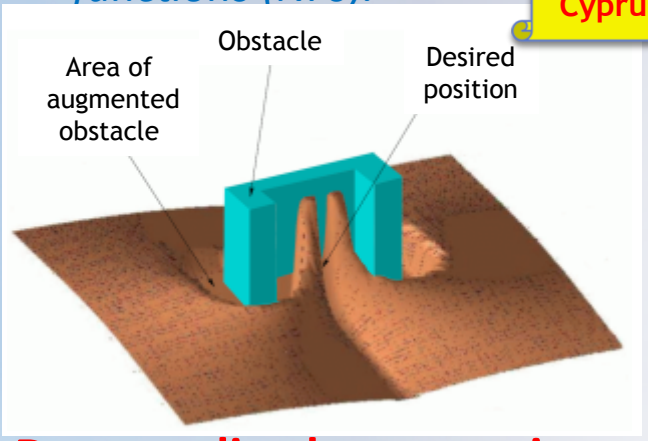
Distributed multi-agent cooperation based on formal methods in both the continuous and discrete domains

Our Previous Work

Centralized cooperative navigation schemes:

- *Dipolar vector fields,*
- *Centralized navigation functions (NFs).*

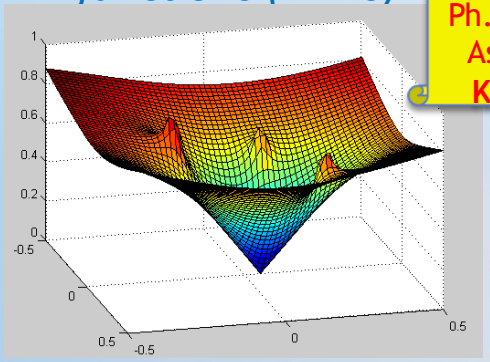
S. Loizou's Ph.D Thesis Now Ass. Prof. at Cyprus Univ. of Techn.

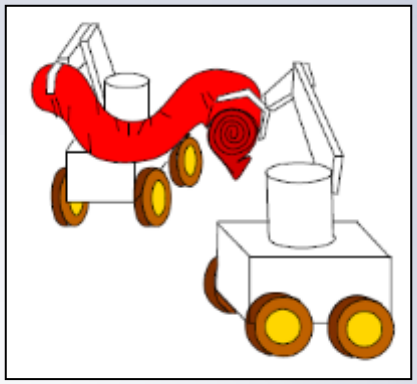


Decentralized cooperative navigation schemes:

- *Decentralized navigation functions (DNFs).*

D. Dimarogonas' Ph.D Thesis. Now Assoc. Prof. at KTH, Sweden





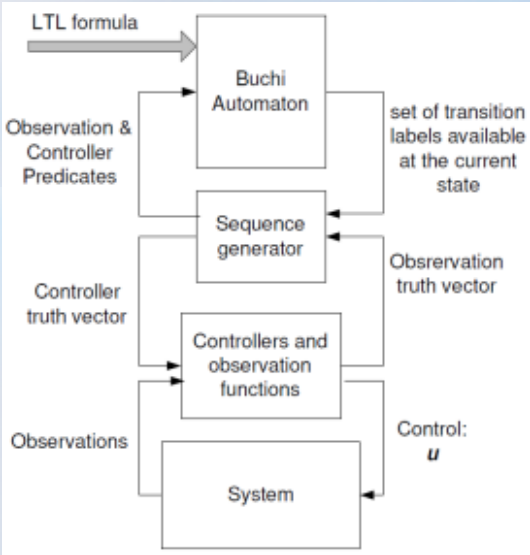
Centralized cooperative mobile manipulation:

- *Deformable objects,*
- *Modeling with Kane's approach,*
- *Dipolar vector fields.*

H. Tanner's Ph.D Thesis. Now Assoc. Prof. at U. Delaware

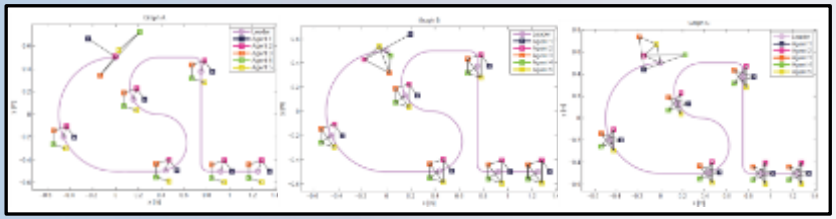
Multi-agent discrete control synthesis from LTL specifications

- *Independent synthesis of hybrid controller,*
- *Decentralized verification via model checking,*
- *Provably correct motion planning.*



