Cooperative Mobile Robot Control Architecture for Lifting and Transportation of any Shape Payload

Bassem HICHRI: PhD student
Lounis ADOUANE
Jean-Christophe FAUROUX
Youcef MEZOUAR
Institut Pascal/UBP/CNRS,
Clermont Ferrand France.
Ioan DOROFTEI
Gh. Asachi Technical University of Iasi, Romania

Projet co-financé par l'Union européenne

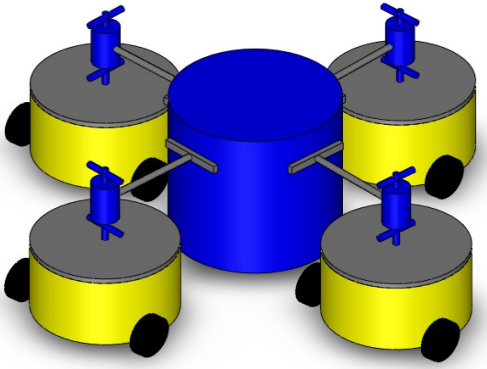
Obstacle crossing with heavy payload

Co-manipulation and transport with two operators

Bio-inspired co-manipulation

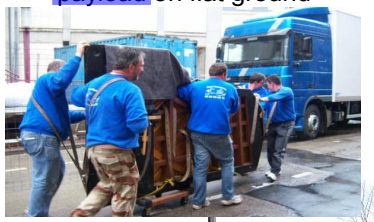
Object transport on smooth ground

Object transport with several operators

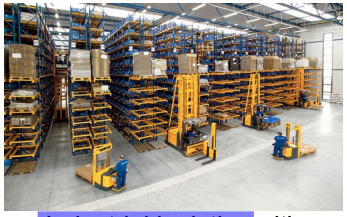


The **C³BOTS poly-robot**
Collaborative **C**ross and **C**arry mobile ro**BOTS**

Co-manipulation of a heavy payload on flat ground



Co-manipulation of a heavy payload with obstacle crossing



Industrial logistics with several carts on flat ground

Collaborative
Cross
Carry

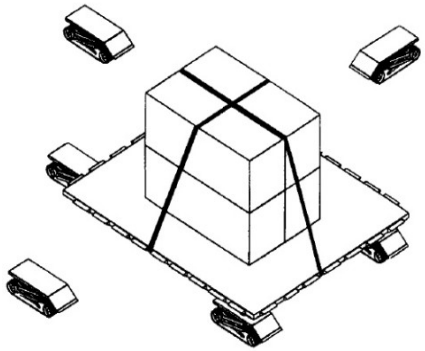
Co-transport of stretchers on irregular ground

Co-transport of a rigid long object on a flat ground

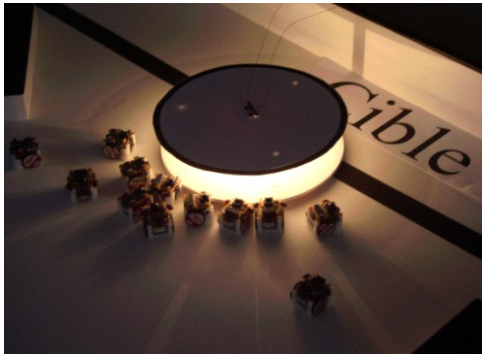
Co-manipulation of compliant bars on a flat but unstructured environment (building area)

Collaborative Robots that carry objects

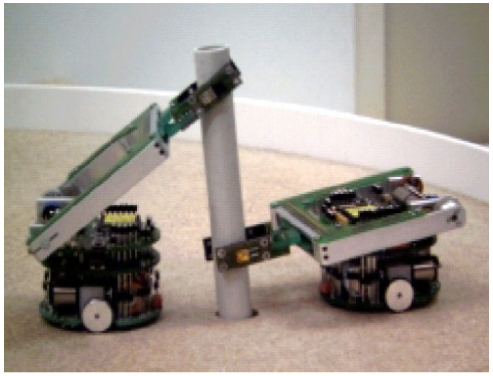
Stanford robotic platform [Khatib, 1999]:
Two holonomic mobile platforms equipped with PUMA robot arms



