Control Scheme for Distributed Computing in Robot Networks Destined to Humanitarian Demining

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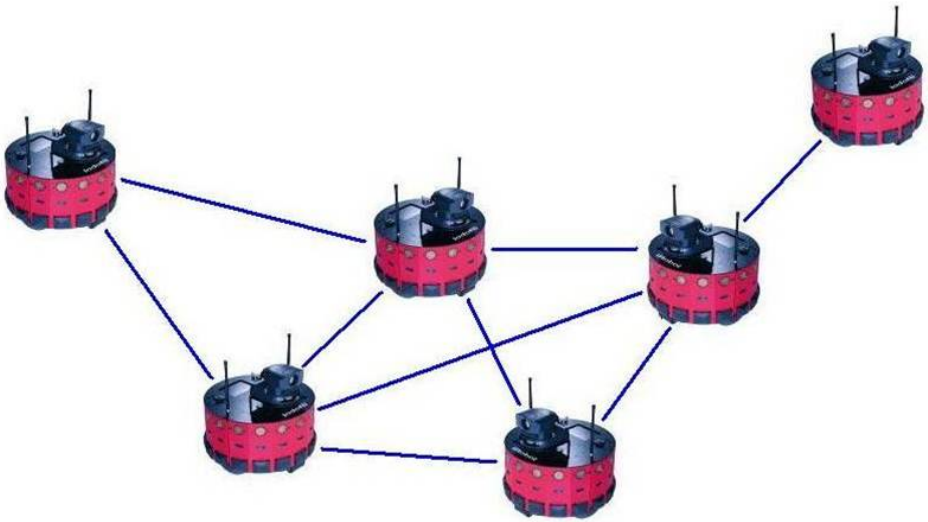
Outline

Distributed Robotic Systems



Benefits:

SCALABILITY,
FLEXIBILITY,
PARALLELISM,
INCREASING THE PERFORMANCE, ...

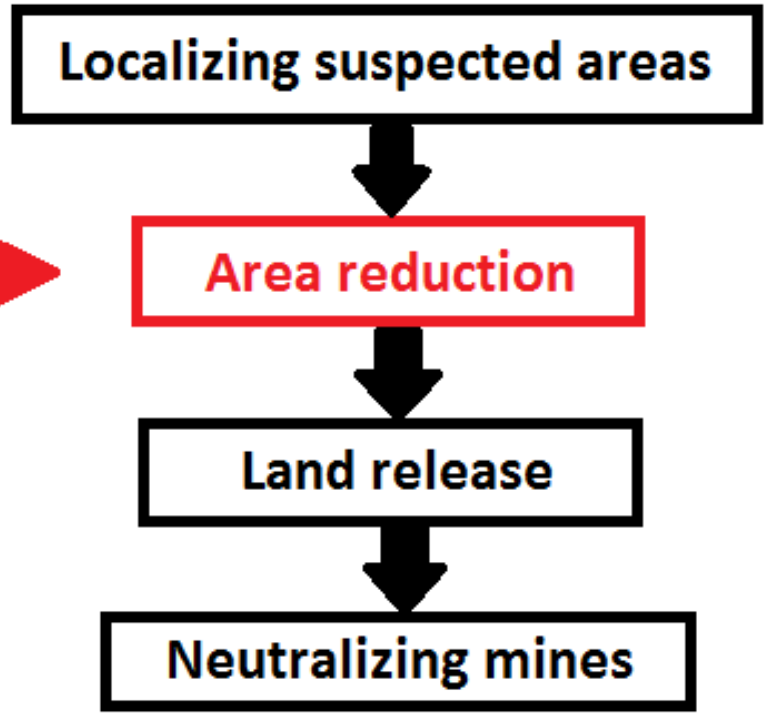
Landmine Contamination

Humanitarian demining

Anti-personnel mine

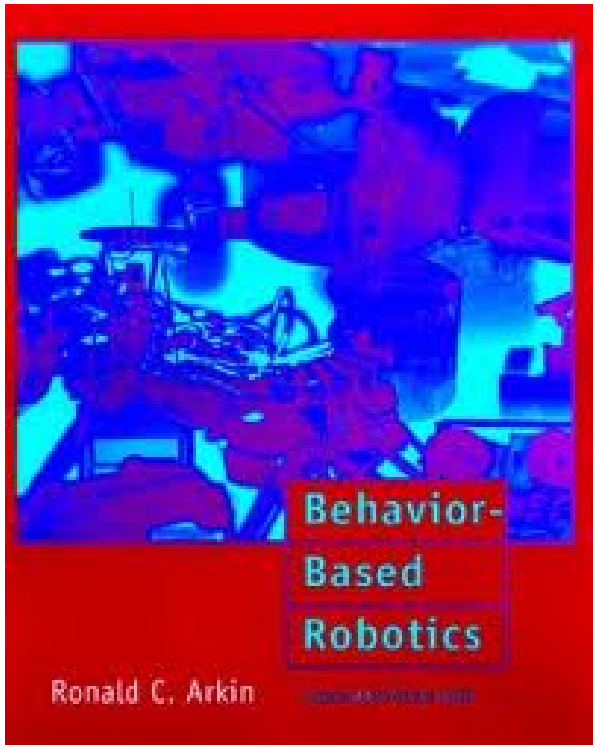
Colombia, Argentina, Chile, Ecuador, Perú.