Current Research Directions

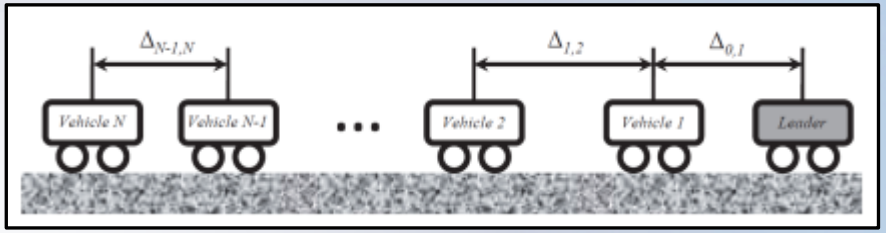
- **Robust model-free formation control with prescribed performance and connectivity maintenance.**



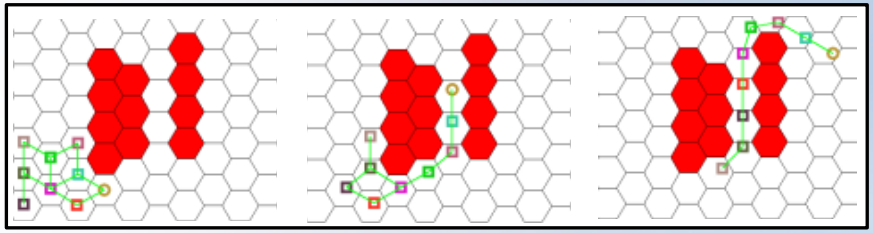
- **Collaborative transportation via implicit communication.**



- **Robust control of large vehicular platoons.**



- **Reconfigurable discrete control synthesis based on connectivity specifications.**



Objectives/Contributions:

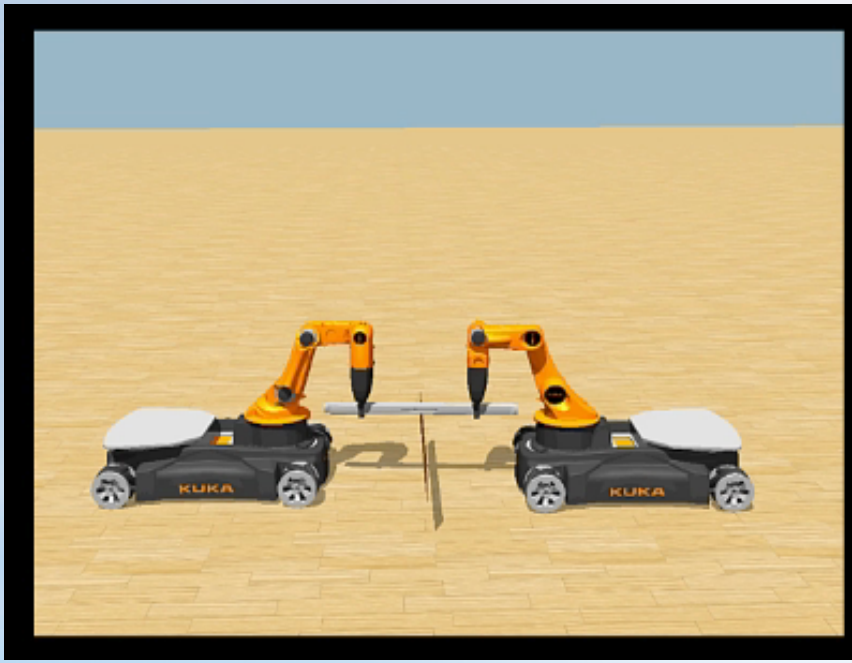
- *Increased **robustness** against: i) model uncertainties and ii) external disturbances,*
- ***Prescribed** transient and steady state **performance**,*
- ***Low design complexity** and easy hardware implementation,*
- ***Lean communication** via implicit feedback,*
- ***Reconfigurable plans**.*

