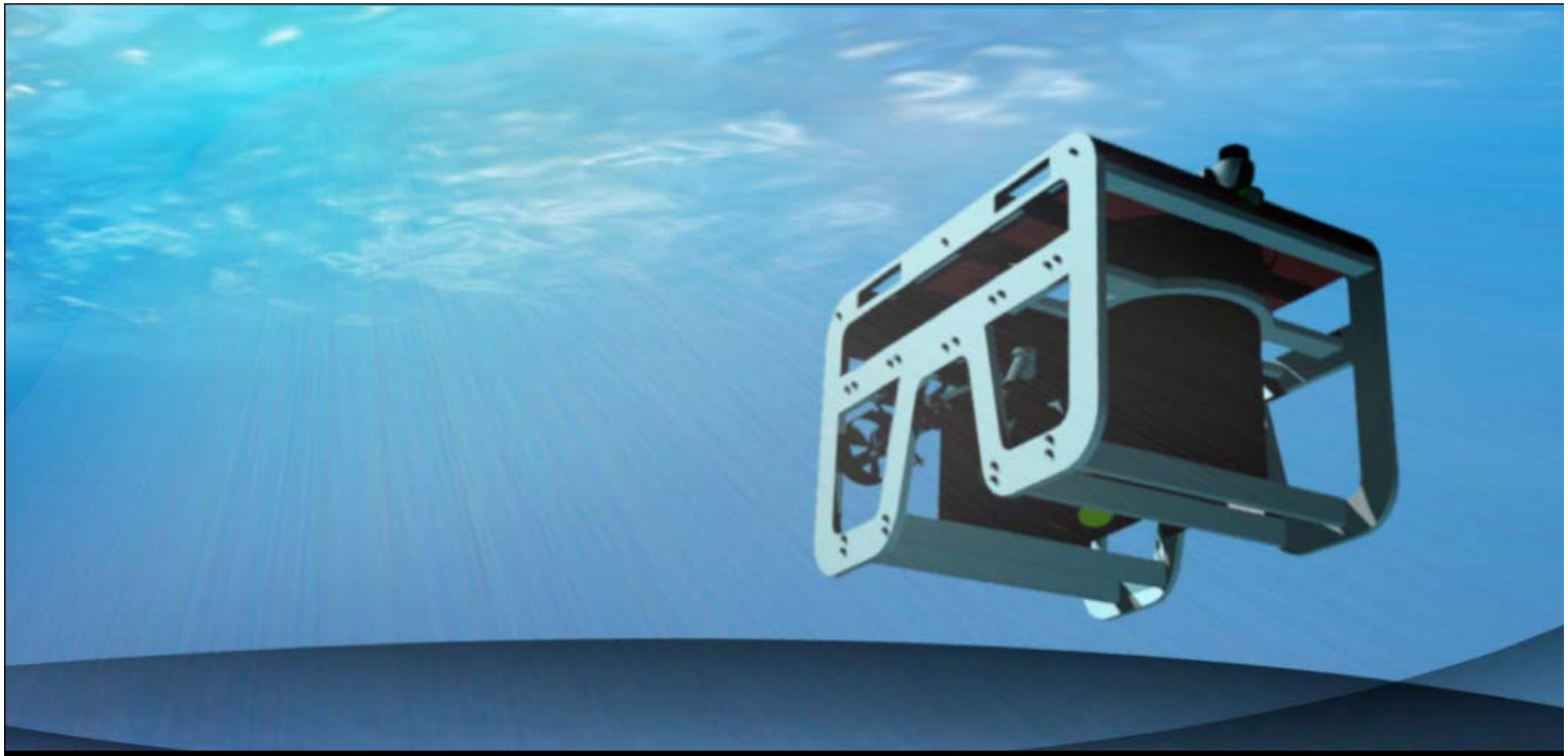


10 Años de Robótica Submarina a la UdG

Pere Ridao

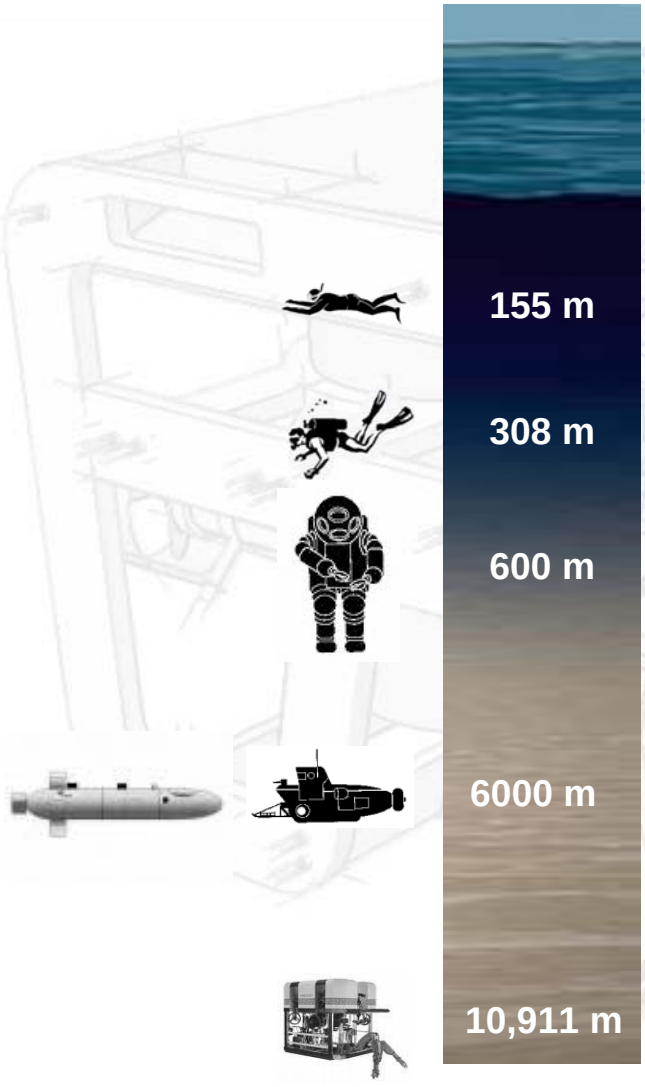
Universitat de Girona

Importancia de los oceános

- 361 millones km^2
- **71 %** de la superficie terrestre
- 37 % de la población vive a menos de 100 Km de les costas
- Fuente de recursos naturales y alimentos
- Repercusión en el Clima y en la vida del planeta

- 3904 Km de los 5849 Km **(66,7 %)** del perímetro peninsular están bañados por el mar

Tecnología submarina



- La profundidad fija la tecnología necesaria para la observación

Róbotica Submarina en España: Investigación

Róbotica Submarina en España: Empresas

Evolución de los Robots de la UdG

1995

GARBI: Robot Teleoperado con Cable para la Exploración

2 Brazos teleroperados

Evolución de los Robots de la UdG

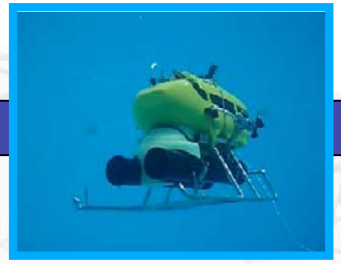
1995

2001

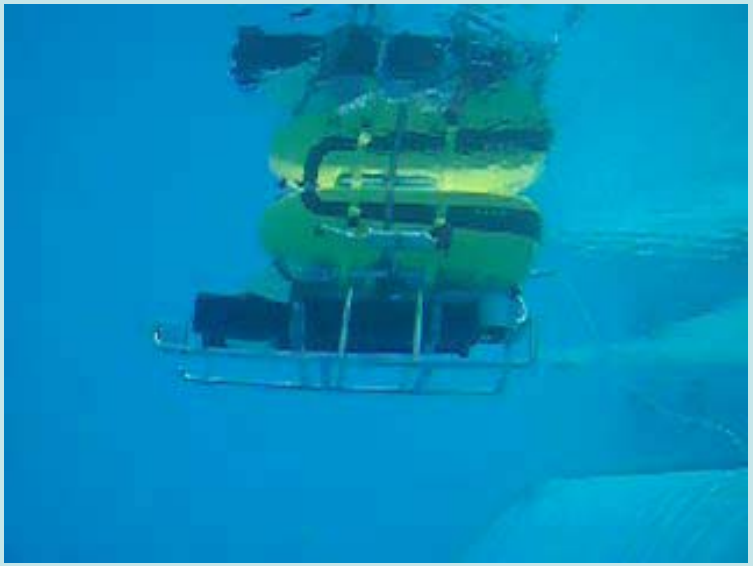
URIS: Robot Autónomo Alimentado por Cable

Evolución de los Robots de la UdG

1995 2001 2005



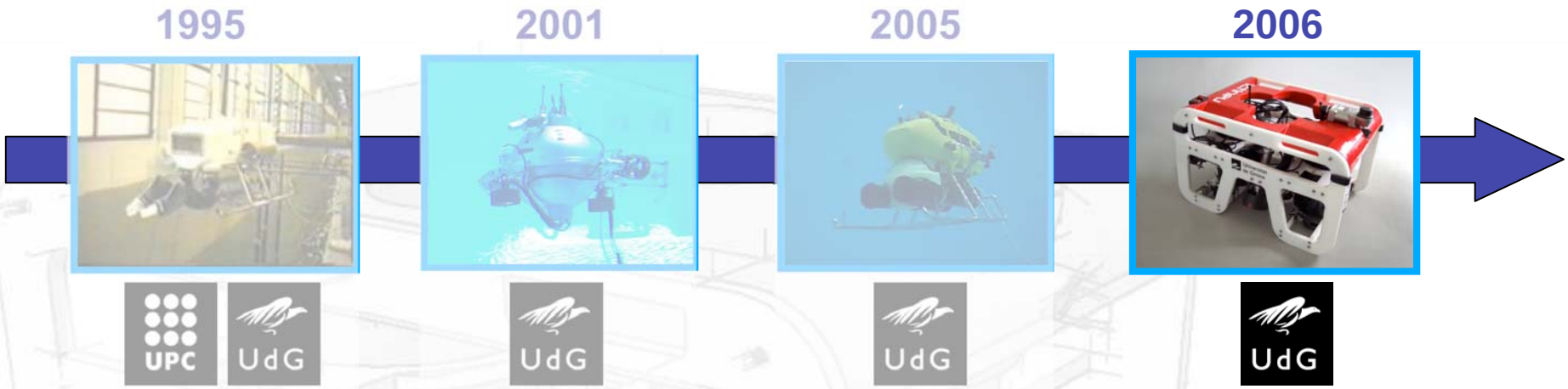
UPC UdG UdG UdG



UdG

GARBI^{AUV}: Robot Autónomo Sin Cable

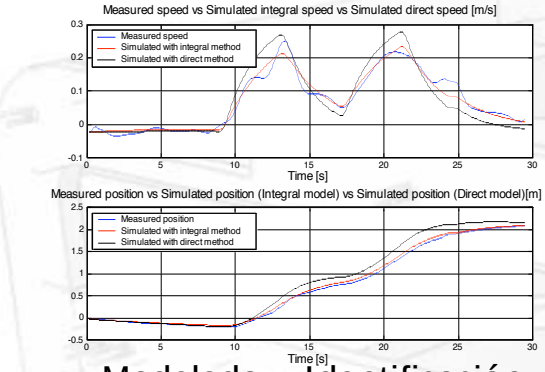
Evolución de los Robots de la UdG



UdG

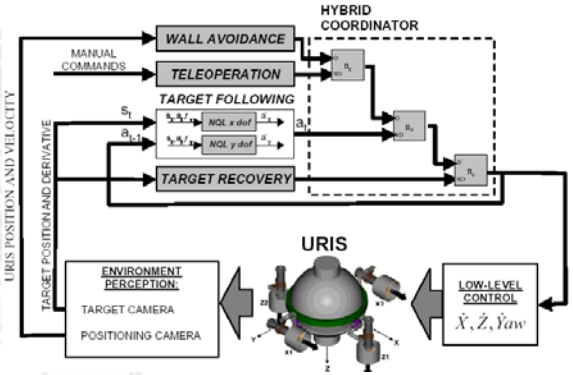
ICTINEU^{AUV}: Robot Autónomo Sin Cable Ganador del 1er premio del SAUC-E 2006

Líneas de Investigación



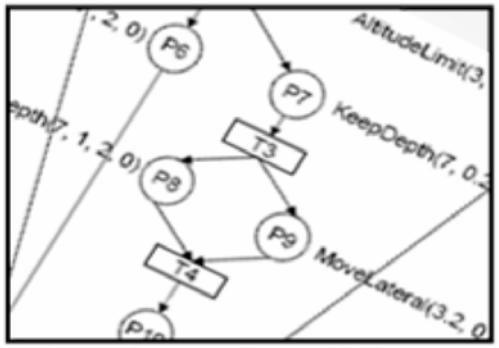
Modelado y Identificación

Simulación
Hardware in the loop



Arquitecturas basadas
En comportamientos

Navegación



Control de Misión

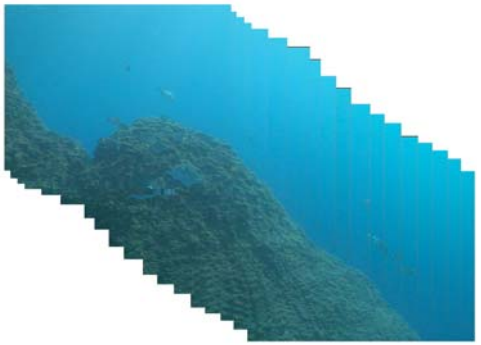
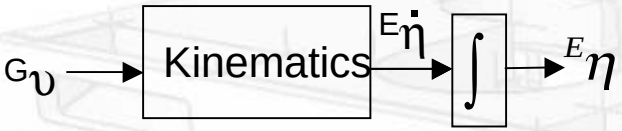