Demining Process

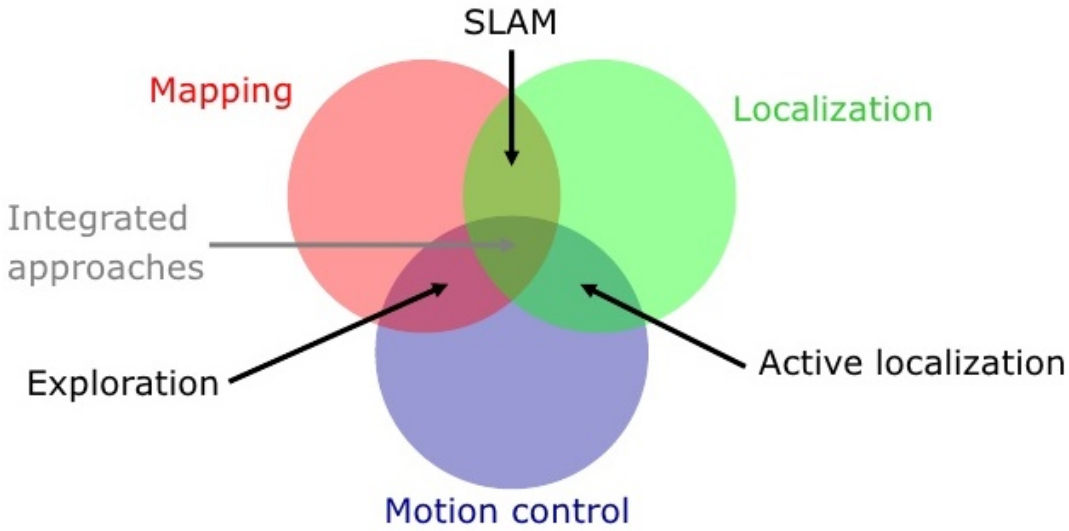


Alternative tools:
Robotic systems

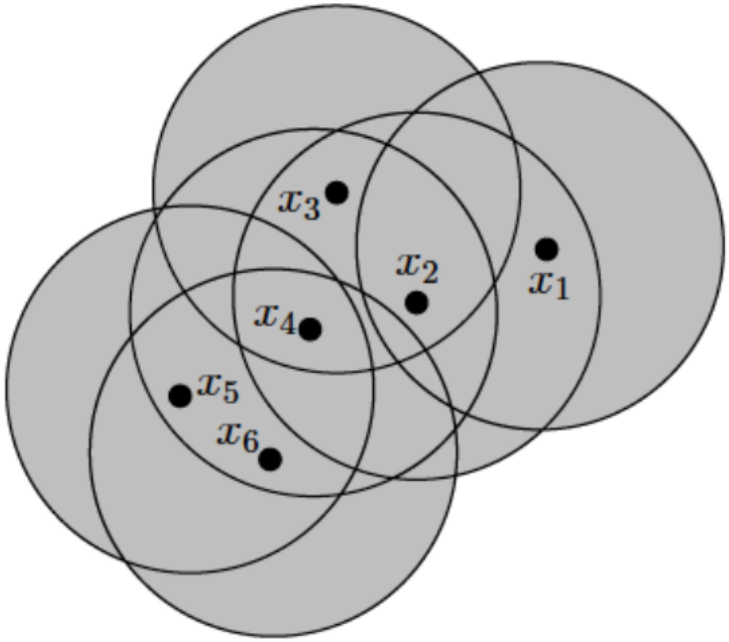
Reactive Control

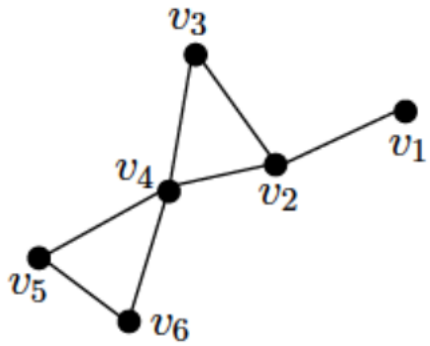


Cognitive Control



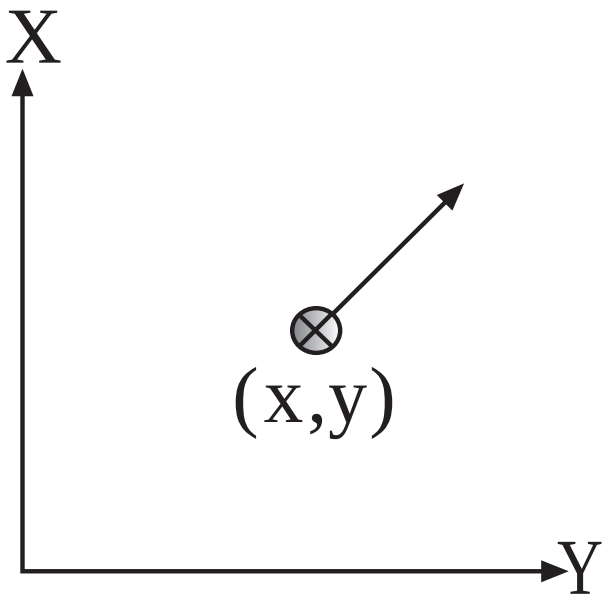
Communication Network





Robot network representation, $\mathcal{G} = (V, E)$.

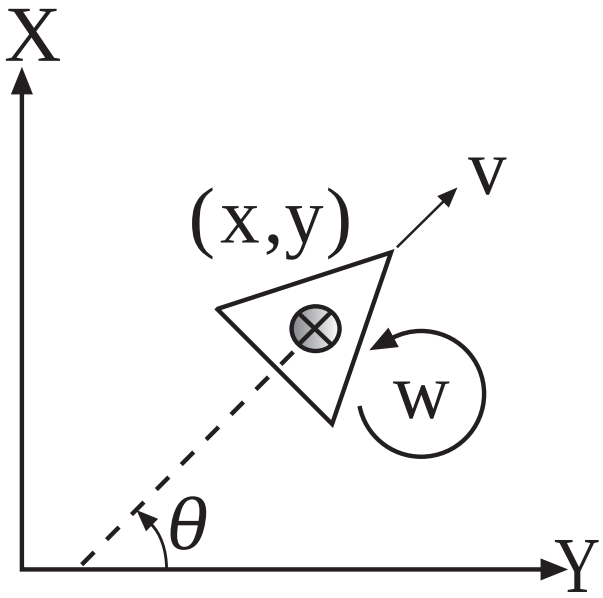
Mathematical models



Simple Integrator

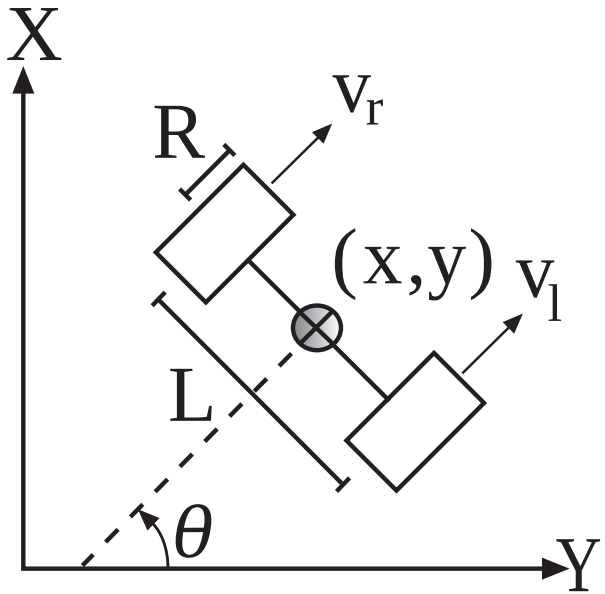
$$q = (x, y)$$

$$\dot{q} = u \ , \ u \in \mathbb{R}^2 \qquad (1)$$



Unicycle

$$\dot{x} = v \cos\theta$$
$$\dot{y} = v \sin\theta$$
$$\dot{\theta} = w \qquad (2)$$