*Collaborative transportation via implicit communication

Demo simulation

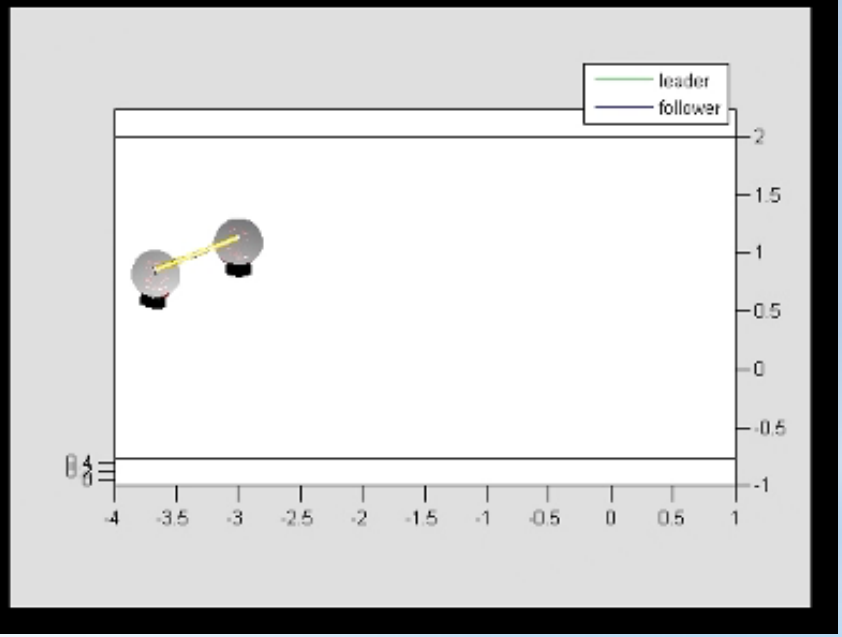
Case - A

Mobile manipulators: Rigid contacts



Case - B

Mobile robots: Compliant contacts



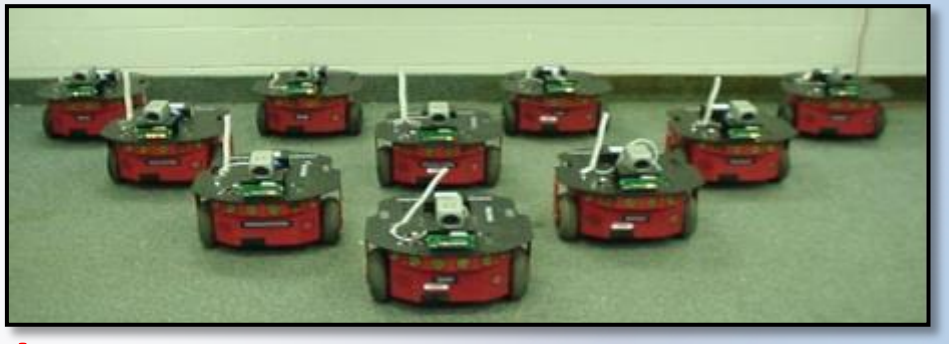
Properties:

- Decentralized schemes based on implicit communication,
- Certain parameters are transmitted offline,
- Follower manages to keep up using only force/torque measurements,
- The object reaches close to its goal configuration (position/orientation).

Future Directions

Robust model-free formation control with prescribed performance and connectivity maintenance:

- Consider underactuated robot models,
- Include directed communication graphs (i.e., visual communication),
- Involve collision avoidance,
- Experimental validation.



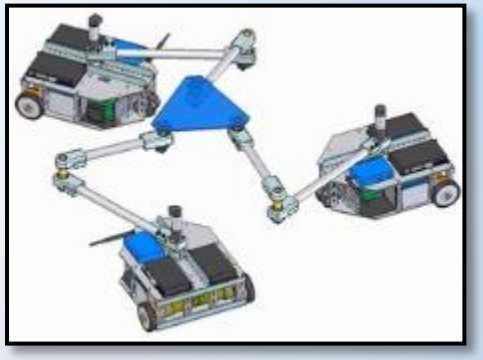
Robust control of large vehicular platoons:

- Include multi-dimensional cases,
- Experimental validation.



Collaborative transportation via implicit communication:

- Study the effects of fewer degrees of actuation,
- Consider more agents in the transportation task,
- Experimental validation.