Image Mosaicking

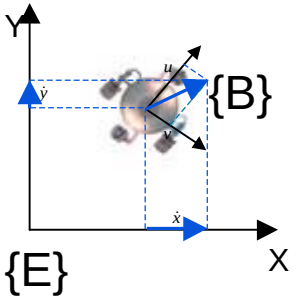
Modelado e Identificación

Kinematics Model of an UUV

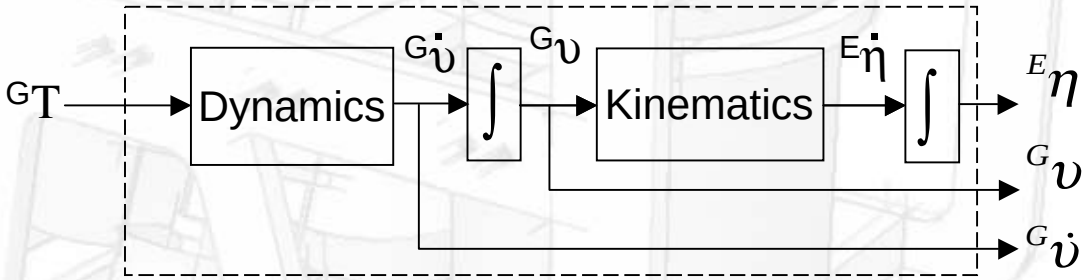


$$\begin{pmatrix} {}^{E}\dot{\eta}_1 \\ {}^{E}\dot{\eta}_2 \end{pmatrix} = \begin{pmatrix} {}^{E}R_B & 0_{3\times3} \\ 0_{3\times3} & J(\eta_2)^{-1} \end{pmatrix} \begin{pmatrix} {}^{B}\upsilon_1 \\ {}^{B}\upsilon_2 \end{pmatrix}$$

$${}^{E}\eta = \int {}^{E}\dot{\eta}\, dt$$



Hydrodynamics Model of an UUV



Position

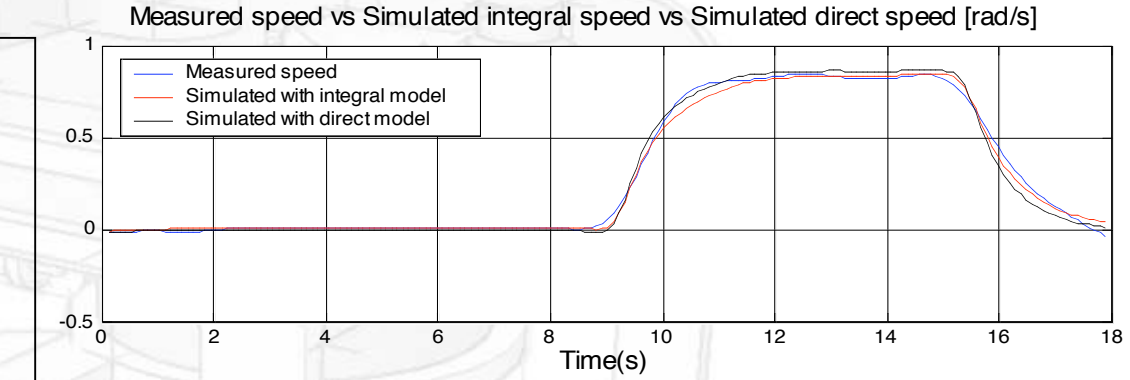
Velocity

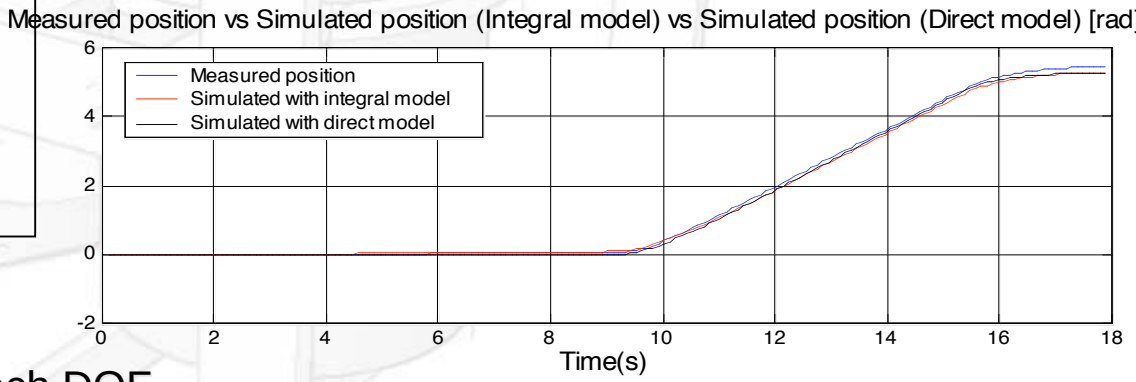
Acceleration

$${}^{B}T_B + {}^{B}G(\eta) + D({}^{B}\upsilon)\,{}^{B}\upsilon + P_E = (M_{RB} + M_A)\cdot {}^{B}\dot{\upsilon} + \left(C_{RB}({}^{B}\upsilon) + C_A({}^{B}\upsilon)\right)\cdot {}^{B}\upsilon$$

Modelado e Identificación

Yaw





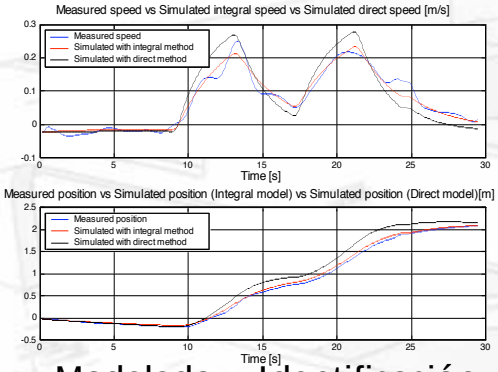
Identification:

- Uncoupled experiments for each DOF
- LS applied to the Uncoupled equation of motion
- LS applied to the integral of the Uncoupled equation of motion

[CEP'03 Ridao]

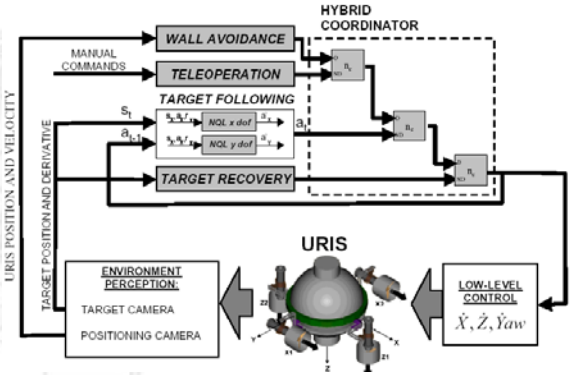
Colaboración con el Prof. Antonio Tiano.

Líneas de Investigación



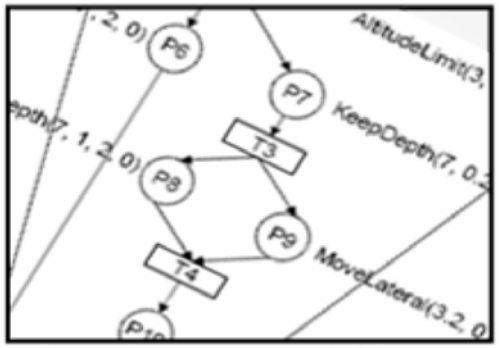
Modelado y Identificación

Simulación
Hardware in the loop



Arquitecturas basadas
En comportamientos

Navegación



Control de Misión

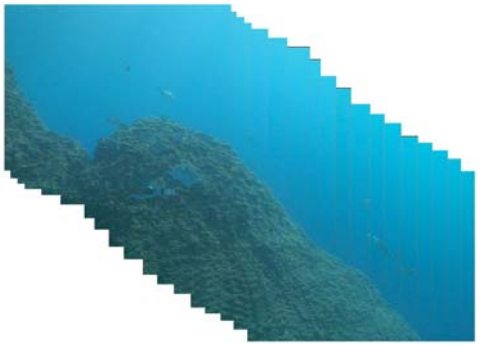
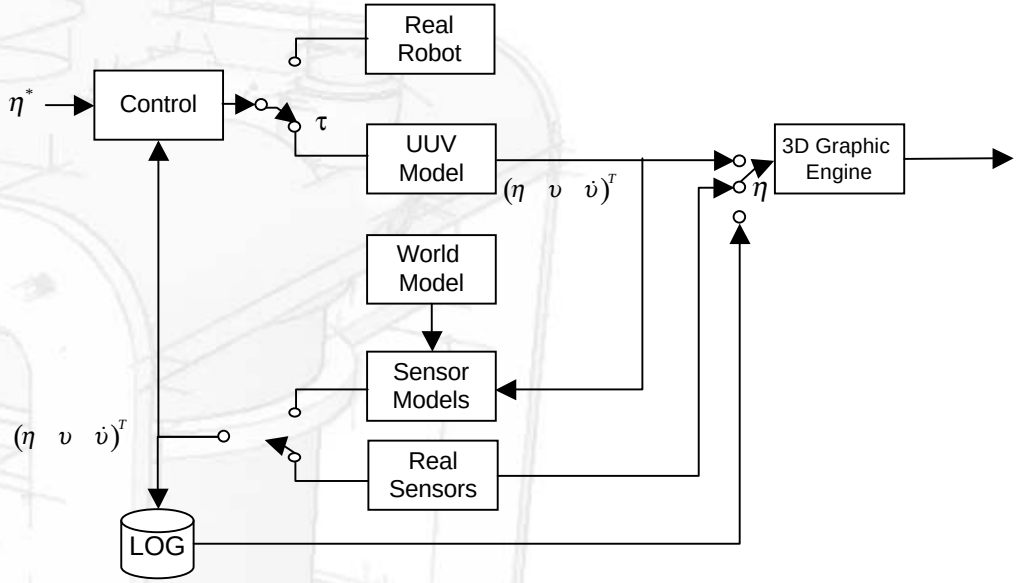


Image Mosaicking

NEPTUNE: Simulación HIL



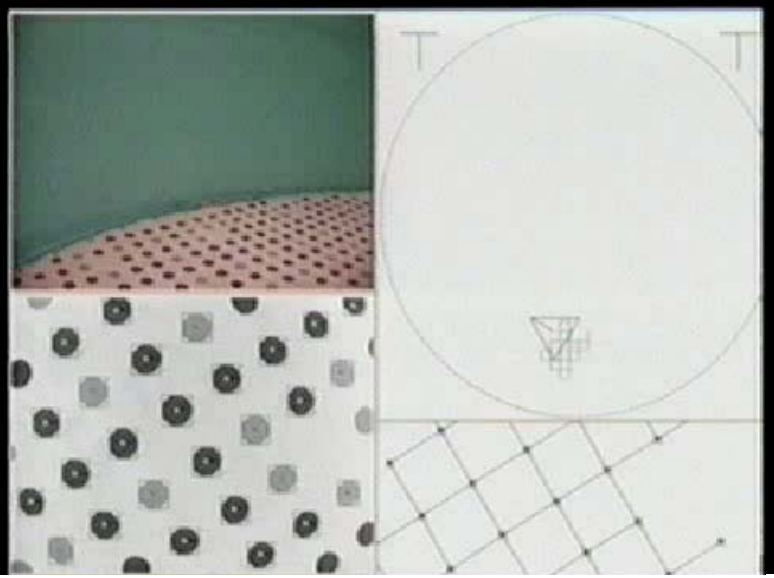
- Multivehículo
- Multivista
- Mundos Virtuales modelados: (1) VRML (2) Batimetria.
- Soporta Sonar y visión.

[OCEANS'04 Ridao]

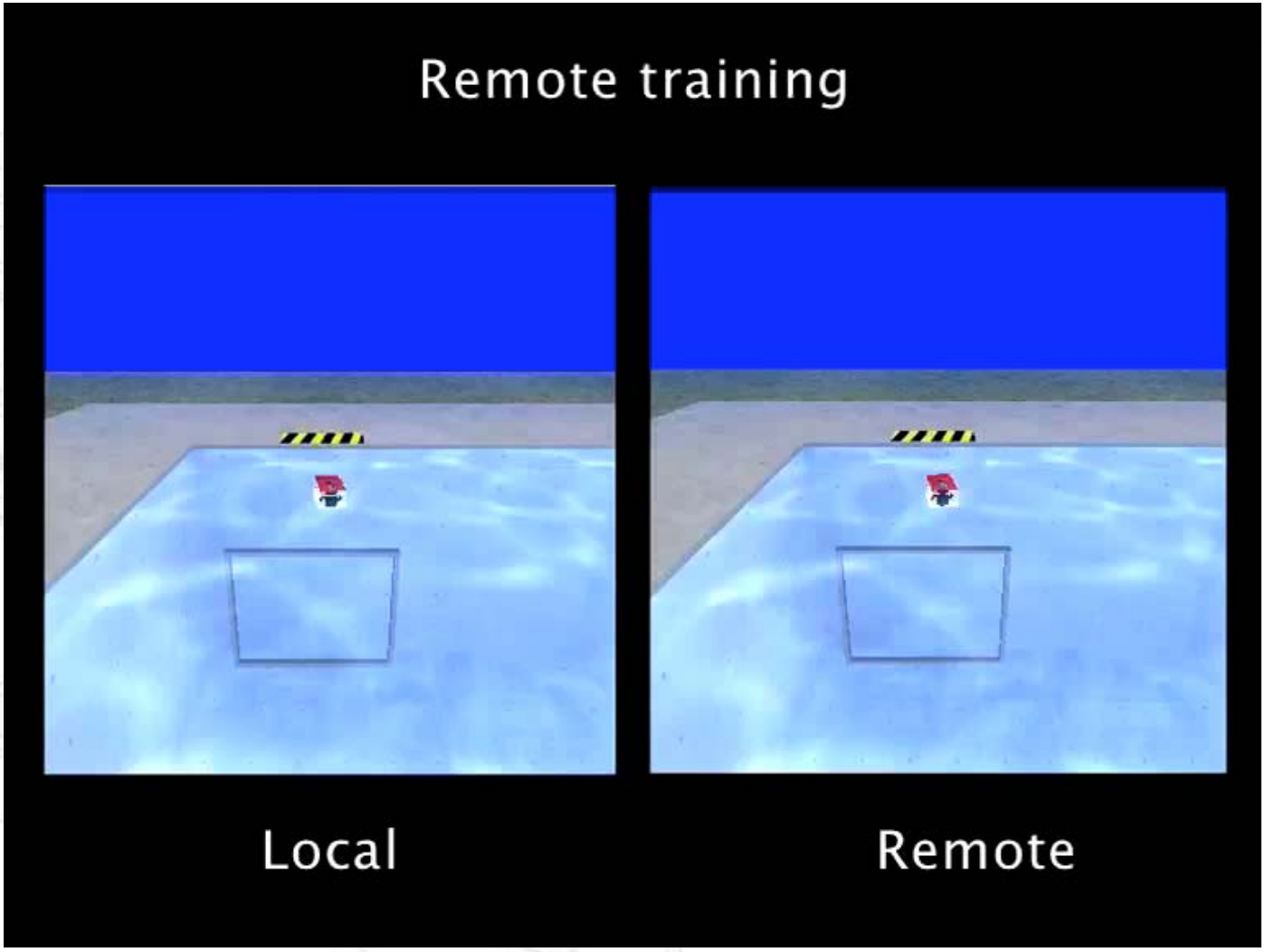
NEPTUNE: Simulación HIL

Hardware in the loop

Real

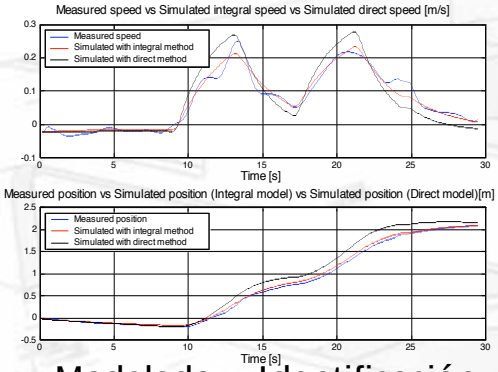


NEPTUNE: Experimentación Remota



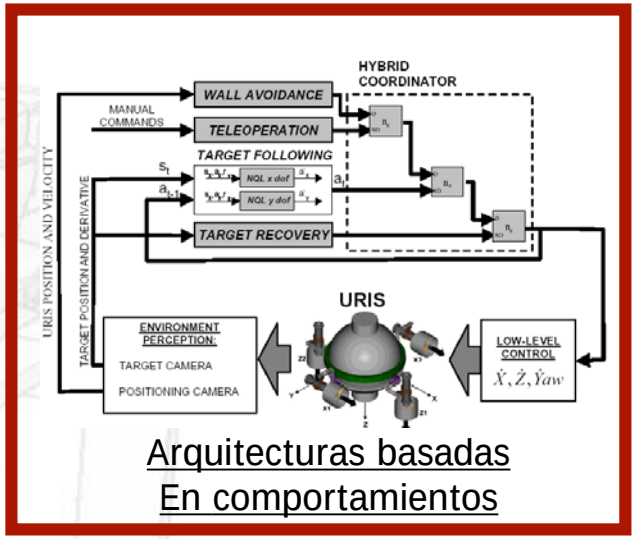
[MCMC'06 Ridao]