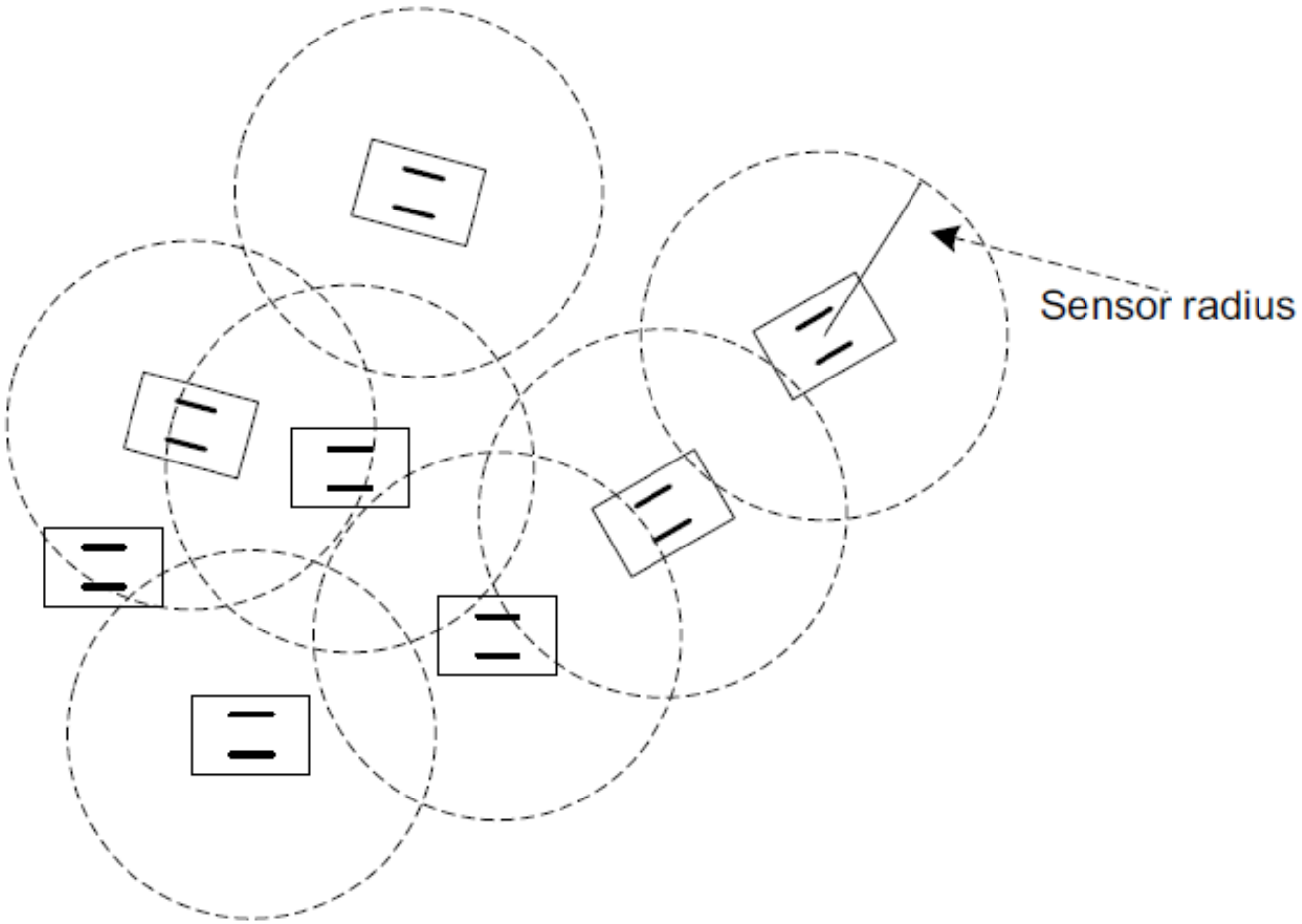


Differential Drive

$$\dot{x} = \frac{R}{2}(v_r + v_l)\cos\theta$$
$$\dot{y} = \frac{R}{2}(v_r + v_l)\sin\theta$$
$$\dot{\theta} = \frac{R}{L}(v_r - v_l) \qquad (3)$$

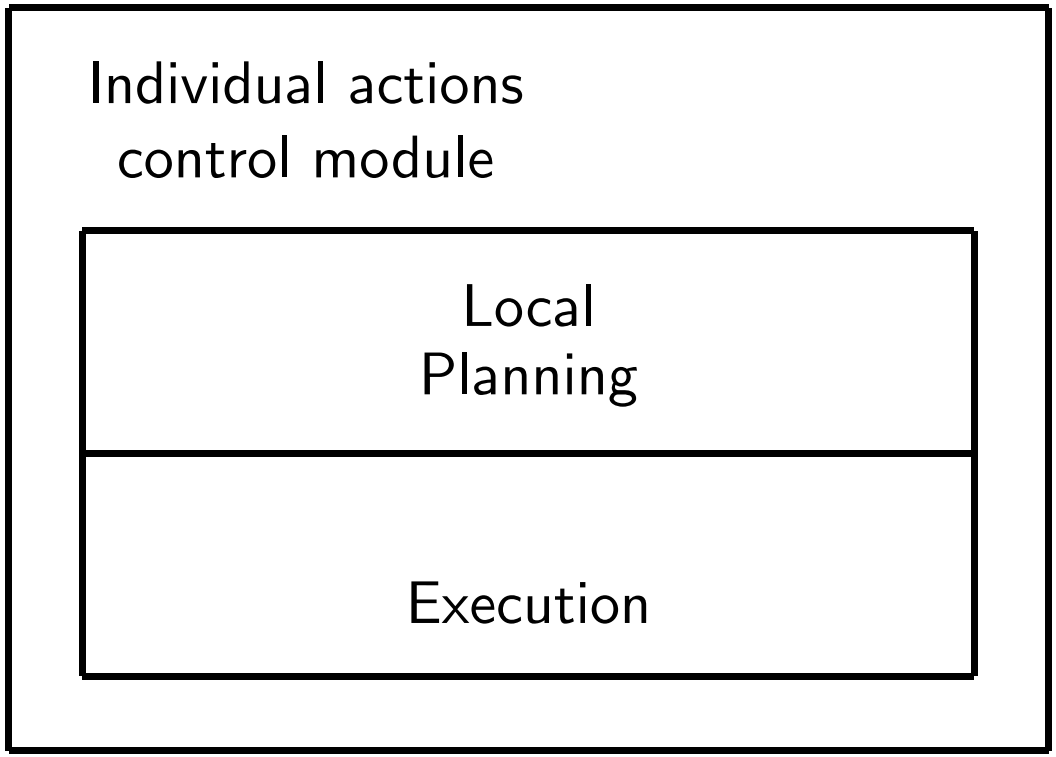
Disk abstraction for sensors

Disk abstraction is used for distance sensors and metal detectors.



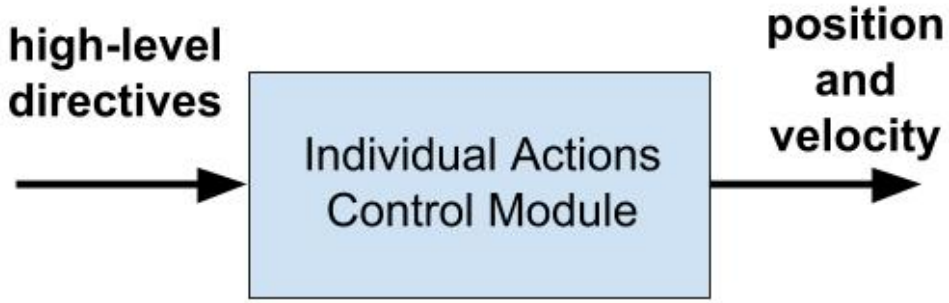
Control module design for individual actions

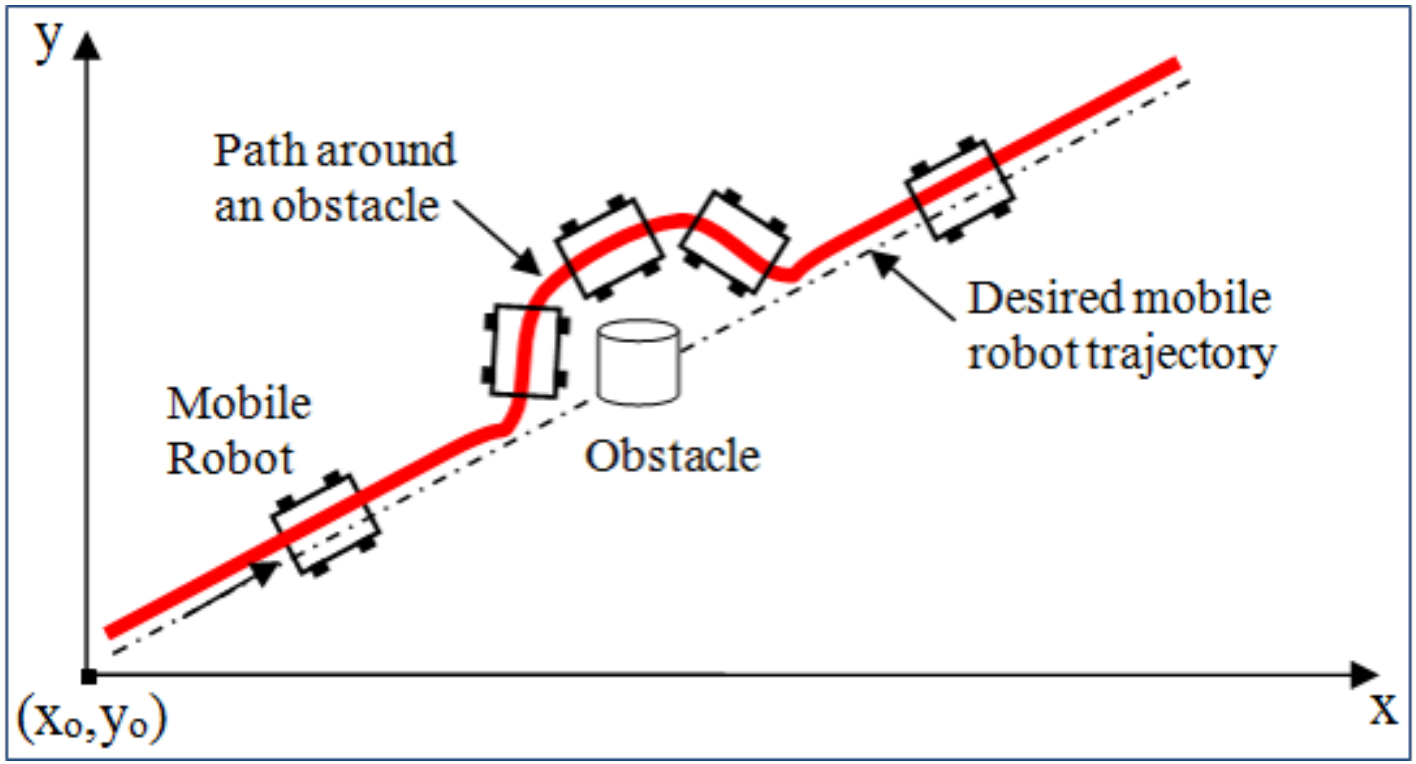
Bottom-Up methodology suggests working on the individual actions control in order to guarantee autonomous navigation capability on each robot.