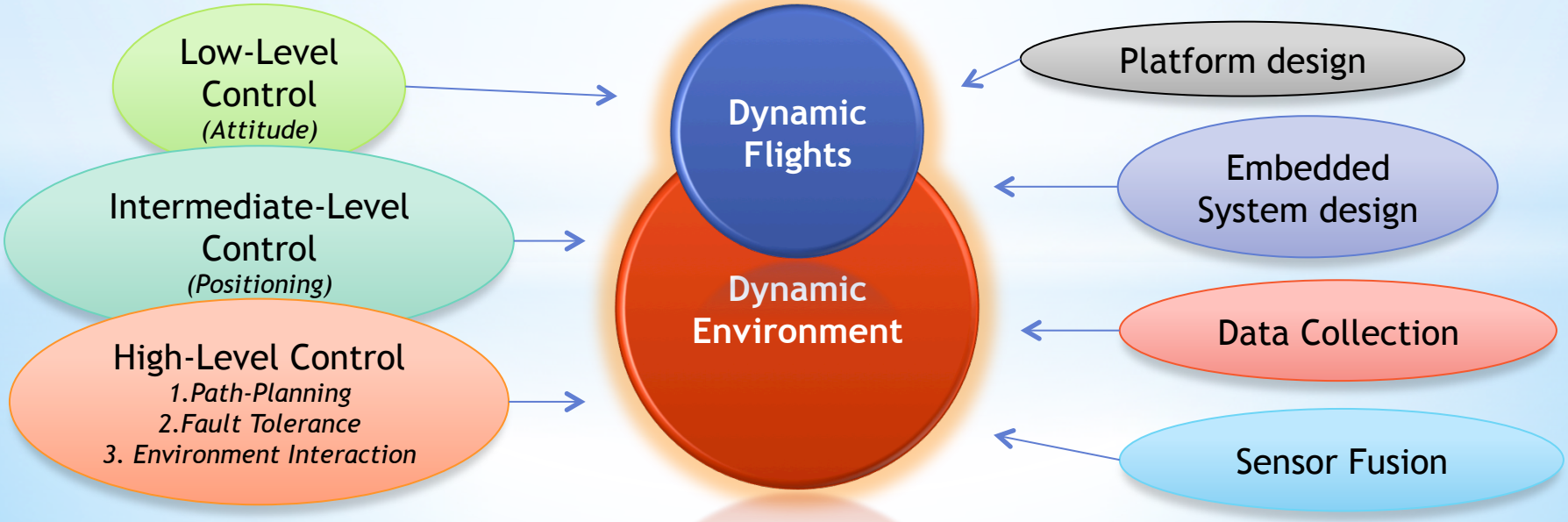
Dynamic Flights in a Dynamic Environment

Design, Sensor Fusion, Control

Introduction

*Basic Concept

- Our aim is to design and development of Unmanned Aerial Vehicles able to dynamically contribute in dynamic environments…
- **Challenges:**
  - ✓ Modeling in the whole flight envelope (high accelerations, unknown aerodynamic parameters)
  - ✓ Unknown dynamic environment (wind gusts, obstacles)
  - ✓ Fault Detection (sensor or model fault tolerance and recovery)
  - ✓ Interaction with the environment (landing, manipulation of real life objects)



Unmanned Helicopters

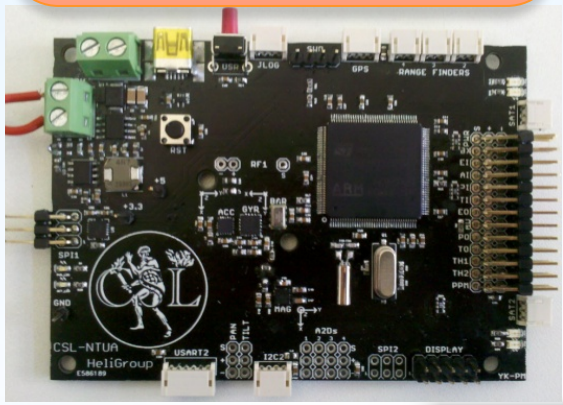
*CSL Helicopter Platforms: Embedded System Design

"Deadalus"

Chassis: *Maxi Joker 2*
Blades diameter: *1.8m*
Tail Boom: *1m*
Weights: *8.2kg*
Motor: *520kV (Electrical)*
Electronics:
Embedded PC: *Intel Atom*
GPS: *Magellan DG14 (D-GPS)*
IMU : *9-DOF XSENS*
CAMERA: *DFK-A3 60fps*
µC: *CSL HeliBoard*

"CSL HeliBoard"

µC: ARM Cortex-M4
IMU: 9-DOF low-cost MEMS
Other Sensors: Barometer, Ultrasound RFs, Battery Sensors, RPM Sensors



"Mini - Deadalus"

Chassis: Mini-Titan Flybarless
Blades diameter: *0.65m*
Tail Boom: *0.4m*
Weights: *0.98kg*
Motor: *3.5kV (Electrical)*
Electronics:
Embedded PC: *ARM9 OdroidXU*
GPS: : *Low-Cost UP501*
IMU : *Embedded*
CAMERA: *Playstation Eye 125fps*
µC: *CSL HeliBoard*

Sensor Fusion for State Estimation:
A combination of

- an Attitude Heading Reference System (AHRS), and
- a GPS/INS based Unscented Kalman Filter.