Líneas de Investigación



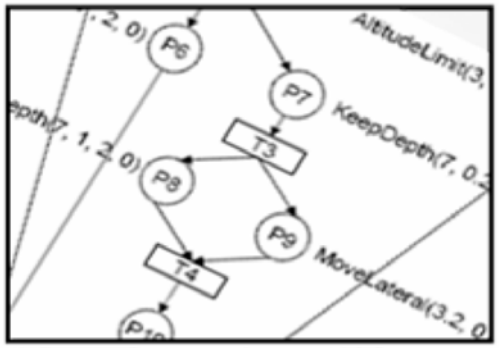
Modelado y Identificación

Simulación
Hardware in the loop



Arquitecturas basadas
En comportamientos

Navegación



Control de Misión

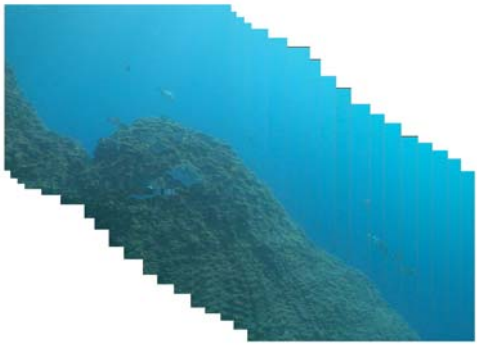
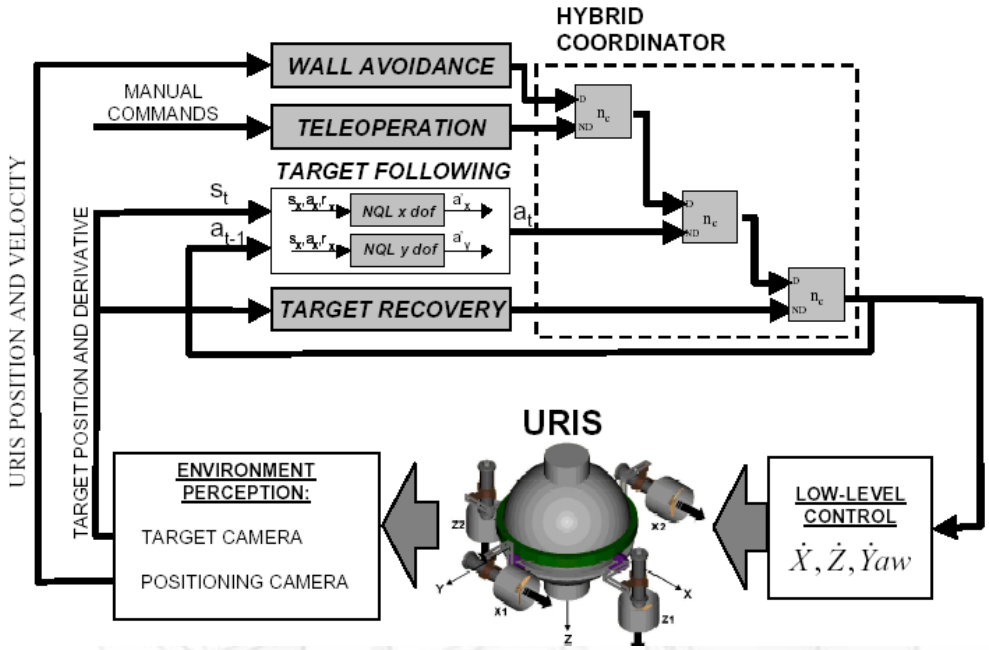


Image Mosaicking

Comportamientos: Aprendizaje.



Efficient Learning of Reactive Robot Behaviors with a Neural-Q_learning approach

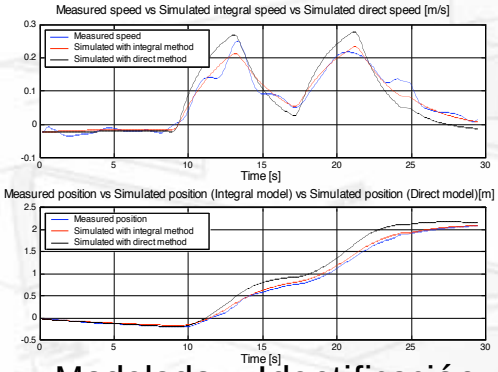
University of Girona
Spain

IROS 2002, Switzerland

- Comportamientos paralelos cada uno con su propio objetivo
- Programados o aprendidos automáticamente
- Cada comportamiento:
  - tiene una prioridad.
  - puede habilitarse o deshabilitarse
  - tiene un timeout

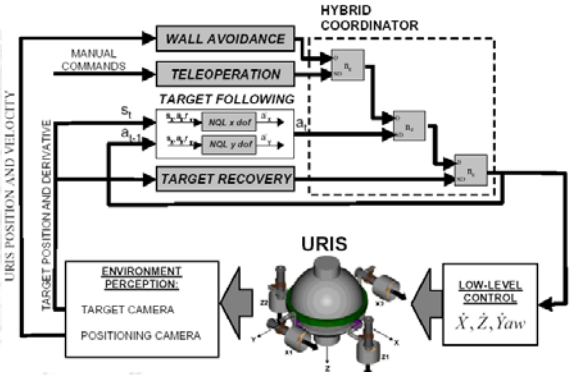
[IROS'02 Carreras]

Líneas de Investigación



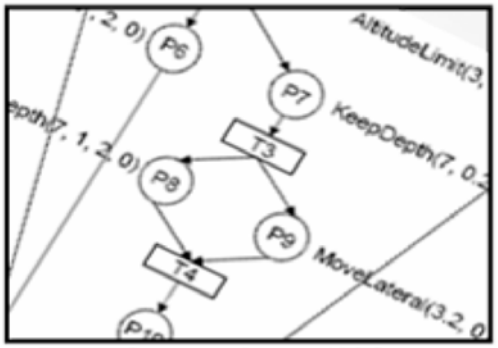
Modelado y Identificación

Simulación
Hardware in the loop



Arquitecturas basadas
En comportamientos

Navegación



Control de Misión

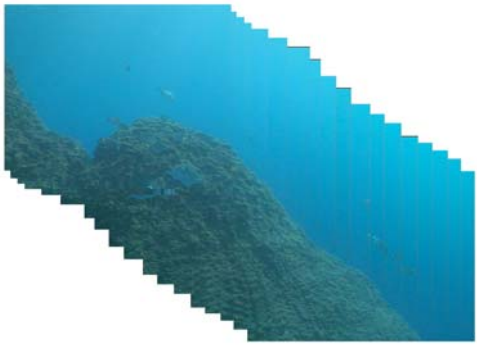
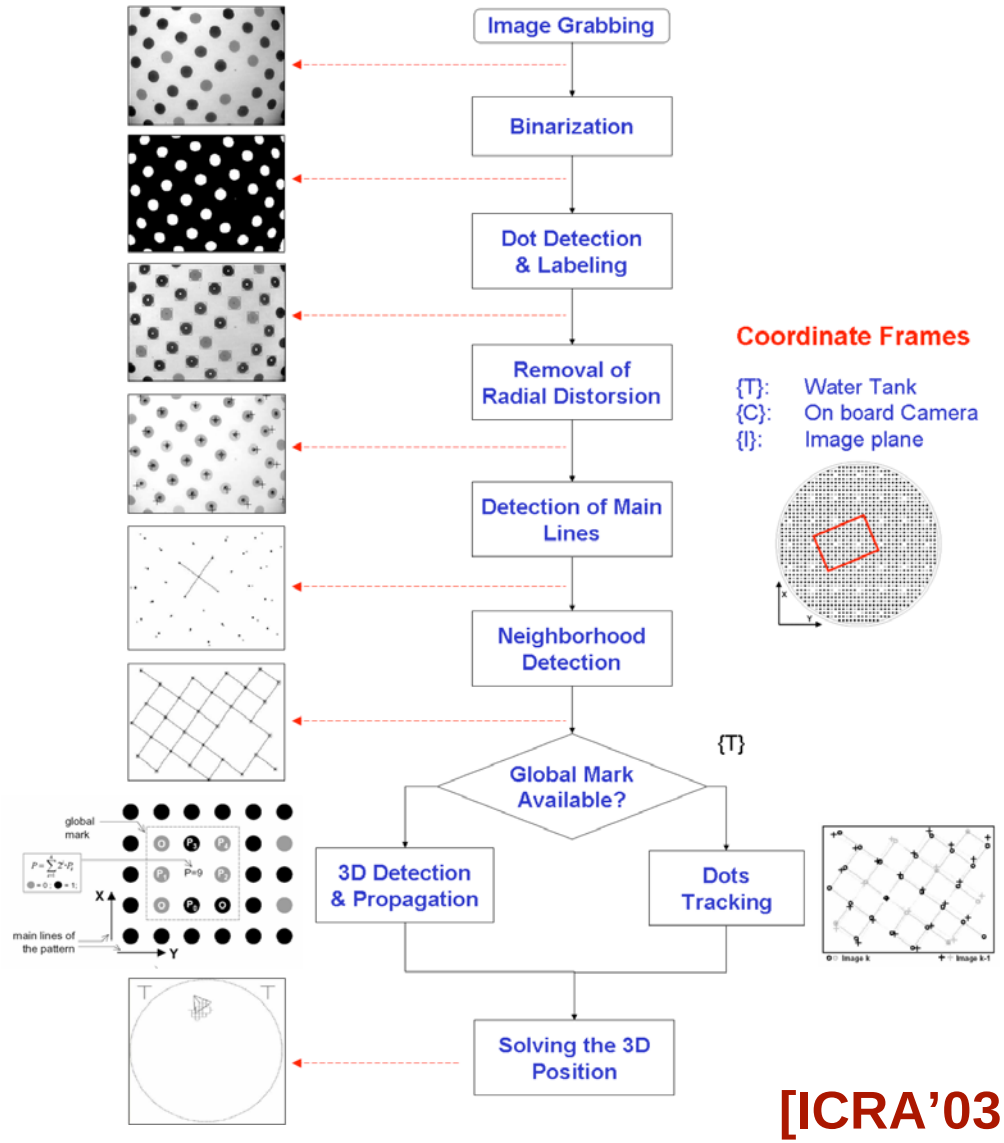


Image Mosaicking

Localización en entornos estructurados y conocidos: Visión



Coordinate Frames

{T}: Water Tank
{C}: On board Camera
{I}: Image plane

Vision-based Localization of an Underwater Robot in a Structured Environment

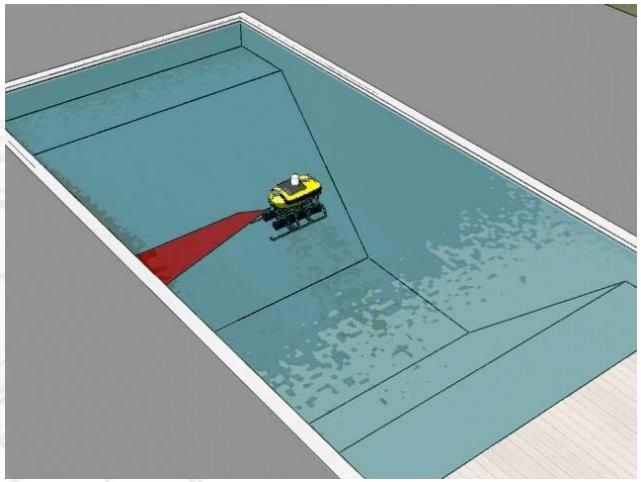
University of Girona
Spain

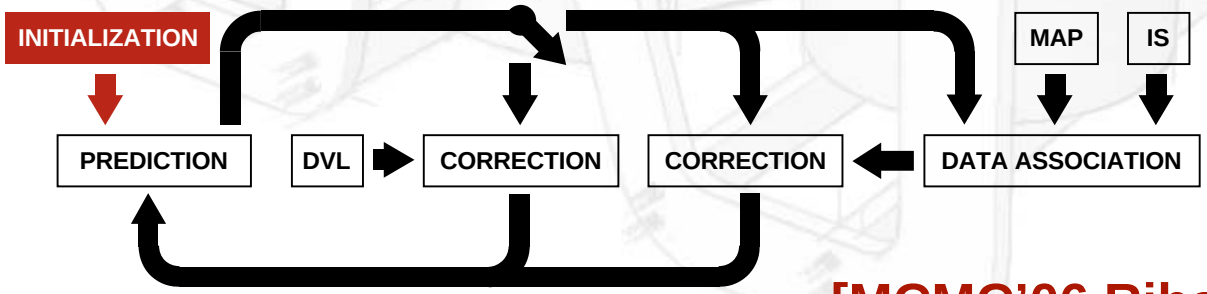
Aplicable también a estructuras submarinas

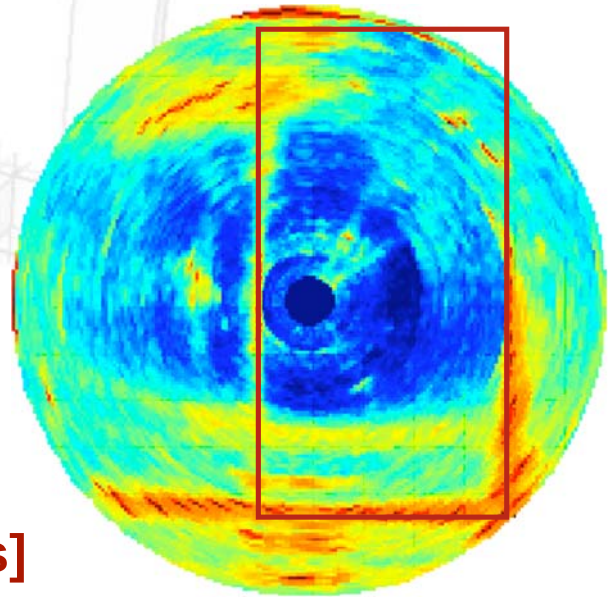
[ICRA'03 Carreras]

Localización en entornos estructurados y conocidos: Sonar

- **Localización EKF basada en Mapa**
- **Sensores: DVL + IS**
- **Modelo de velocidad constante**
- **Medidas de:**
  1. **DVL (Vel., prof. Y Yaw)**
  2. **Puntos $\in$ a los bordes**
- **Asociación con NN**



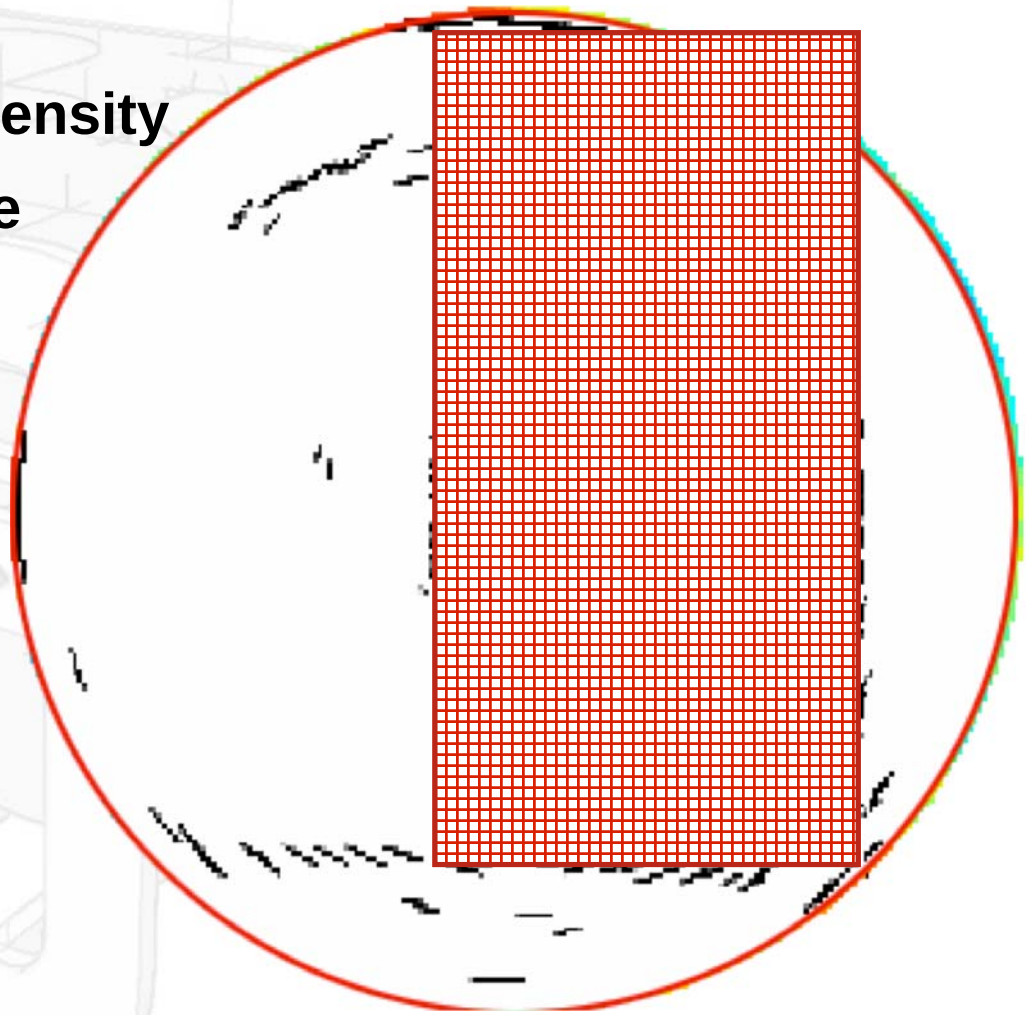




[MCMC'06 Ribas]