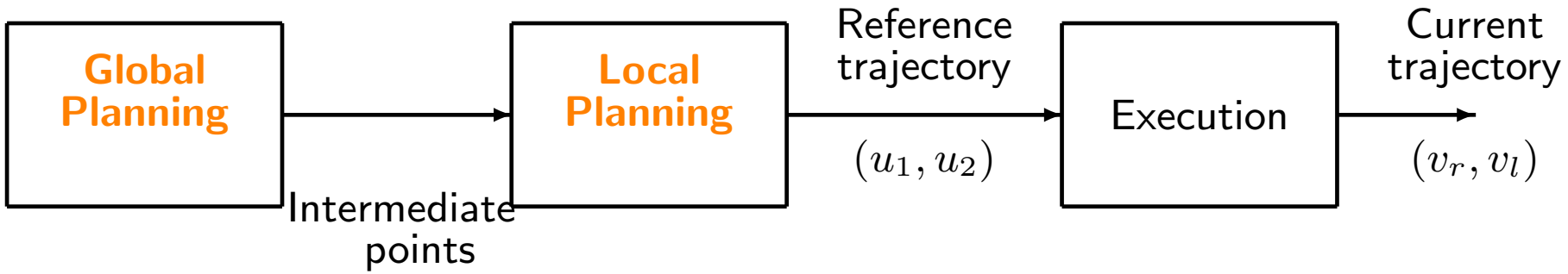
Control module design for individual actions

Bottom-Up Methodology: Guarantee robot control.





Global planning to Local planning



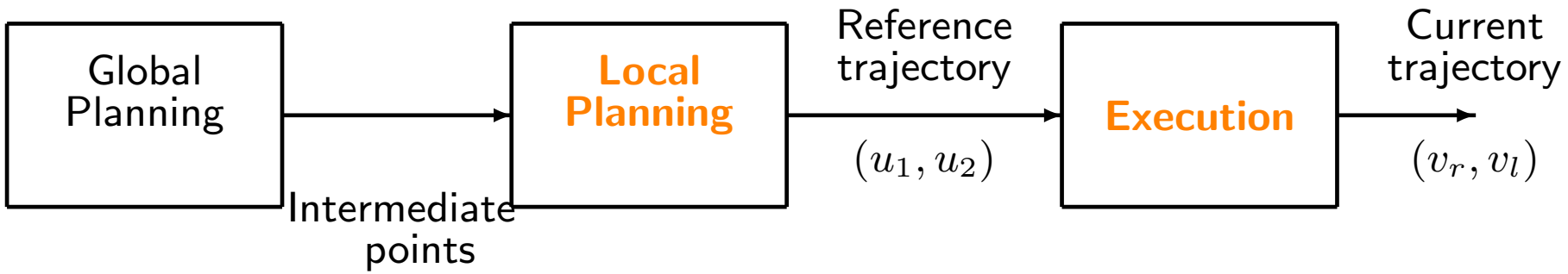
Considering the resultant vector, $u \in \mathbb{R}^2$, after local planning process.
Desired angular velocity (w):

$$\theta_{des} = \arctan\left(\frac{u_2}{u_1}\right) \quad ; \quad e = \theta_{des} - \theta_{actual}$$

$$w_{des} = PID_{(e)} = K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_D \dot{e}(t)$$

Desired linear velocity (v): $v_{des} = \sqrt{u_1^2 + u_2^2}$

Local planning to Execution

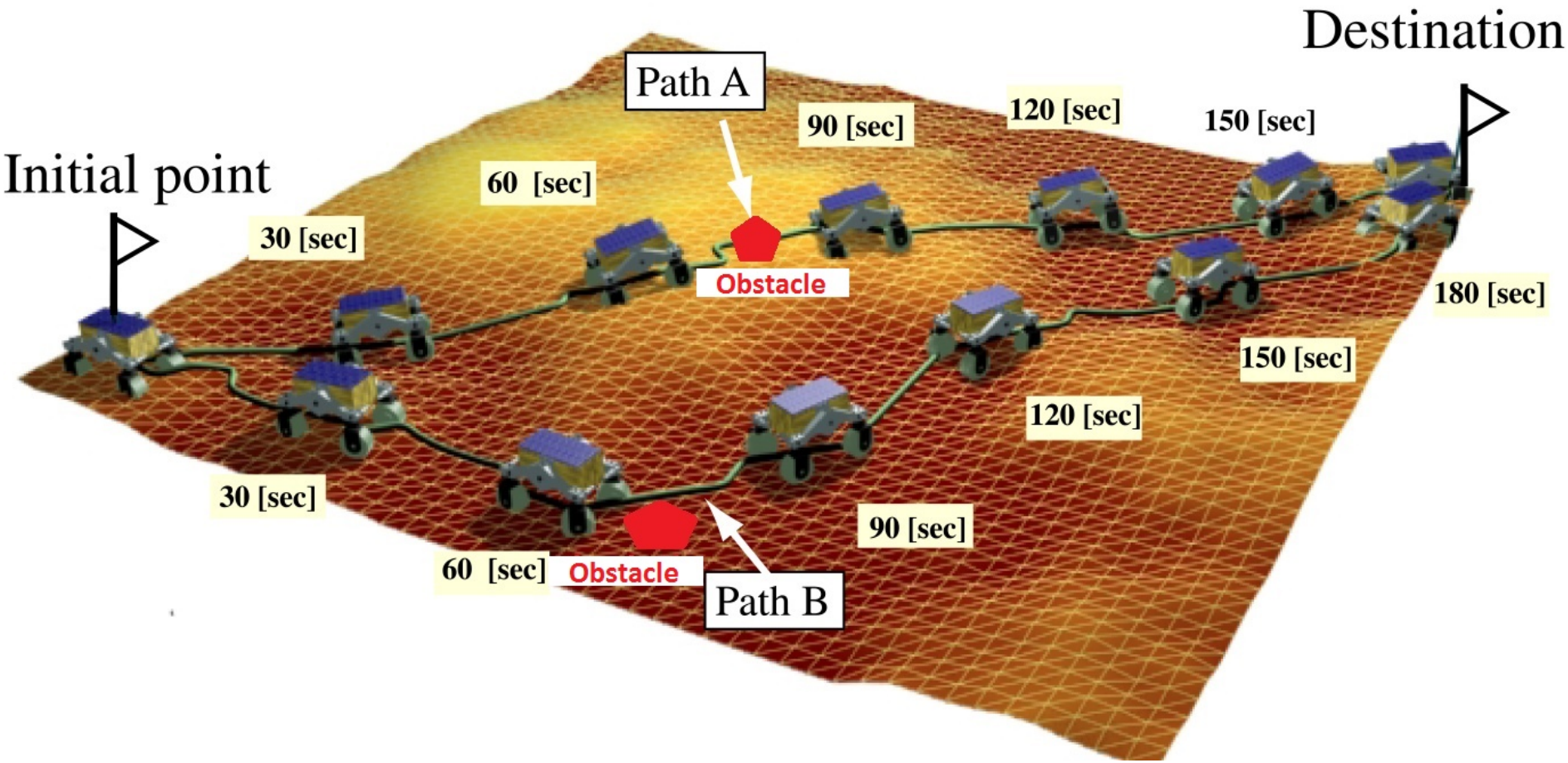


Relationship between Unicycle model and Differential Drive model:

$$v_r = \frac{2v_{des} + w_{des}L}{2R} \quad ; \quad v_l = \frac{2v_{des} - w_{des}L}{2R}$$