Data Collection Experiments

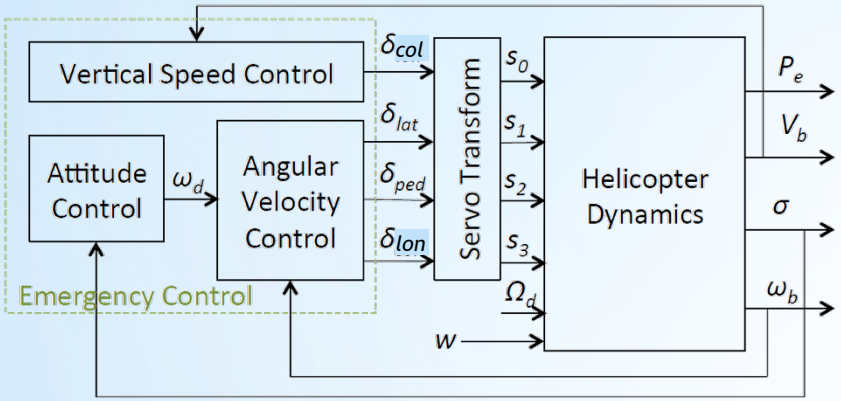


"CESAR: Cost-efficient methods and processes for safety relevant embedded systems – Sub-Program 6: Aerospace", ARTEMIS JTI, 2009-13

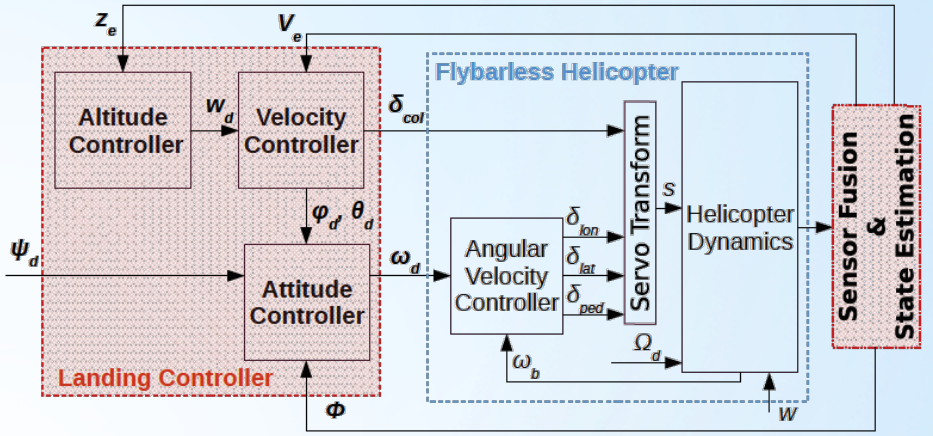
Unmanned Helicopters

*Model-Free Attitude stabilization & Autonomous Landing

Emergency Attitude Stabilization: *We design an emergency scheme in order to stabilize the attitude of the helicopter using Stereographic coordinates*



Autonomous Landing: *merge our senor fusion techniques and a model-free controller*



Design Specifications:

- Model free control scheme of low complexity
- Guaranteed transient and steady state performance
- Robustness against time-varying external disturbances like wind gusts

Flight Scenario 1

Trial 1

Current Efforts

❖ *Applying forces/torques in 6DOF task space*



- Structure Specifications
  - ✓ Control oriented optimization
  - ✓ Minimize aerodynamic interaction
  - ✓ Optimally selected thrusters/end-effector positions/direction with minimum structure volume
- Controller Specifications
  - ✓ Robust Adaptive Backstepping Controller
  - ✓ Trajectory tracking of position and orientation
- Applications of the proposed system
  - ✓ Aerial Cooperation /Maintenance of Aerial Lines
  - ✓ Manipulation tasks in Dynamic Environments

* Fault Diagnosis & Fault Tolerant Control of HCUAV – The First Greek Civilian UAV
  - *A joint effort among research and commercial partners, tailored according to the operational needs of Greece: forest fire detection, sea-borders monitoring, etc.)*
* CSL role:
  - Provide algorithms for:
    - ✓ *Adaptive attitude control*
    - ✓ *Trajectory planning (MPC)*
    - ✓ *Health Monitoring*
  - Provide a full hardware suite to implement the autopilot (Embedded Linux, ROS)



"HCUAV – Hellenic Civil Unmanned Air Vehicle", GSRT, 2013-16

Thank you !


FORZA NAPOLI
ONORE E GLORIA AI MIGLIORI !!!
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TI AMIAMO CON TUTTO IL CUORE
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