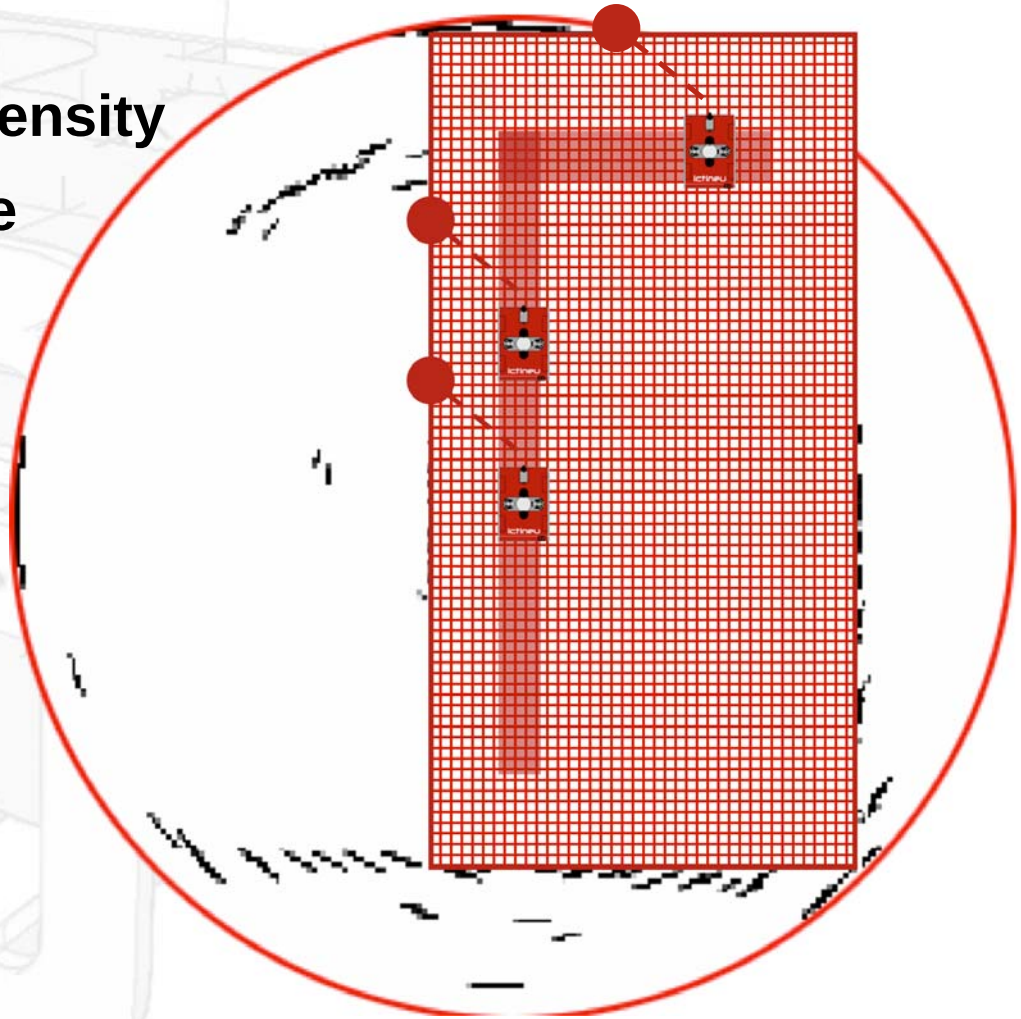
Localización en entornos estructurados y conocidos: SAUC-E

1. **Gather a complete scan**
2. **Select echoes with max. intensity**
3. **Define a grid position space**



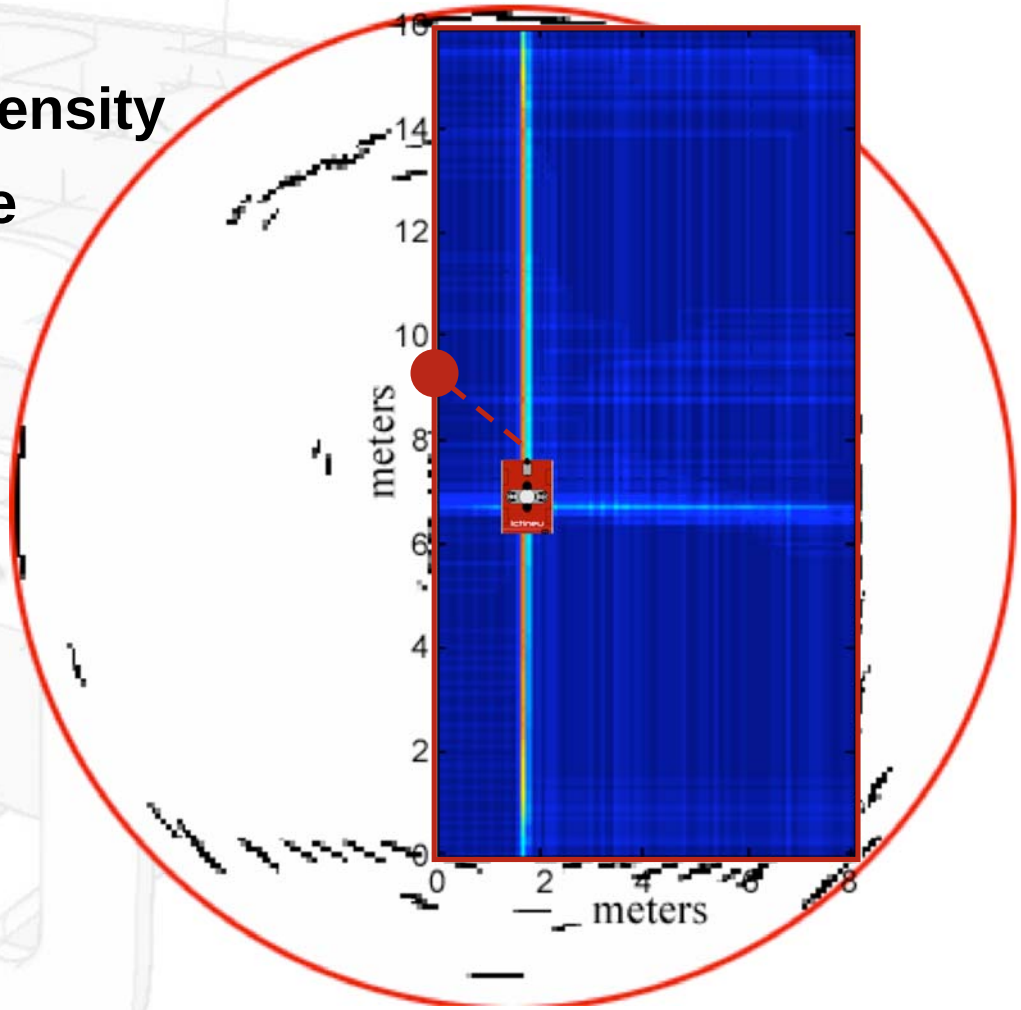
Localización en entornos estructurados y conocidos: SAUC-E

1. **Gather a complete scan**
2. **Select echoes with max. intensity**
3. **Define a grid position space**
4. **For each beam vote for the candidate positions**



Localización en entornos estructurados y conocidos: SAUC-E

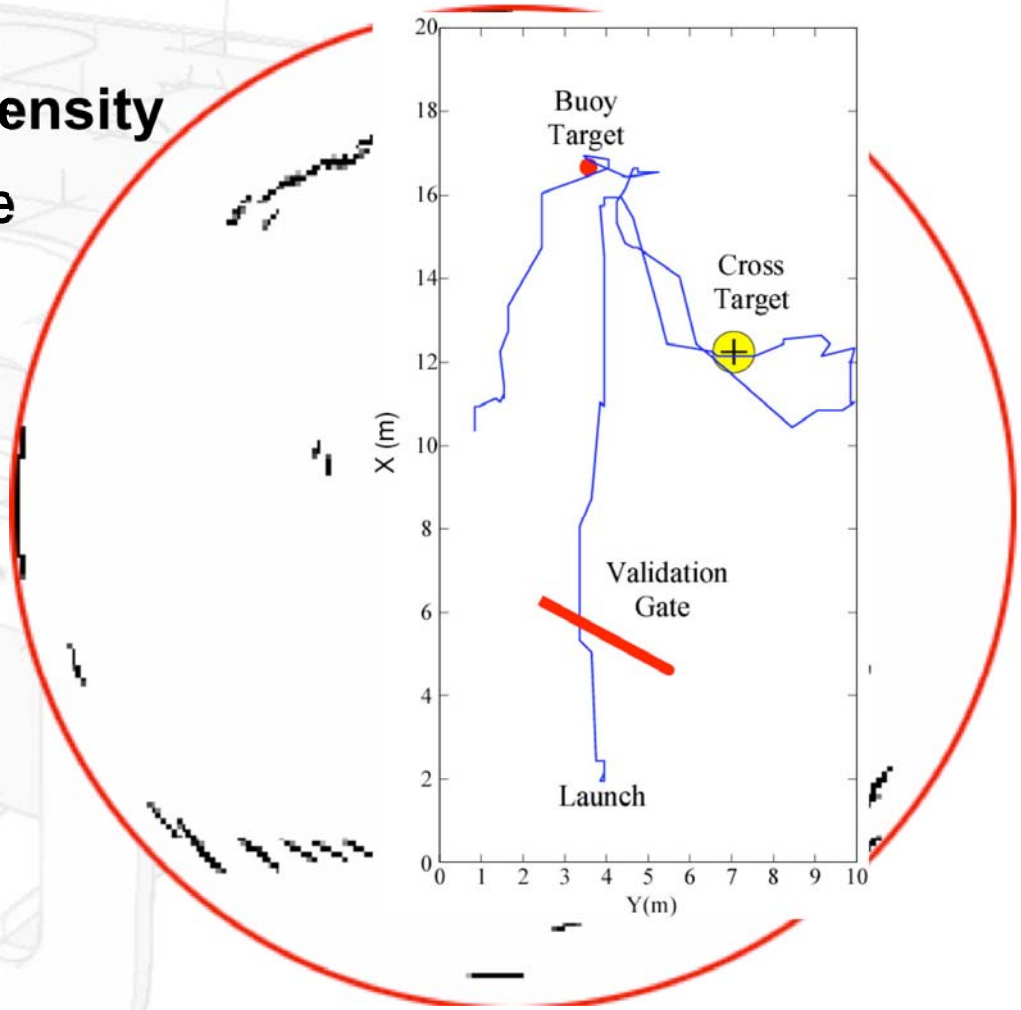
1. **Gather a complete scan**
2. **Select echoes with max. intensity**
3. **Define a grid position space**
4. **For each beam vote for the candidate positions**
5. **Select the most voted cell**



Localización en entornos estructurados y conocidos: SAUC-E

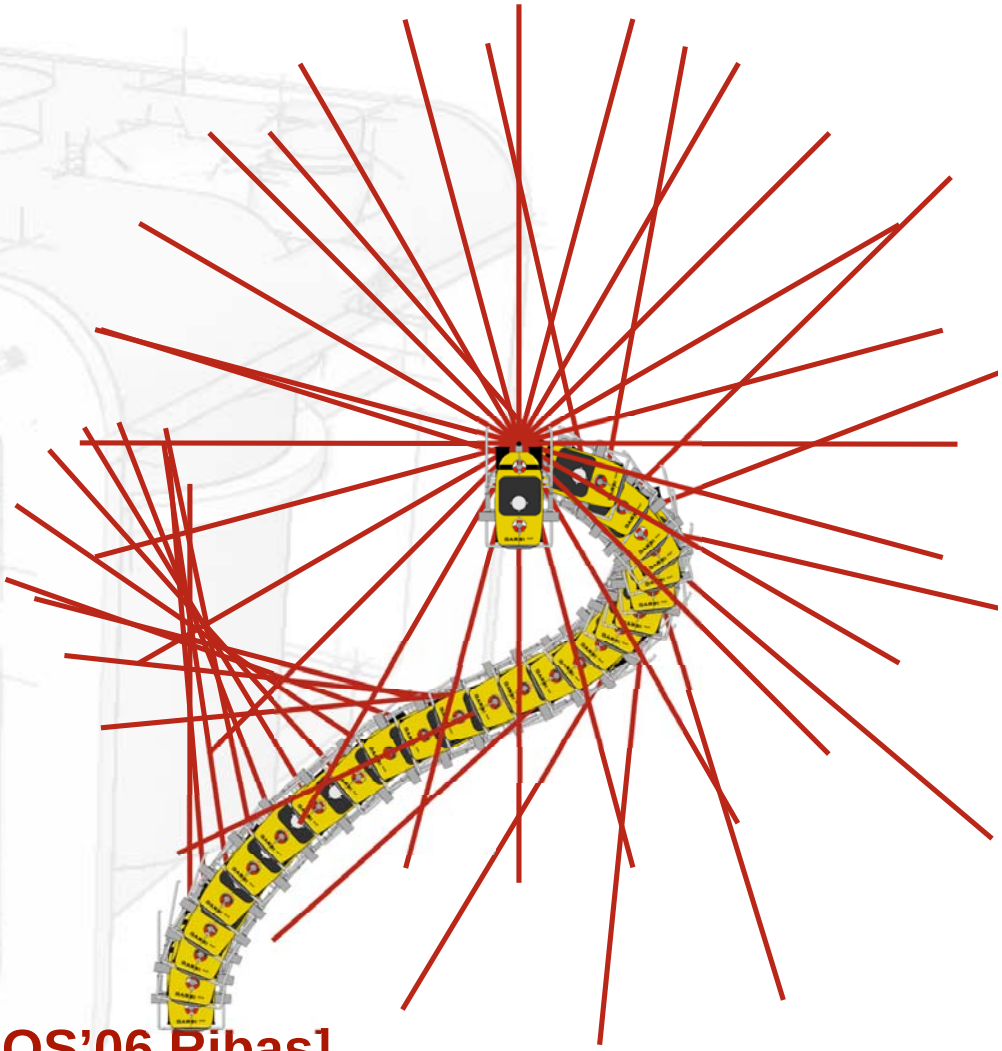
1. **Gather a complete scan**
2. **Select echoes with max. intensity**
3. **Define a grid position space**
4. **For each beam vote for the candidate positions**
5. **Select the most voted cell**

The highest intensity in the voting space describes the trajectory.