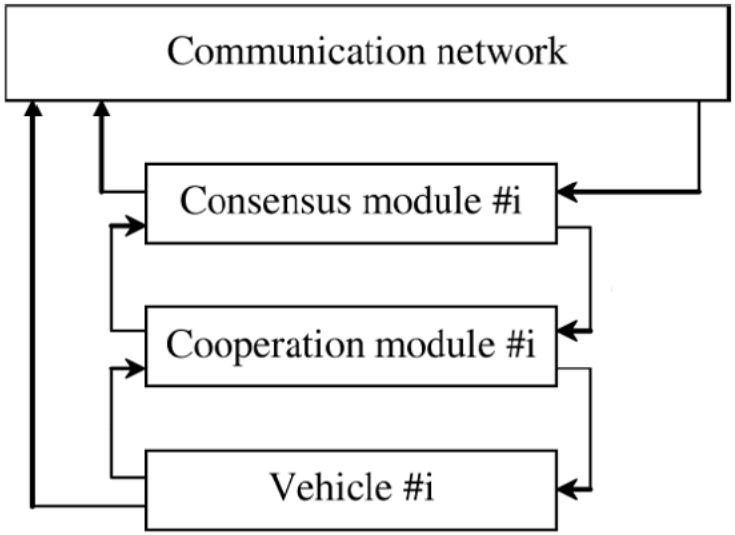
Reactive navigation

Global Planning Indicates the objective points.
Local Planning Indicates movement direction of the robot.
Execution allows movements in desired directions.

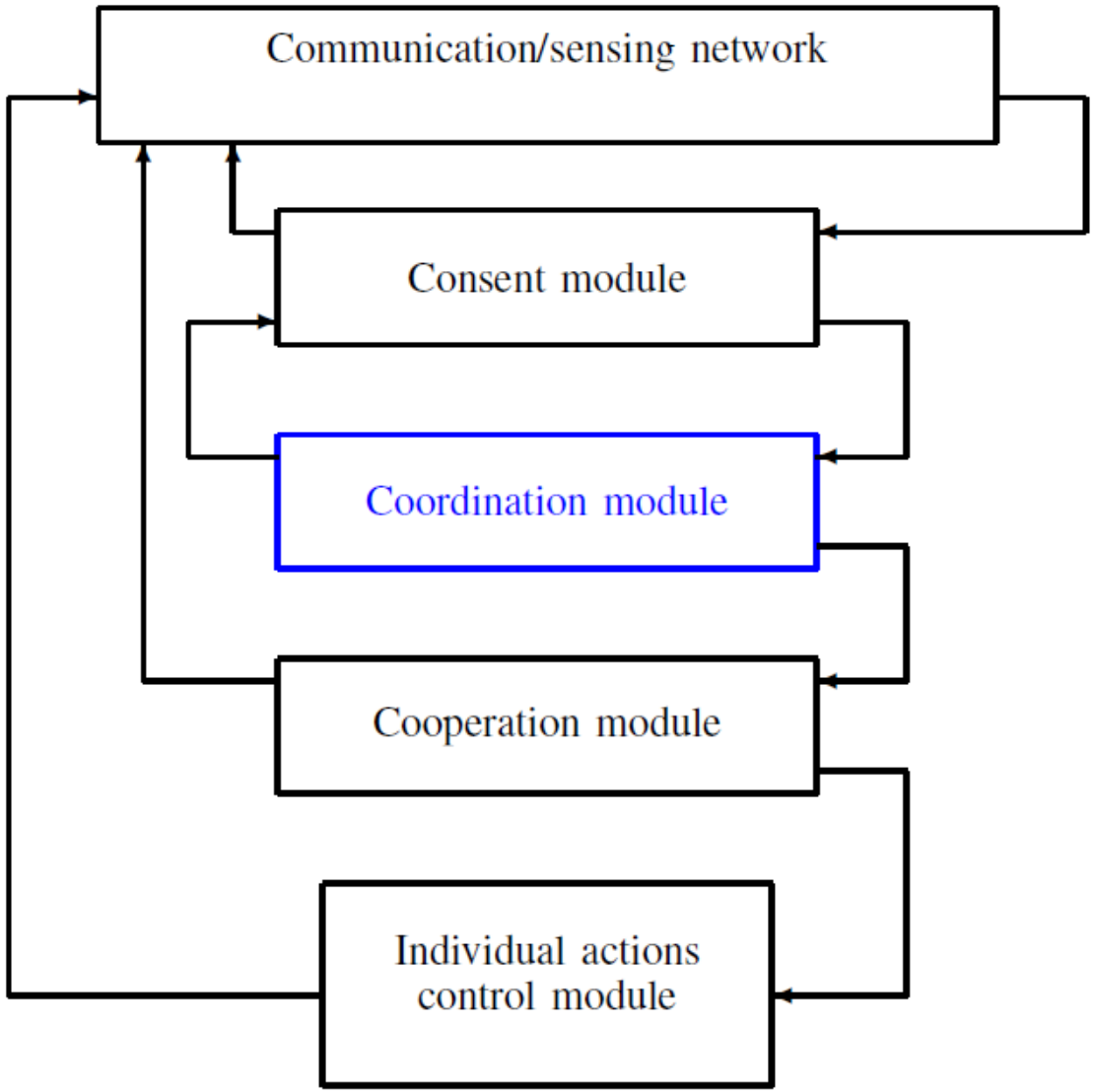


Control scheme development

Modification of the control scheme proposed by Ren y Beard.



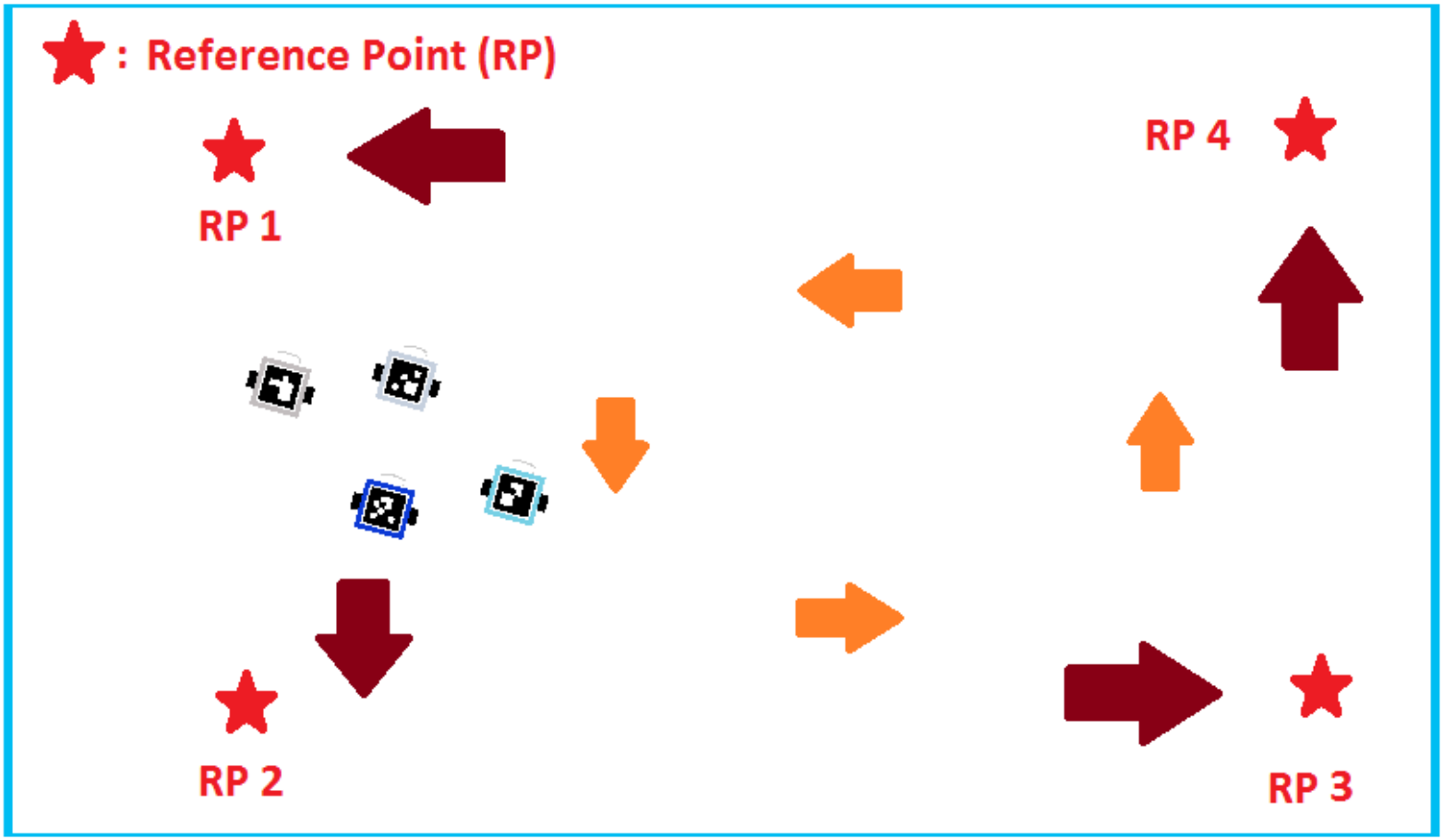
INICIAL SCHEME



PROPOSED SCHEME

Progressive Reduction Collective Behavior (PRCB)

A robot group progressively inspect an area searching for landmines.