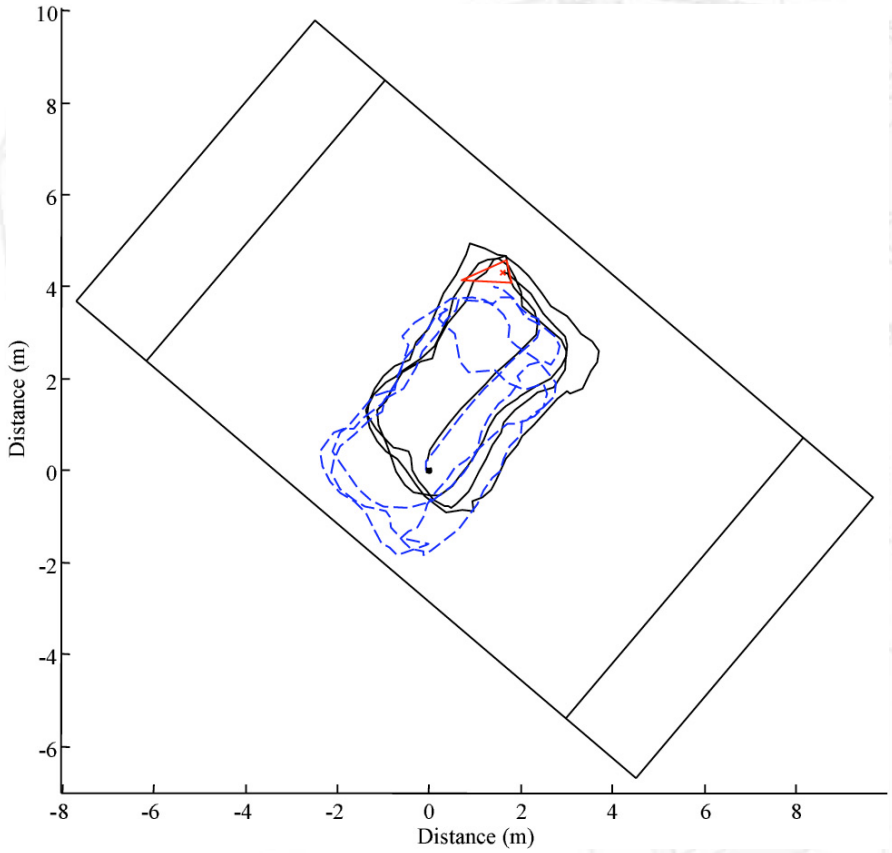
Localización en entornos estructurados y desconocidos: Sonar

- **SLAM con líneas**
- **Sensores: DVL + IS**
- **Modelo de velocidad constante**
- **Smoothing de la trayectoria del scan -> corrección de la distorsión**
- **Detección de líneas con Hough**
- **SLAM con retraso**

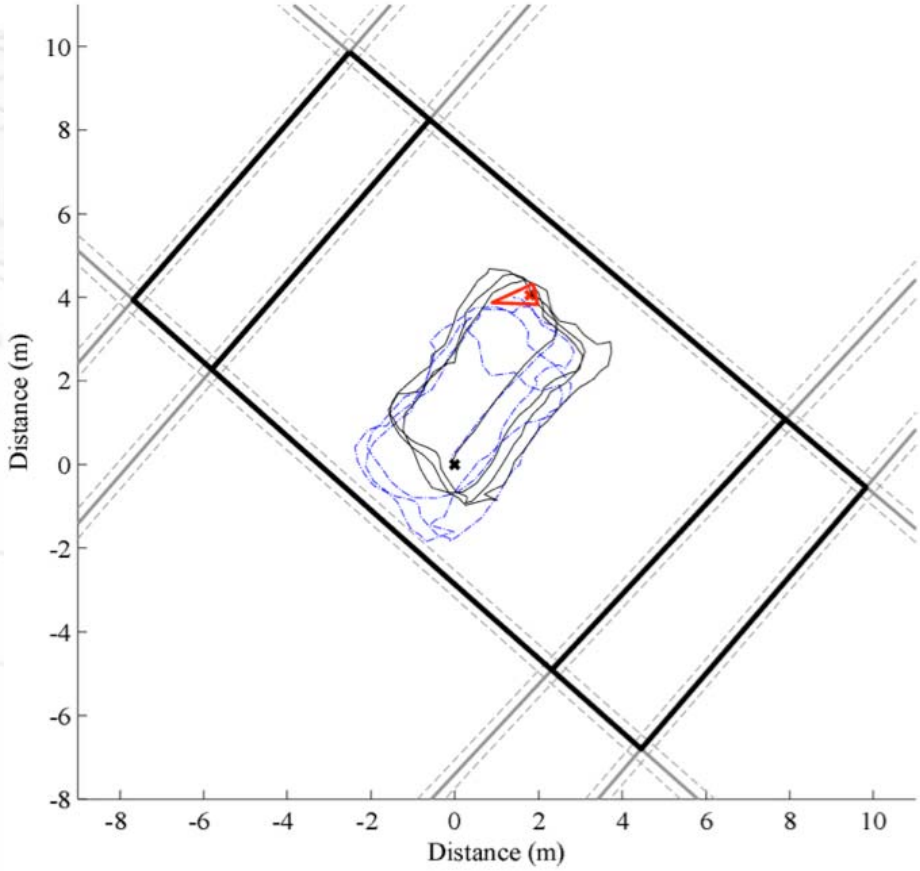


[IROS'06 Ribas]

Localización en entornos estructurados y desconocidos: Sonar



EKF



SLAM

SLAM in structured underwater environments

Objectives

Perform SLAM in structured underwater environments (marinas, harbours, dams)

Applications:

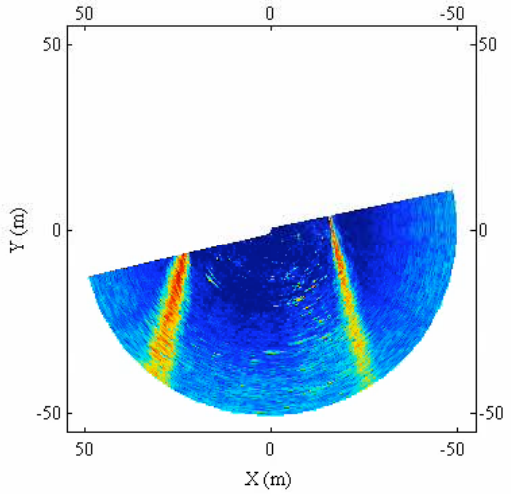
- AUV docking operations
- Inspection
- Harbour surveillance
- Bathymetric surveys …

Those environments are populated with vertical planes

→ **Extraction of line features**

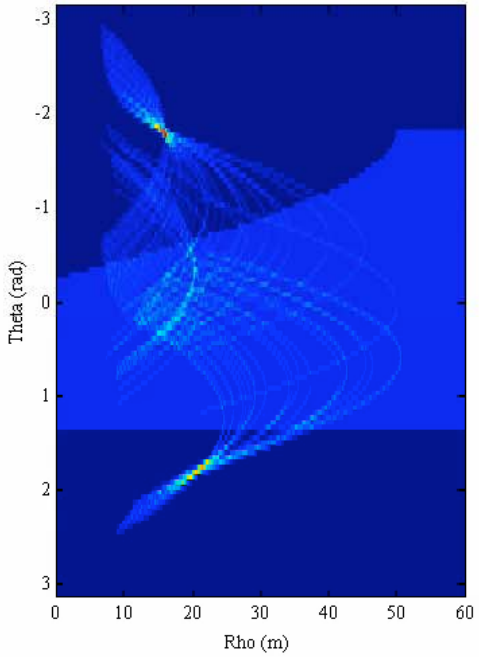
SLAM in structured underwater environments

Cartesian plot



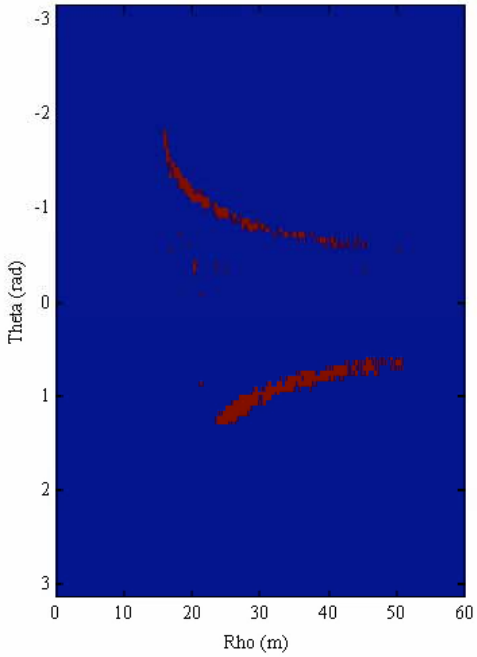
A data buffer containing 180º scan sector is set to deal with the continuous stream of data

Voting space



The voting space evolves with the arrival of new beams.

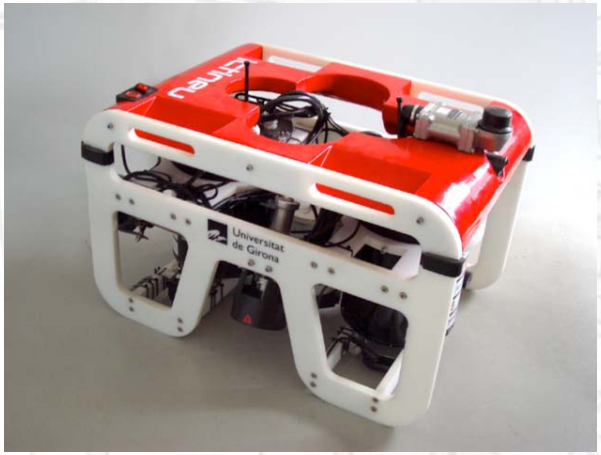
Segmented data

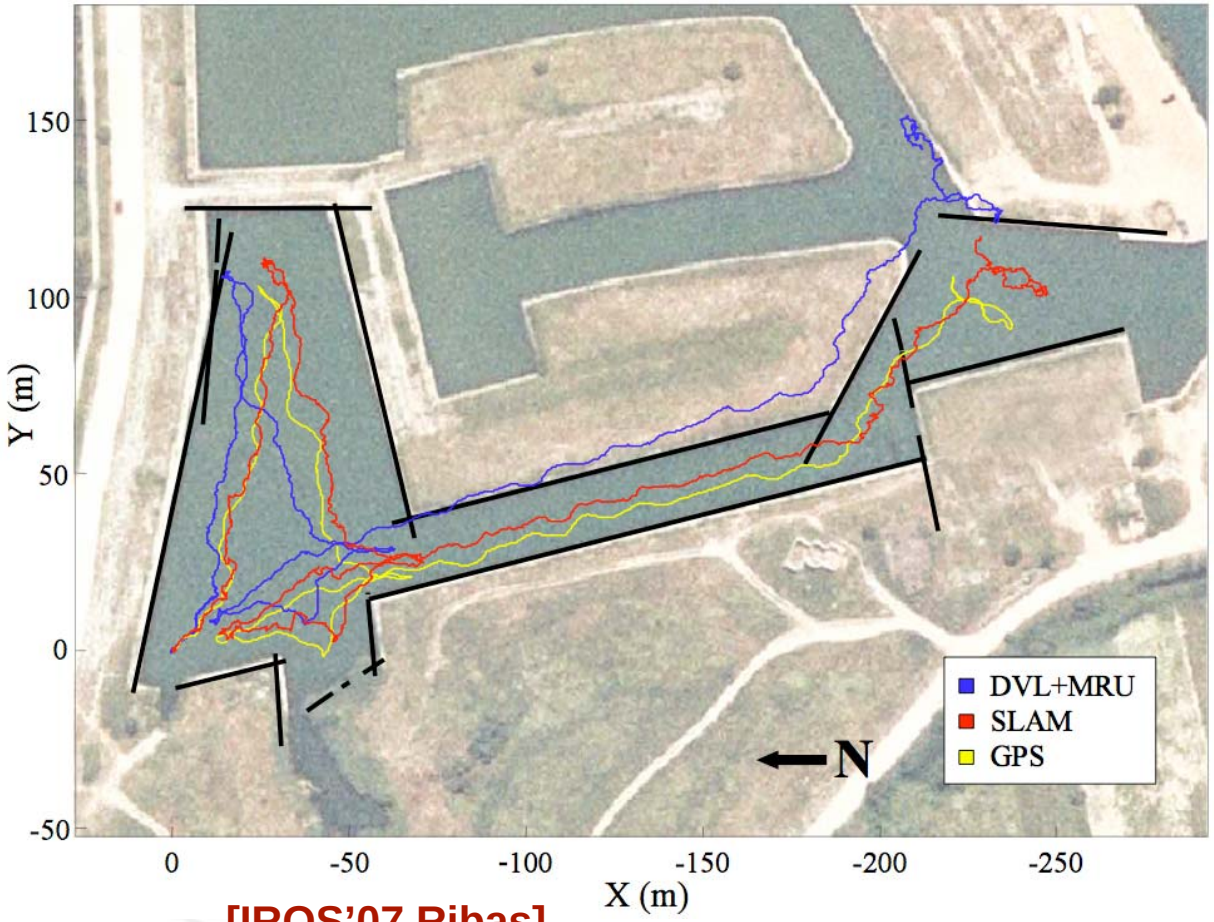


When a line is detected, the feature uncertainty is obtained by analyzing the thresholded image

SLAM in structured underwater environments

SLAM in an abandoned marina with the Ictineu AUV





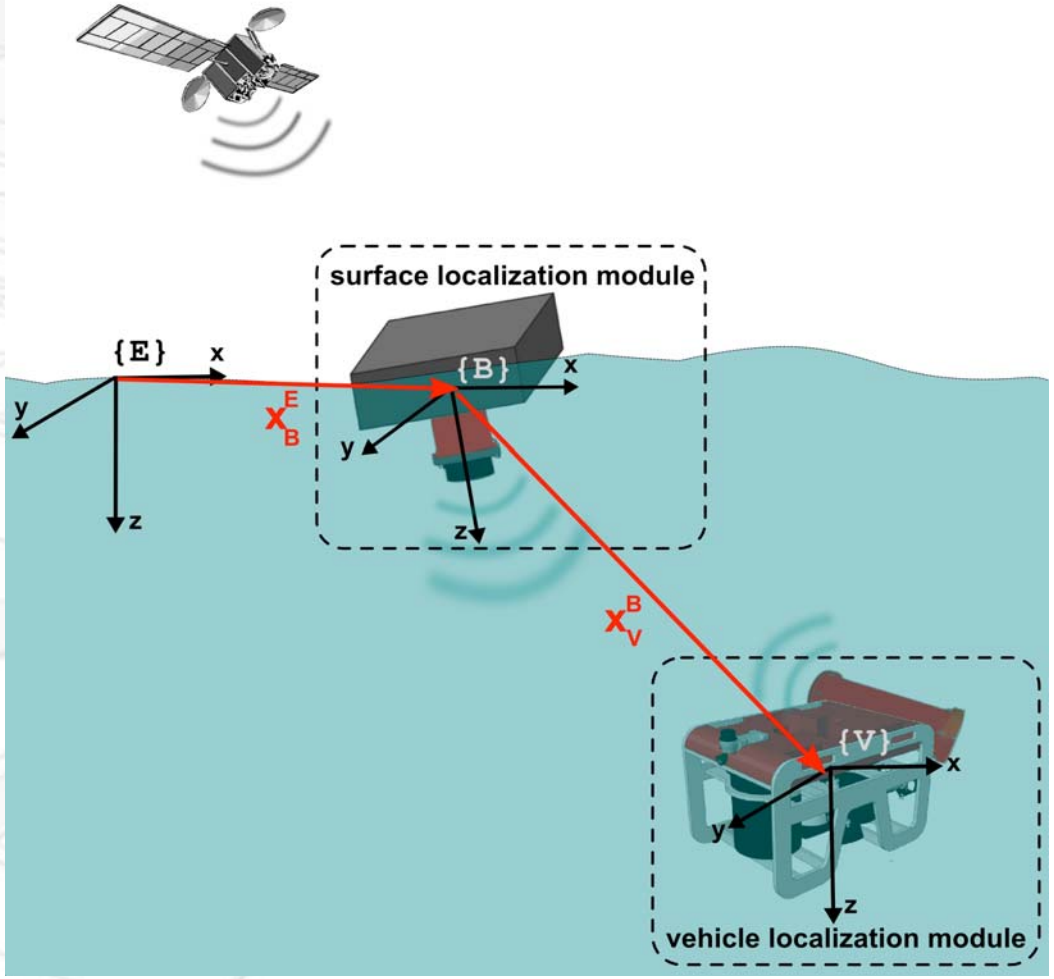
[IROS'07 Ribas]