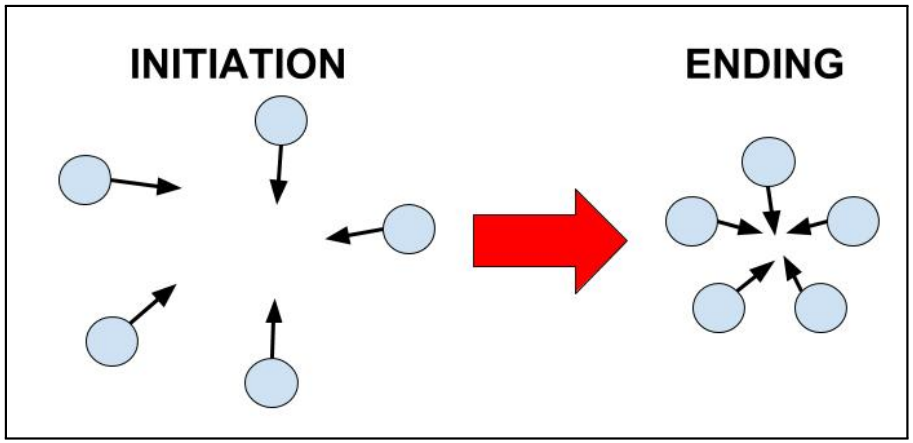


Cooperation module for PRCB

Axiom

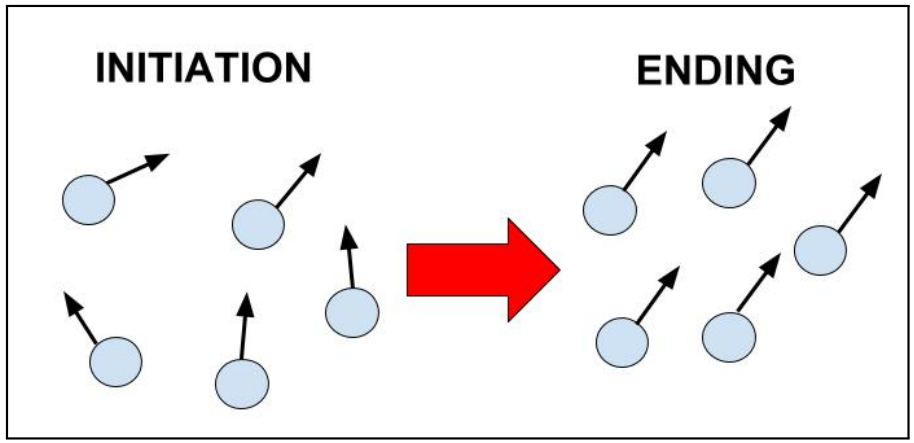
Working together with the same purpose is necessary for cooperation.

AGREGATION



$$\dot{q}_i(t) = -\sum_{j \in N(i)} (q_i(t) - q_j(t))$$
$$i = 1, ..., n$$

FLOCKING



$$\dot{q}_i(t) = -\sum_{j \in N(i)} (\dot{q}_i(t) - \dot{q}_j(t))$$
$$i = 1, ..., n$$

$N(i)$: **neighboring robots** q_i : **position** $\dot{q}_i$: **velocity**

Coordination Module for PRCB

Axiom

Arranging means and efforts for a common action is necessary for coordination.

It is modeled as a hybrid automaton, defined with a sevenfold:

$$(L, Q, A, W, E, Inv, Act)$$

where,

$$L = \{l_0, l_1, l_2, l_3, l_4, l_5\} \;\; ; \;\; Q \subset \mathbb{R}^2 \;\; ; \;\; W = \mathbb{R}^2 \;\; ; \;\; Inv(l) \subset Q$$

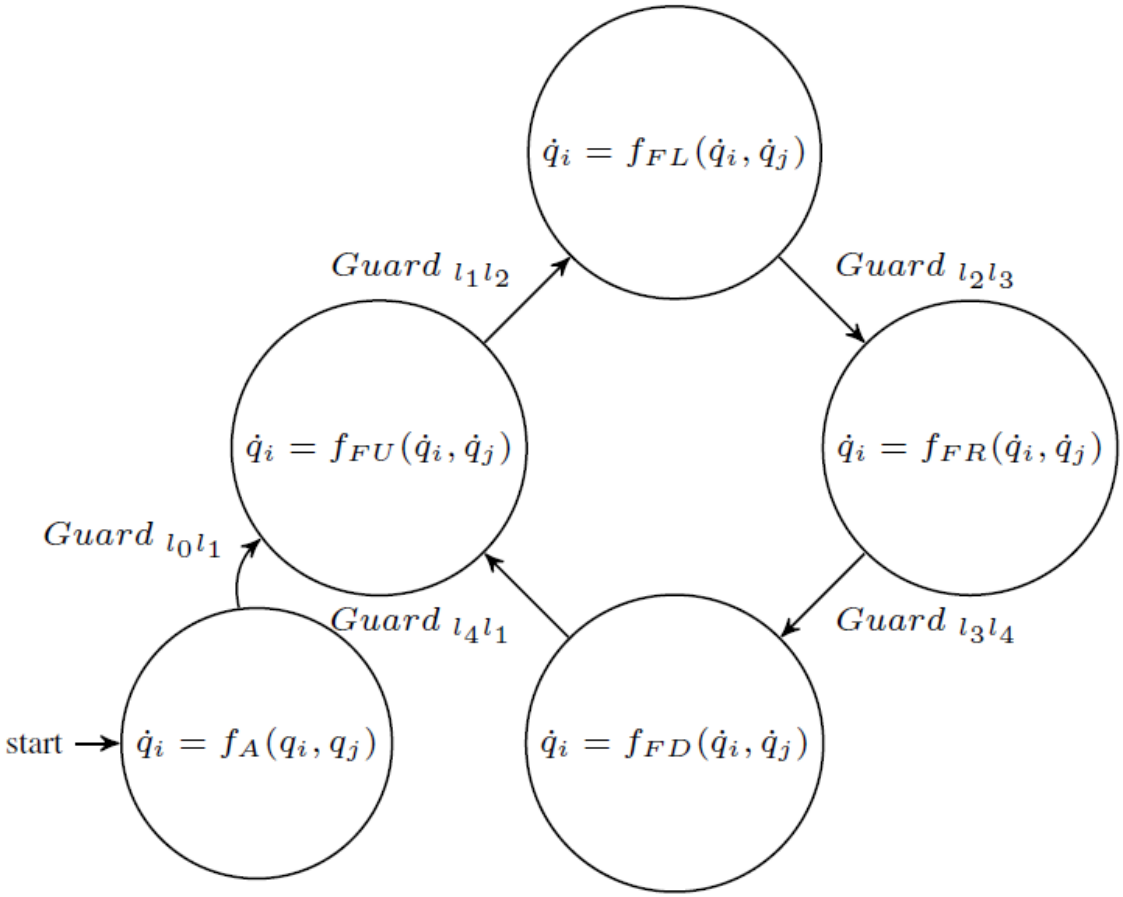
A is a symbol set to label edges.
E is the transitions set.
Act is a mapping that assigns continuous dynamic to each discrete state.