Localization system for non-structured environments

Objective: **Develop a localization system to operate in non-structured environments and perform missions such as dam inspections.**

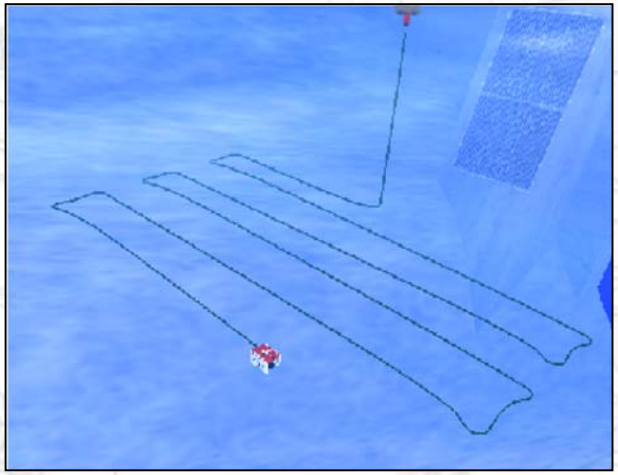
The robot trajectory is estimated with an Extended Kalman Filter (EKF) that uses the measurements from a DVL and a MRU to update a constant velocity kinematic model.

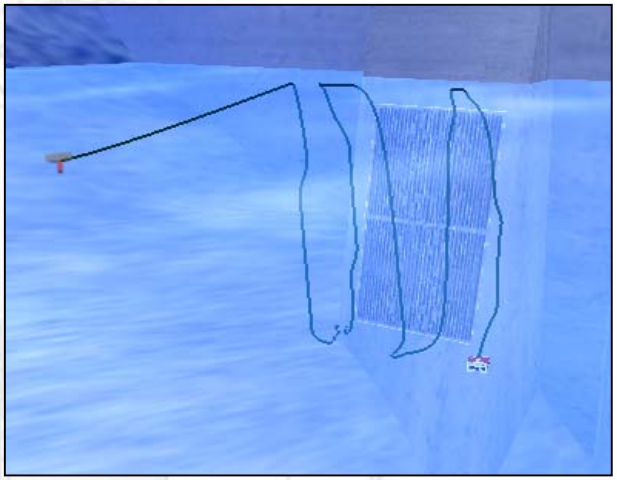
In order to reduce the drift inherent to this process, a USBL-equiped buoy is used to provide absolute position fixes.

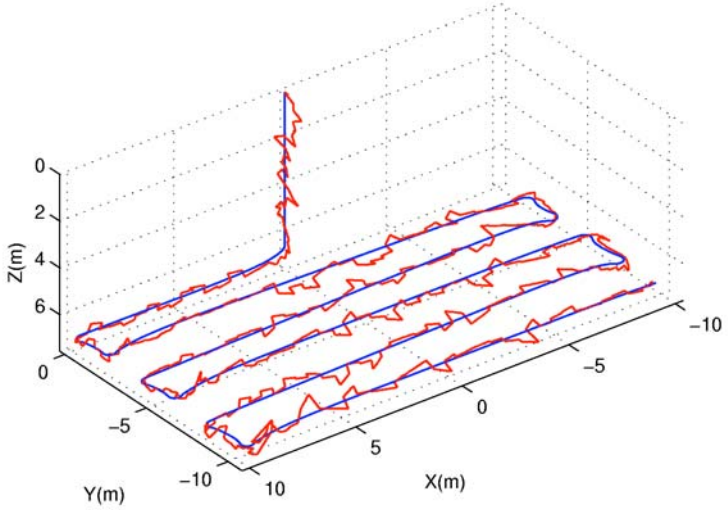


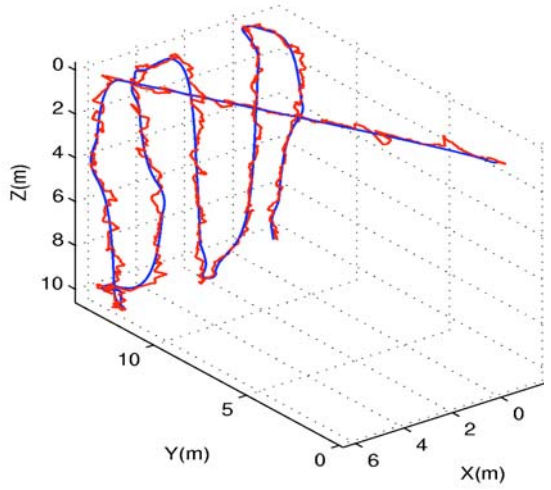
Localization system for non-structured environments

Simulated experiments

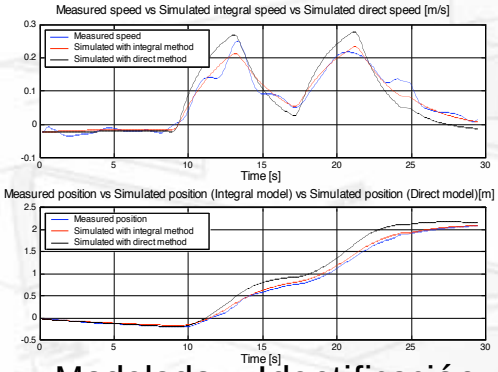






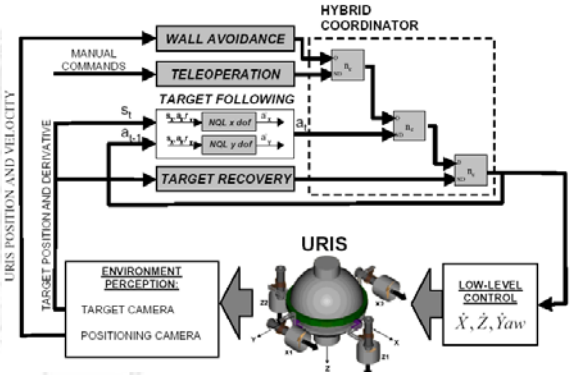


Líneas de Investigación



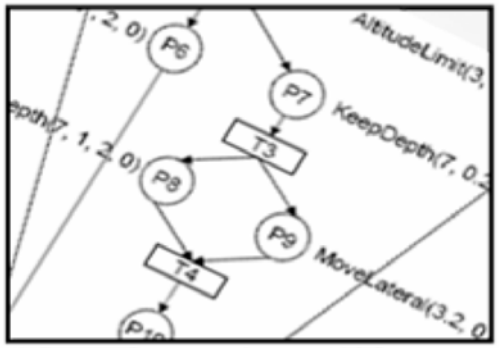
Modelado y Identificación

Simulación
Hardware in the loop



Arquitecturas basadas
En comportamientos

Navegación



Control de Misión

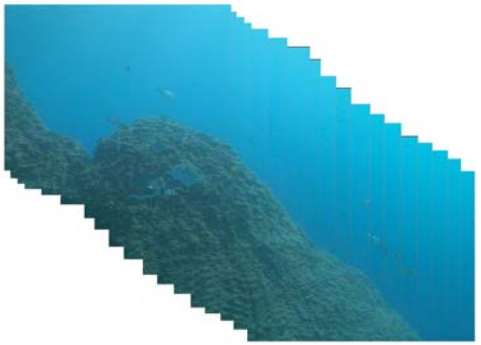
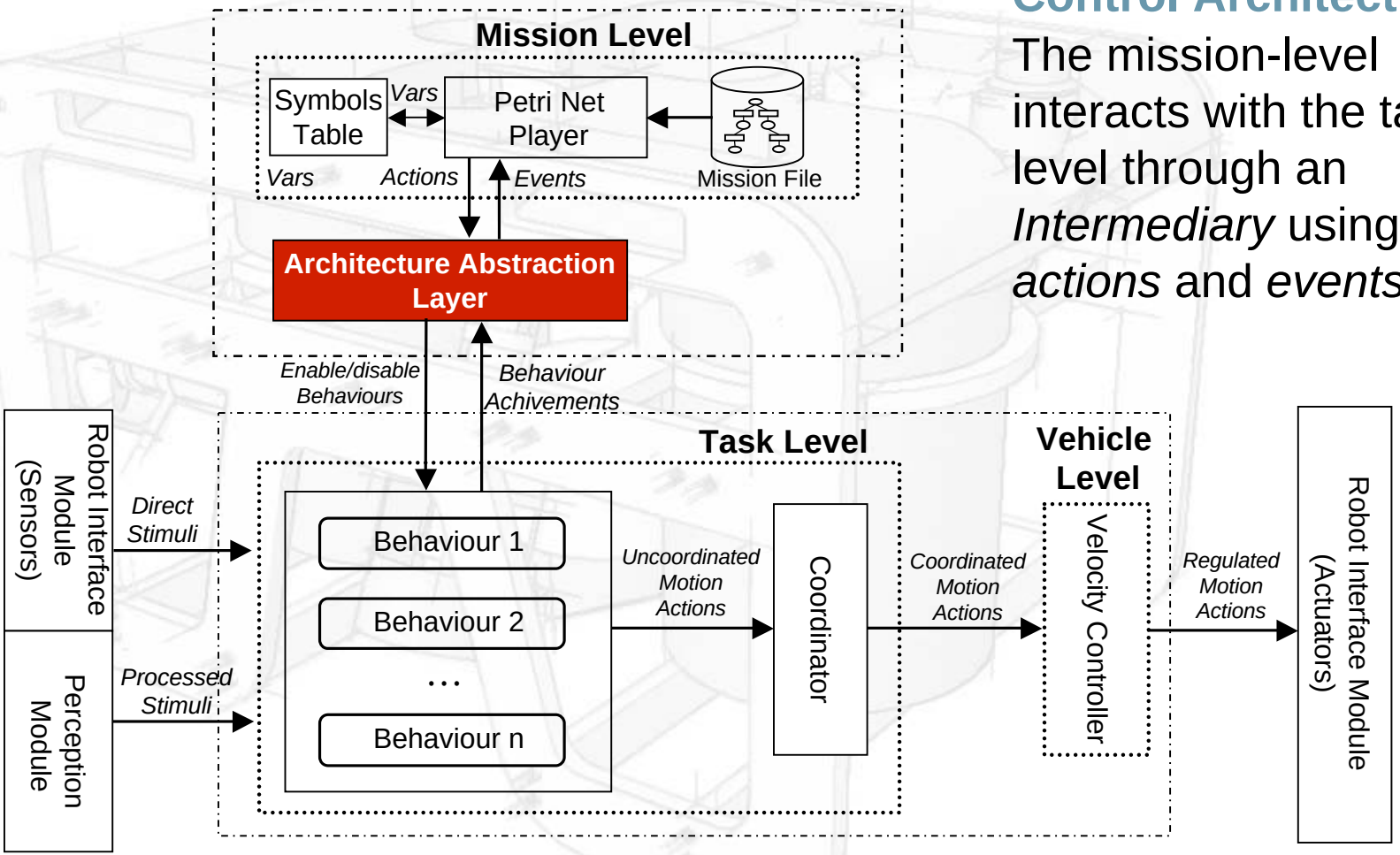


Image Mosaicking

Mission Control System

General Mission Control System



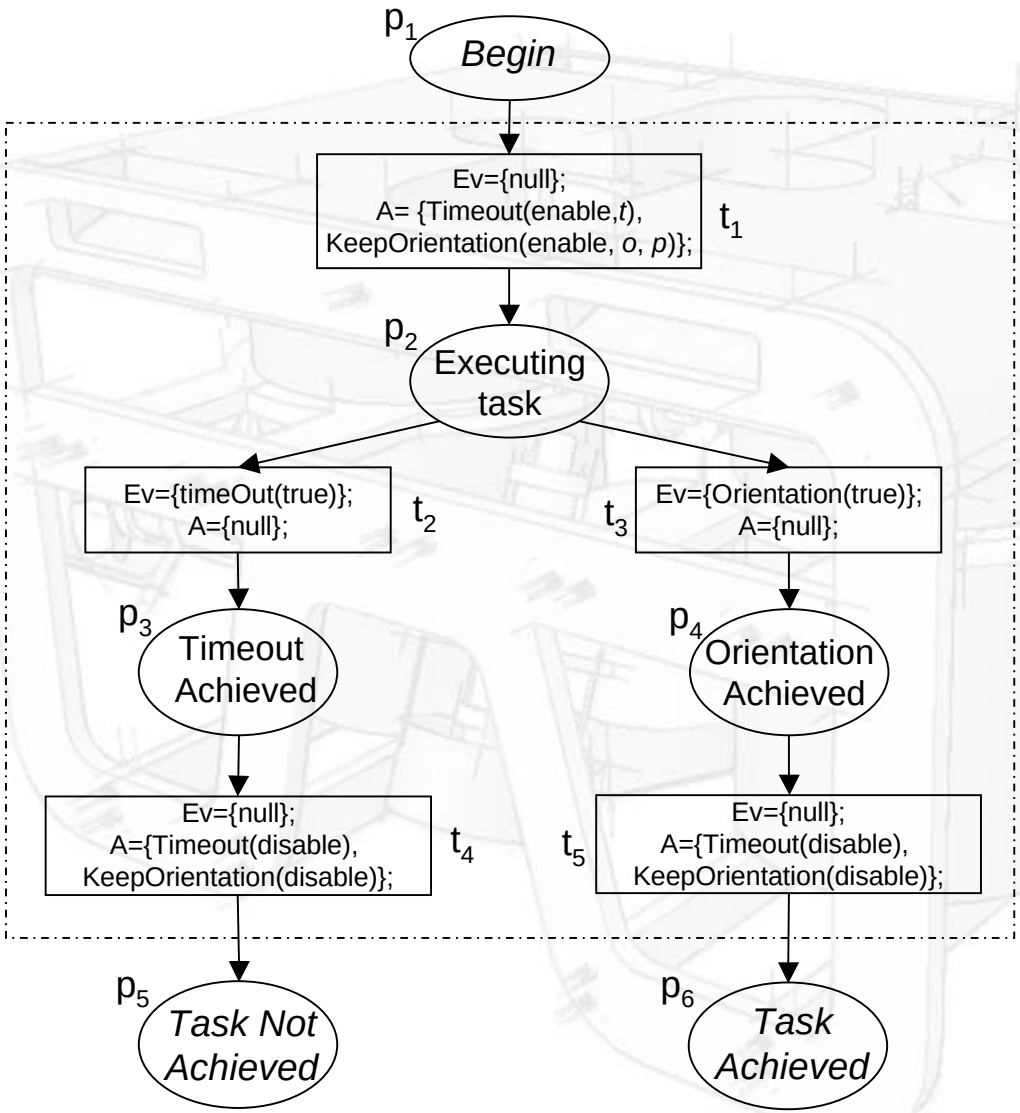
Specific Control Architecture

Control Architecture

The mission-level interacts with the task-level through an *Intermediary* using *actions* and *events*.

[IROS'06 Palomeras]

Mission Control System



Using Petri Nets to control a Discrete Event System

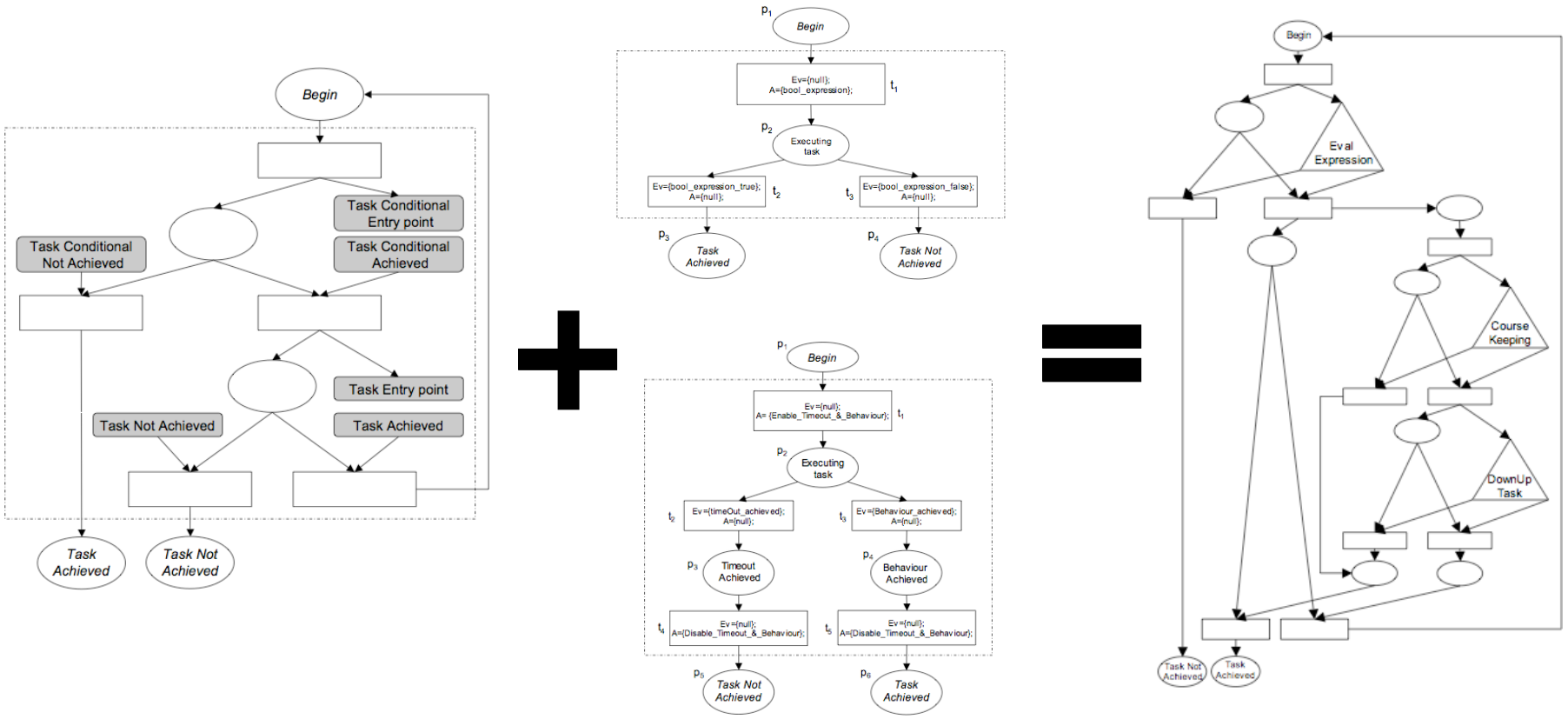
Example of a task used to control the vehicle orientation.

A transition fires when is enabled and a set of events is received. When it fires a set of actions is executed in the task-leve through the Arquitecture Abstraction Layer

Mission Control System

Set up missions joining primitive tasks

Using structures like *While*, *If-Then-Ese*, *conditional* and *unconditionall* sequencing, … is possible join primitive tasks To set-up full missions.



Mission Control System

MCL, a Mission Control Language

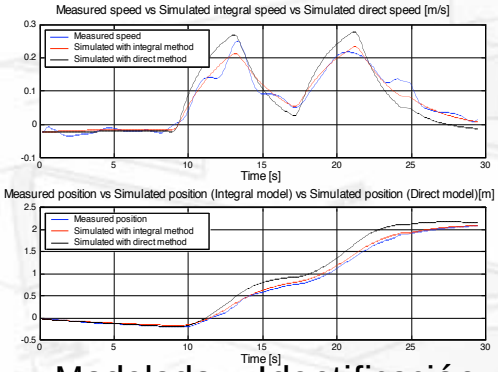
It is possible automatically generate Petri net missions using a pseudo-code like language. *Actions* and *events* have to be defined as well as the Petri nets for the *primitive tasks*. A MCL compiler is under development.

```
Actions {
    Enable_KeepDepth(z, priority); Disable_KeepDepth();
    Enable_KeepOrientation(ψ, priority); Disable_KeepOrientation();
    Enable_KeepVelocity(u, v, w, r, priority); Disable_KeepVelocity();
    Enable_DownUp(depth1, depth2, minAltitude, νz, priority); Disable_DownUp(
    Enable_Timeout_Orientation(t); Disable_Timeout_Orientation();
    Enable_Timeout_Depth(t); Disable_Timeout_Depth();
    Enable_Timeout_Velocity(t); Disable_Timeout_Velocity();
}
Events {
    ev_KeepDepth_Achieved; ev_KeepDepth_Not_Achieved;
    ev_KeepOrientation_Achieved; ev_KeepOrientation_Not_Achieved;
    ev_KeepVelocity_Achieved; ev_KeepVelocity_Not_Achieved;
    ev_DownUp_Achieved; ev_DownUp_Not_Achieved;
    ev_Timeout_Orientation_Achieved;
    ev_Timeout_Depth_Achieved;
    ev_Timeout_Velocity_Achieved;
    exception_General_Failure;
}
System_variables {
    float altitude;
}
Resources {
    resource_depth_DOF;
    resource_yaw_DOF;
    resource_X_velocity_DOF;
}
```

```
Tasks_Pattern {
  AchieveOneGoal (enable_behaviour_&_timeout, disable_behaviour_&_timeout,
timeout_achieved, behaviour_achieved) {
      places {
        p1: Abort; p2: Begin; p3; p4; p5, p6: Task Achieved; p7: Task Not
Achieved;
      }
      transitions {
        t1: Ev={null}; A={null};
        t2: Ev={null}; A={enable_behaviour_&_timeout};
        t3: Ev={timeout_achieved}; A={null};
        t4: Ev={behaviour_achieved}; A={null};
        t5: Ev={null}; A={disable_behaviour_&_timeout};
        t6: Ev={null}; A={disable_behaviour_&_timeout};
      }
      arcs {
        p1 → t1; p2 → t2; p3 → t1; p3 → t3; p3 → t4; p4 → t5; p5 → t6;
        t1 → p4; t2 → p3; t3 → p4; t4 → p5; t5 → p6; t6 → p7;
      }
  }
  KeepTwoGoals (enable_behaviours_&_timeout, disable_behaviours_&_timeout,
timeout_achieved, ...) { ... }
}
Tasks {
  AutoHeading(ψ, t, p = 4): AchieveOneGoal {
    enable_behaviour_&_timeout: Enable_Timeout_Orientation(t),
      Enable_KeepOrientation(ψ, p);
    disable_behaviour_&_timeout: Disable_Timeout(),
      Disable_KeepOrientation();
    timeout_achieved: ev_Timeout_Orientation_Achieved;
    behaviour_achieved: ev_KeepOrientation_Achieved;
    Resources: resource_yaw_DOF;
  }
  CourseKeeping(νx, ψ, t, p): KeepTwoGoals { ... }
  DownUpTask(depth1, depth2, minAltitude, νz, t, p): AchieveOneGoal { ... }
  Surface(t, p): AchieveOneGoal { ... }
}
```

```
Mission {
  float MIN_ALTITUDE = 6.0;
  float ORIENTATION = 1.57;
  int ORIENTATION_T = 90;
  int COURSE_T = 30;
  int DOWN_UP_T = 90;
  int SURFACE_T = 120;
  float VELOCITY_X = 1.0;
  float DEPTH = 2.0;
  float ALTITUDE = 1.0;
  float VELOCITY_Z = 0.3;
  try {
    AutoHeading(ORIENTATION, ORIENTATION_T);
    while (altitude < MIN_ALTITUDE) {
      CourseKeeping(VELOCITY, ORIENTATION, COURSE_T);
      DownUpTask(DEPTH, 0, ALTITUDE, VELOCITY_Z, DOWN_UP_T);
    },
    Surface(SURFACE_T);
  }
  catch(exception_General_Failure) {
    Surface(SURFACE_T);
  };
}
```

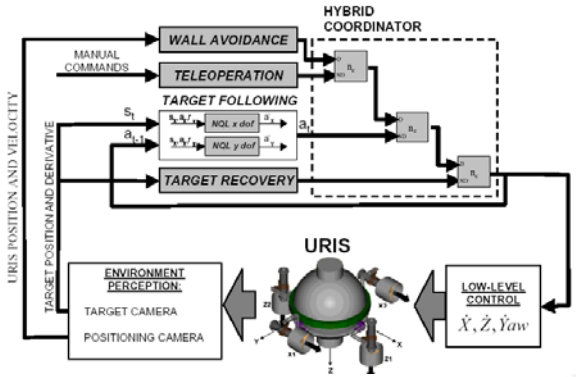
Líneas de Investigación



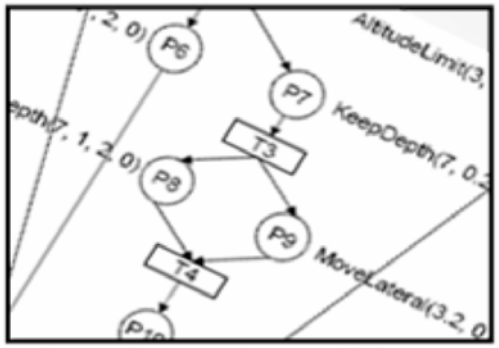
Modelado y Identificación

Simulación
Hardware in the loop

Navegación



Arquitecturas basadas
En comportamientos



Control de Misión

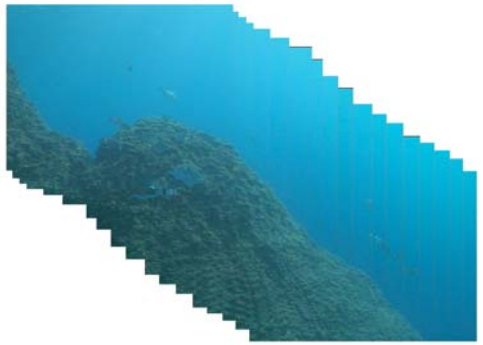
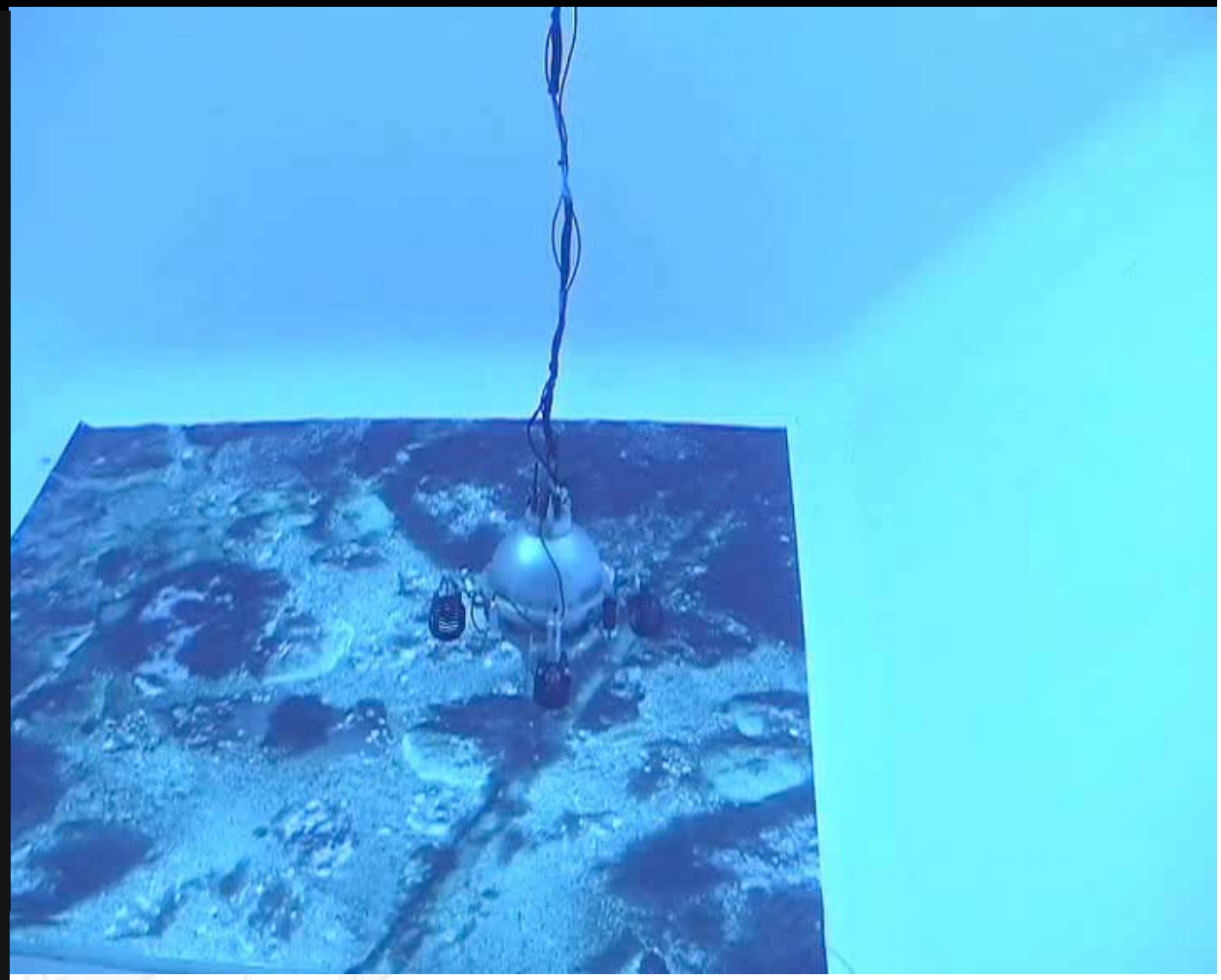
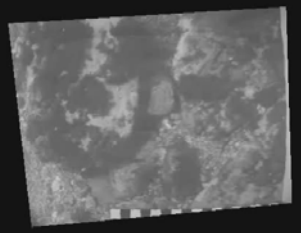


Image Mosaicking

Mosaicos de imágenes

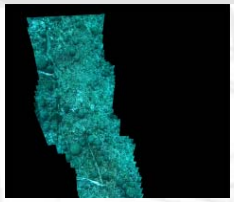


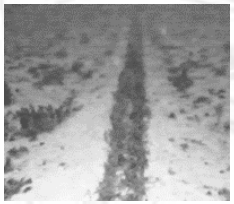


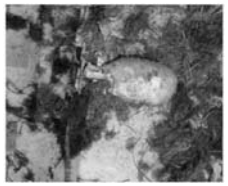
- Construcción de Mapas 2D del fondo del mar
- Problema de la correspondencia: Temporal y espacial
- Aplicaciones: Inspección, mapeo, localización

[Garcia 02]

Inspección de presas hidroeléctricas





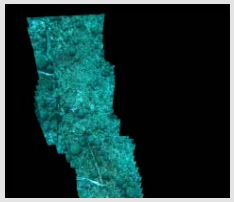


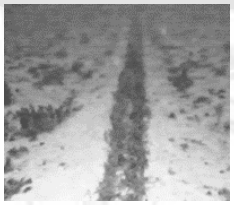
Para ver esta película, debe disponer de QuickTime™ y de un descompresor .