Coordination Module for PRCB

Hybrid Automaton for behaviors coordination.

$Guard_{l_1l_2} : Guard_{l_2l_3} : Guard_{l_3l_4} : Guard_{l_4l_1} : d_{leader} < \zeta_1$

$Guard_{l_0l_1} : \tau_r < \zeta_2$



$\zeta_1 = \Delta_{min}$ y $\zeta_2 = t_{meeting}$ are *coordination thresholds*.

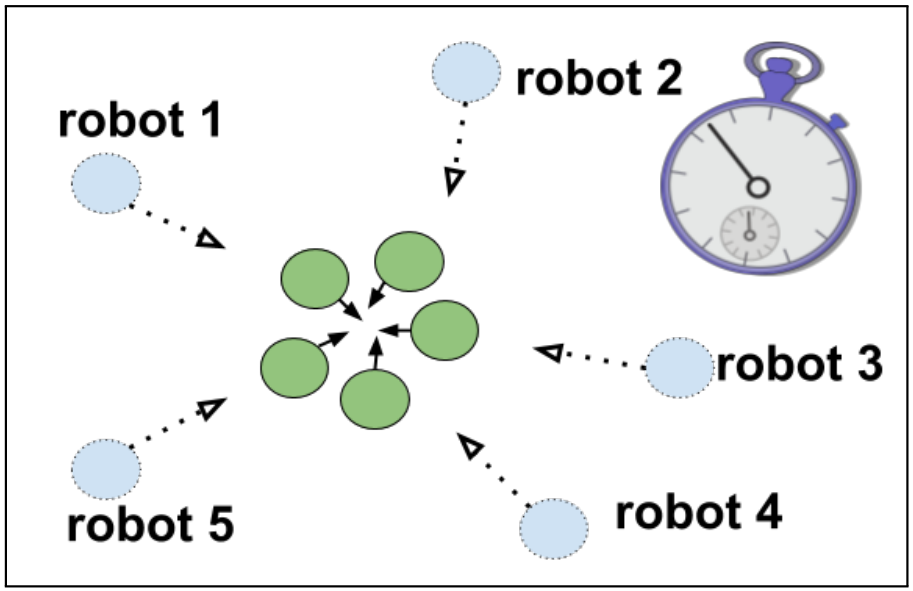
Consent module for PRCB

Axiom

Agreement between all robots is necessary to obtain consent values.

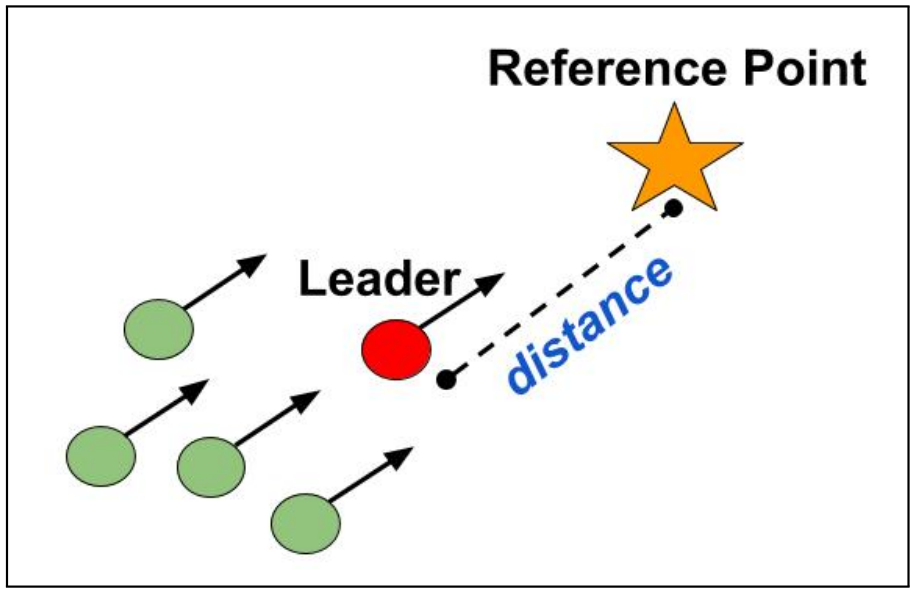
Consent variables for multi-robot system are specified as: $\{\tau_r, d_{leader}\}$

τ_r



Robot group meeting time.

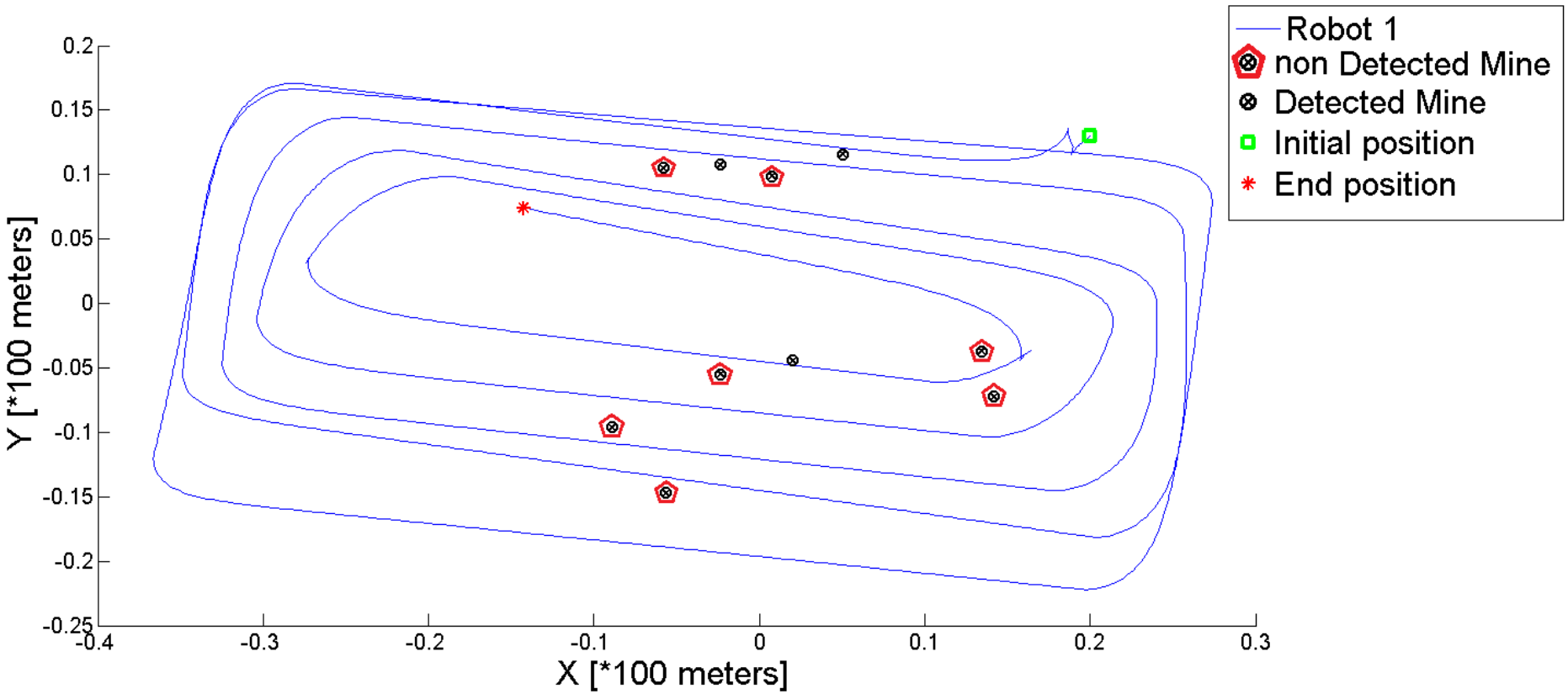
d_{leader}



Leader distance to reference.