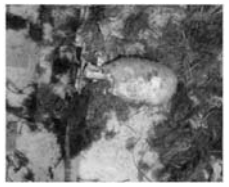
- Colaboración UdG – IPA CIFAT
- Noviembre 2002
- Inspección de la presa Tartina Situada en Cluj (Rumania)
- Estudio de viabilidad

[MCMC'03 Batlle]

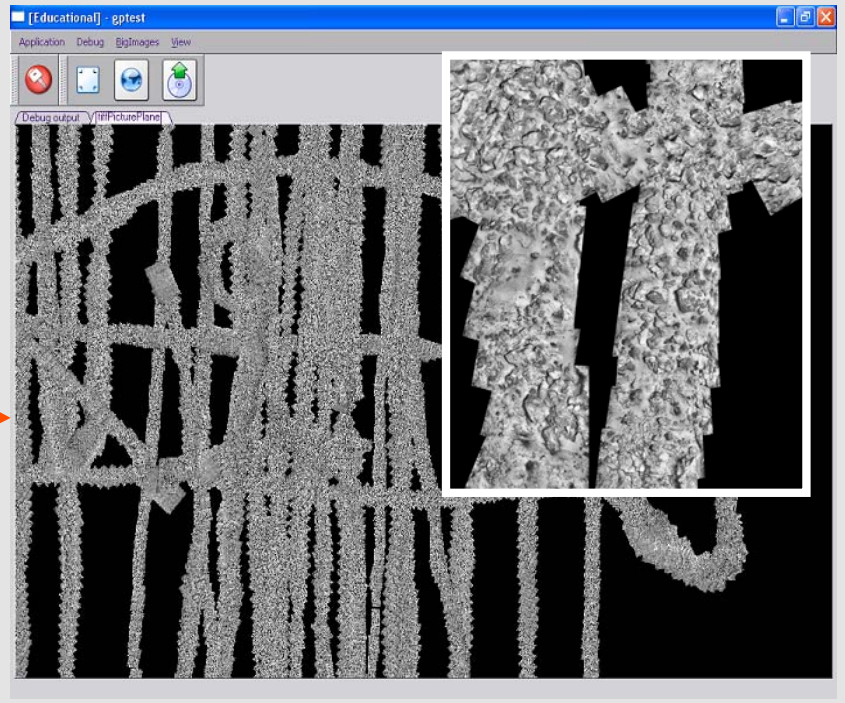
Biología y Geología: Mapeo de zonas hidrotermales





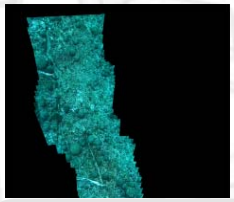


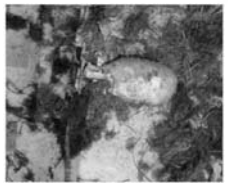
Tamaño mosaico = 71.037px. x 84.099px.



Dades de Woods Hole (Cedides per Dani Fornari)
20.000 Imatges
Campaña LUSTRE'95

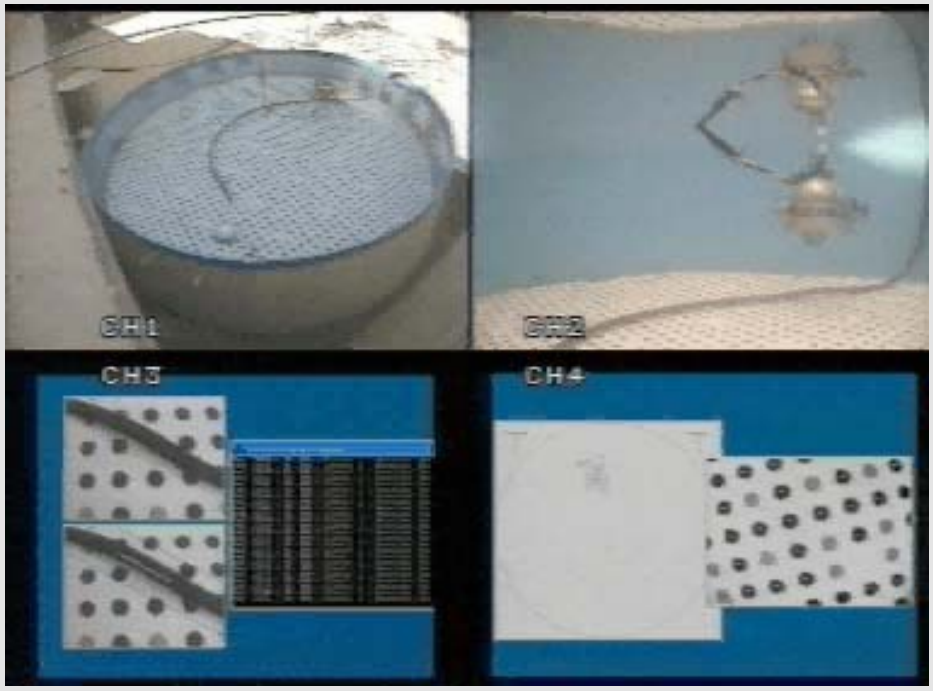
Energía: Inspección de cables y tuberías





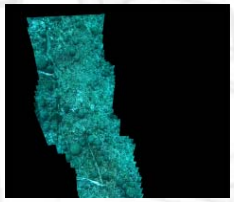
University of the Balearic Islands

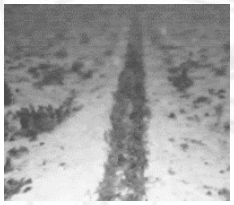
University of Girona

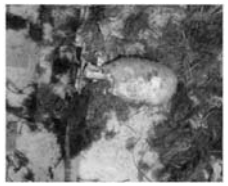


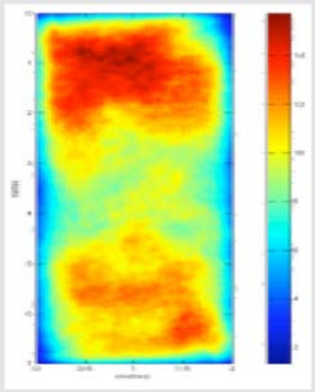
[IAV'04 Antich]

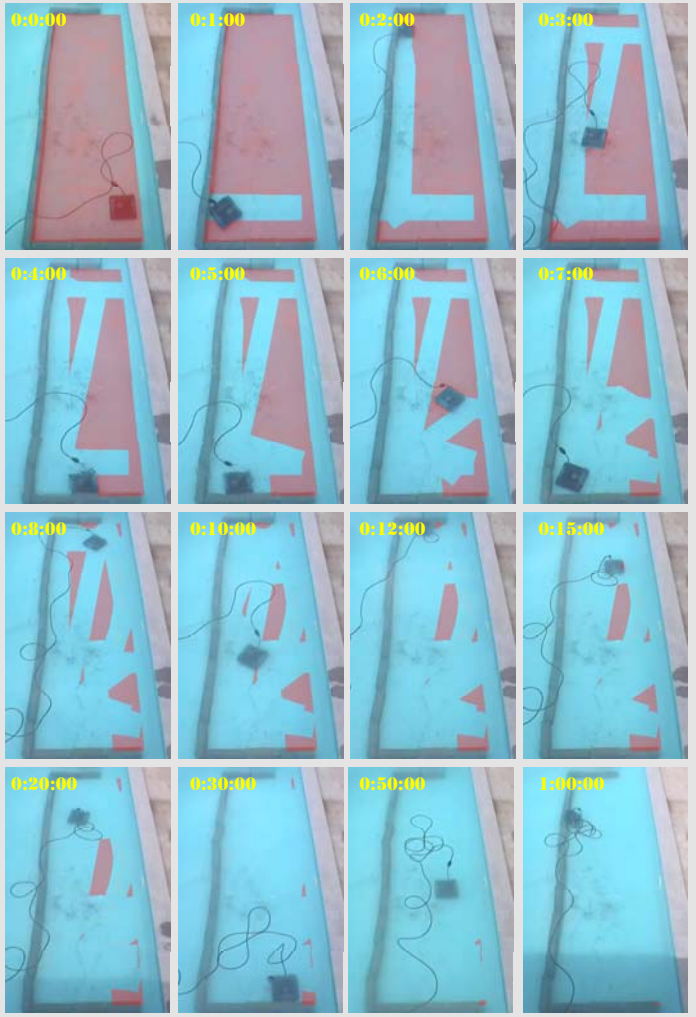
Robots de limpieza



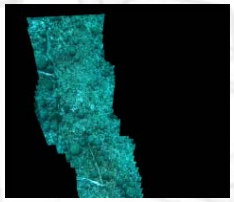


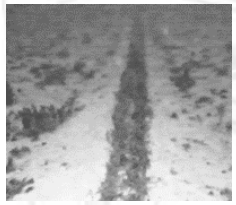


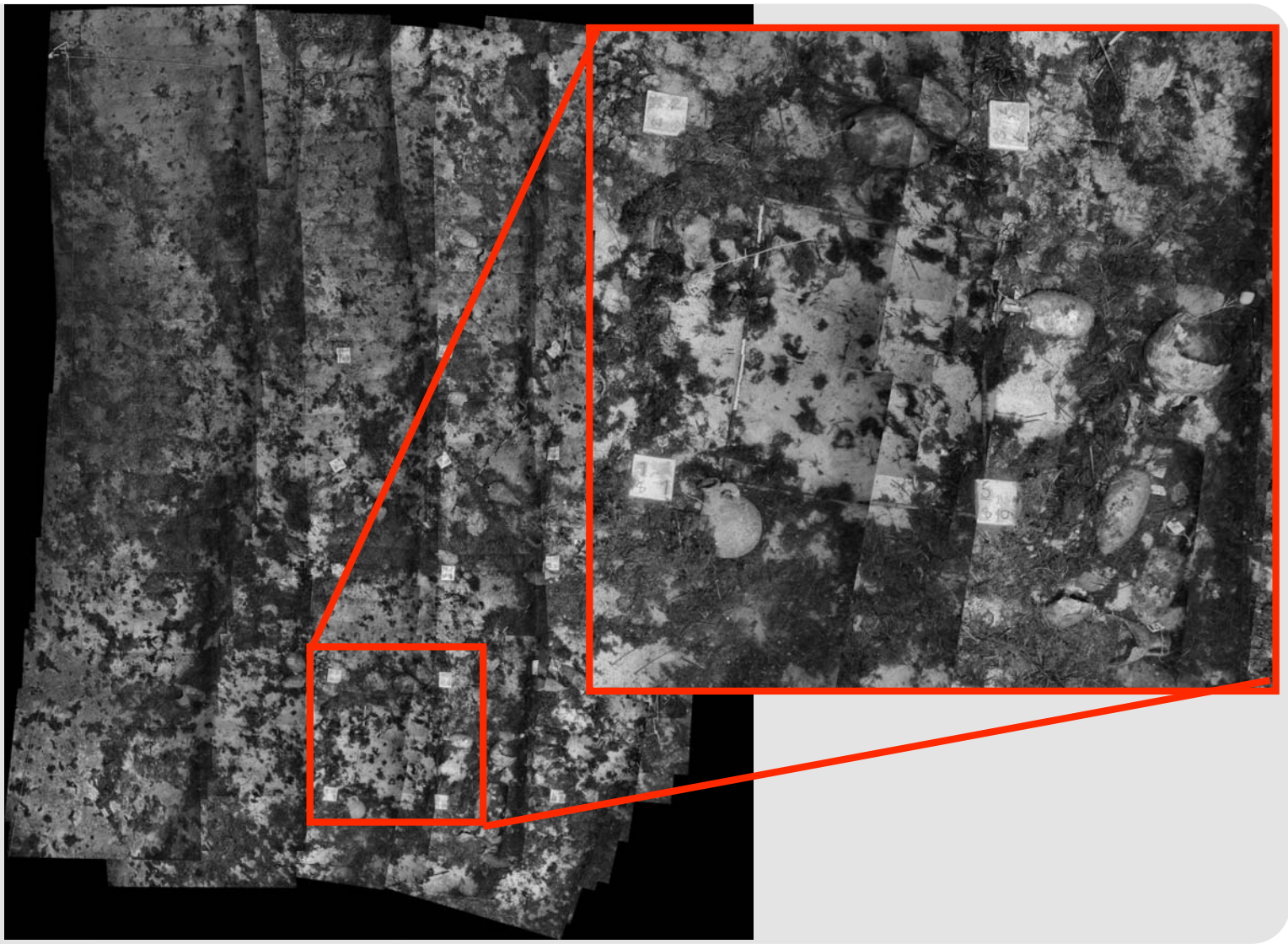




Arqueología

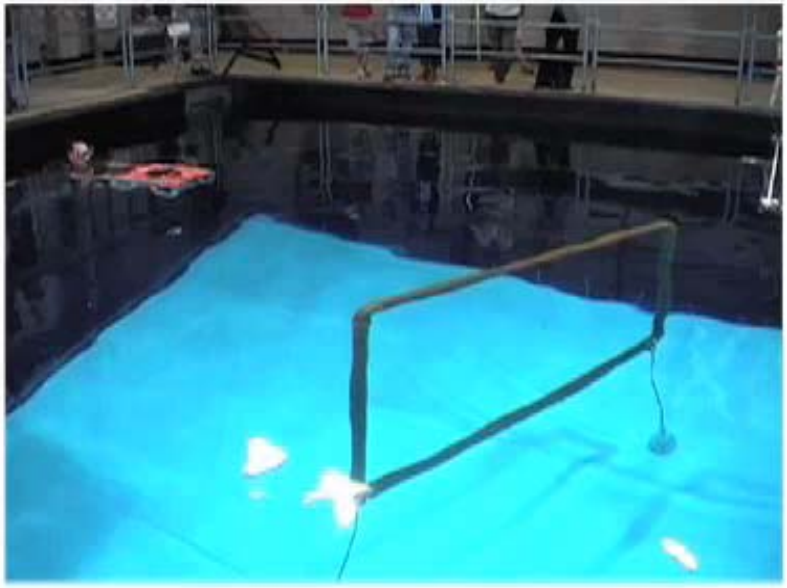


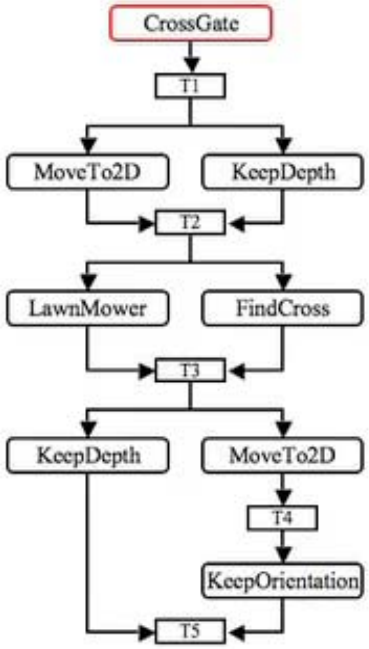




ICTINEU^{AUV} 1er clasificado en el SAUC-E 2006

Aditional Results





IROS 2006 Beijing, China | Internal Conference on Intelligent Robots and Systems

[ICRA'07 Ribas]

Agradecimiento

10 años de Robótica Submarina en la UdG. Pere Ridao