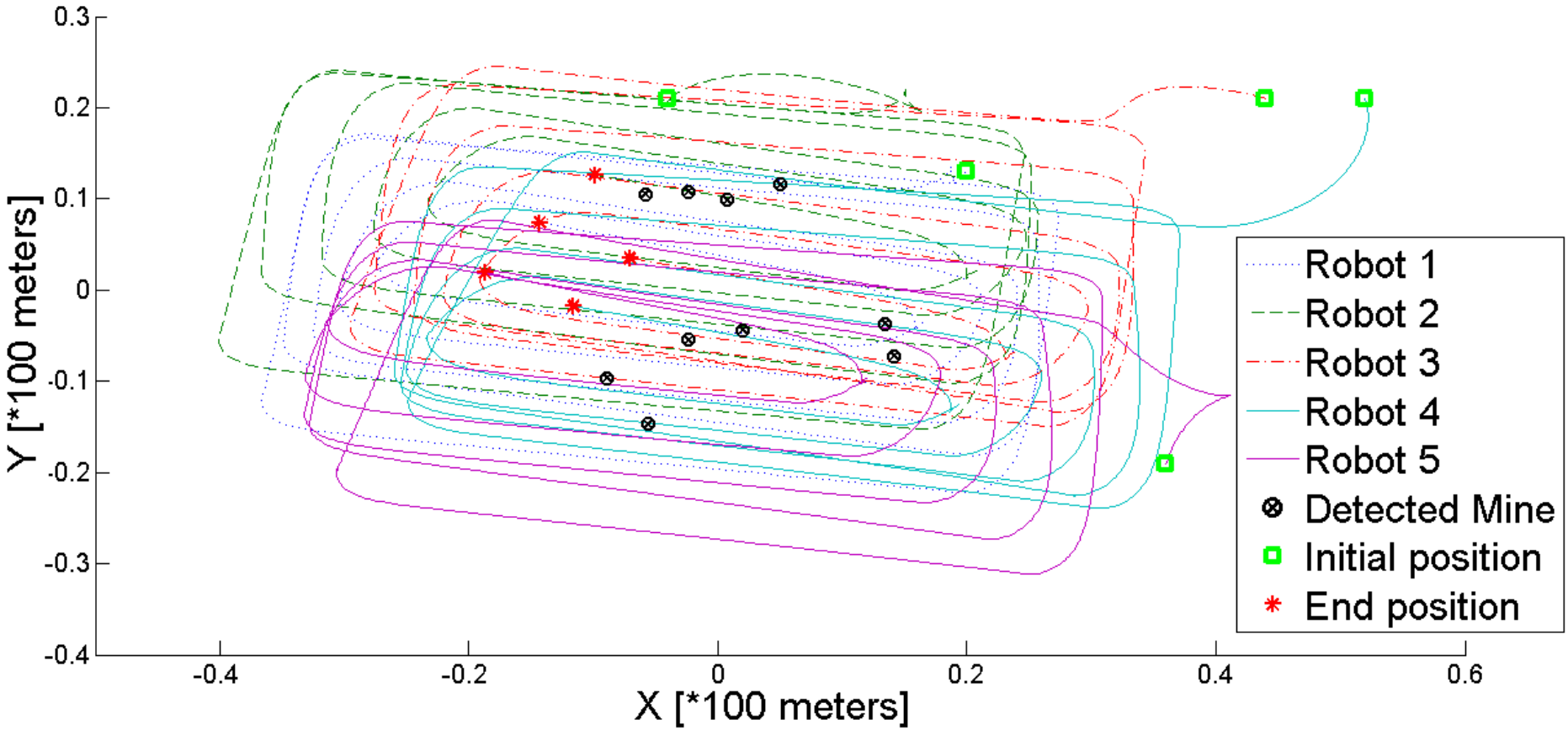
Experimental results

Trajectories of one robot on the minefield.



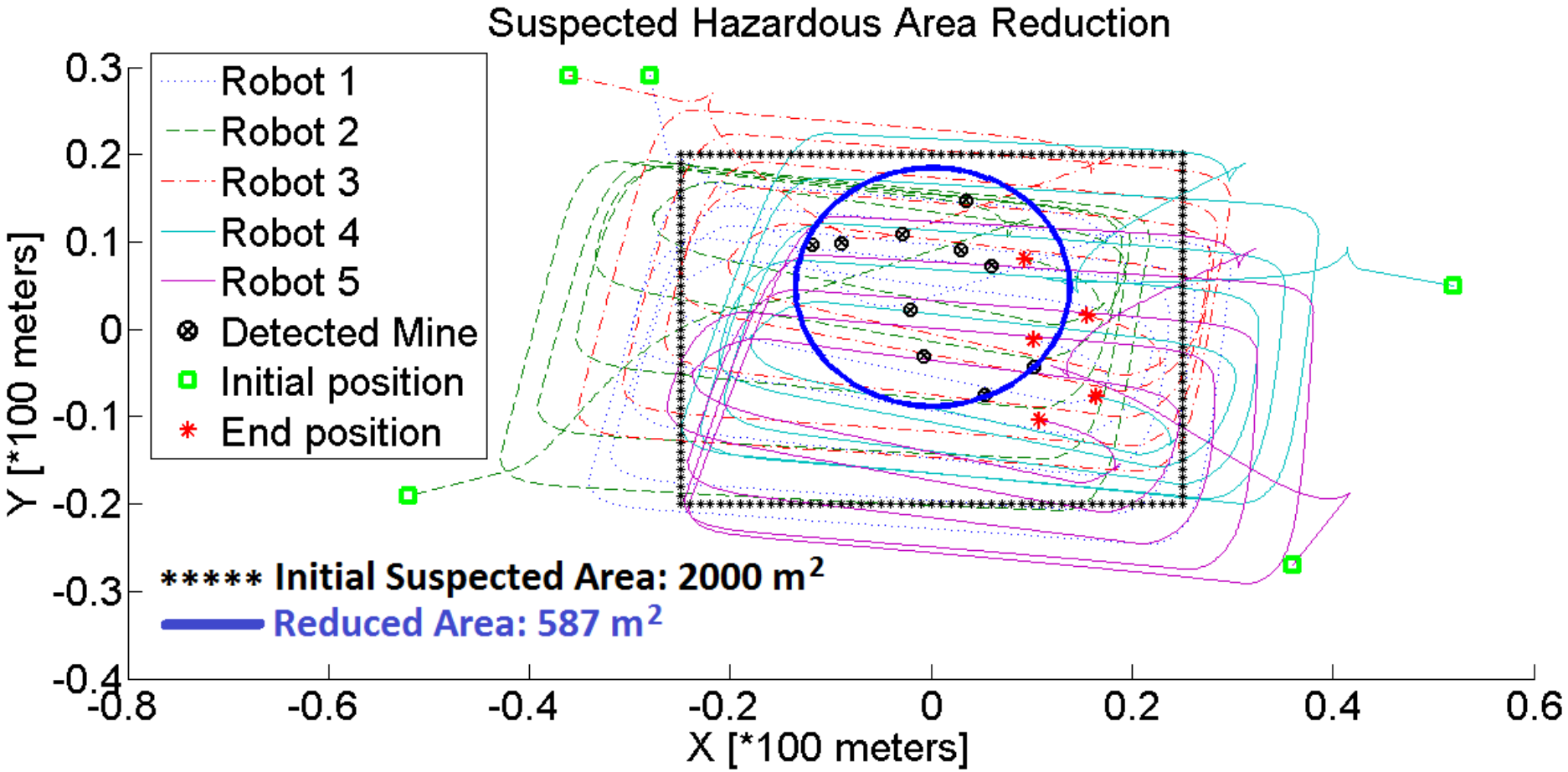
Experimental results

Trajectories of five robot on the minefield.



Experimental results

Area Reduction process with 5 robots executing PRCB.



Experimental results on the *Robotarium* platform

PRCB executed by five robots.

Conclutions

- A modular control scheme allows distributed computing of information in a robot network.
- Proposed scheme allows systematic generation of complex behaviours, such as PRCB.
- Modular structure allows to extend the functionalities.
- It is a contribution to achieve total automation in humanitarian demining tasks, that are dangerous to be realized by humans.

THANK YOU ... !!!

IEEE

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MULTI-ROBOT SYSTEMS

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