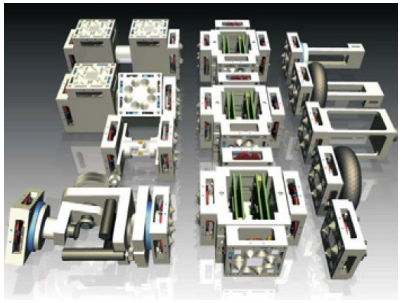
Army-Ant [Bay, 1995]:
Object lifting on robot bodies



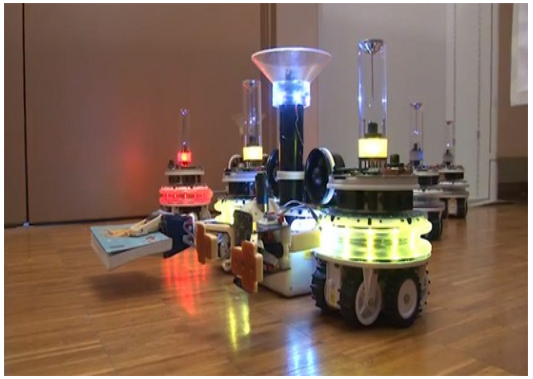
Alice [Adouane, 2004]:
Box pushing collaboration



Collaborative stick-pulling [Ijspeert, 2001]



Smart modules [Baca, 2012]:
Heterogeneous modular robotic design

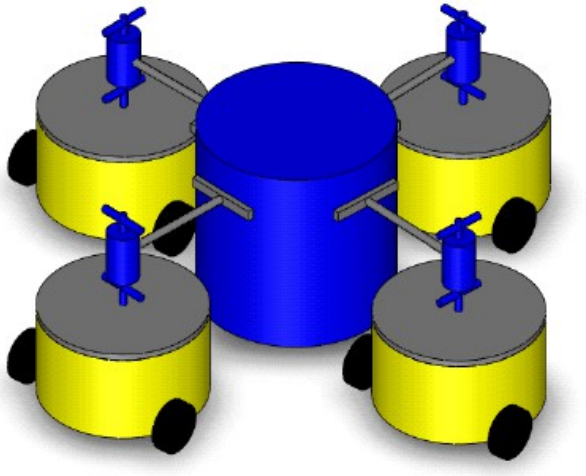


Swarmanoïd [Dorigo, 2012]:
Collaborative robots: fly-bot, hand-bot, foot-bot

Contribution

Existing robotic systems do not ensure **co-manipulation, transport** and **all-terrain capacities** at the same time.

- Make an innovative system with **simple architecture**
- Ensure the **manipulation, transport** and **(obstacles climbing)**



Introduction to the C³Bots project

General goal

C³Bots = Collaborative, Cross & Carry Mobile RoBots

- ✔ **Modularity**: Several **m-bots** that combine into a single **p-bot**
- ✔ **Reconfigurability**

- ✔ Unstructured environments
- ✔ **Obstacle** crossing
- ✔ **Stability**

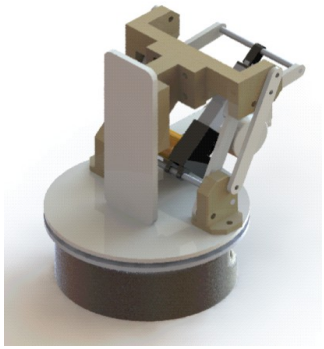
- ✔ Manipulation and **transport**
- ✔ Payloads of **any mass & shape**
- ✔ Removal man task

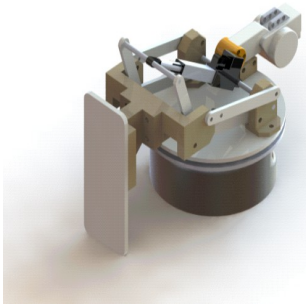
Scientific topics

- Design of a mechatronic system achieving the tasks with **minimal DoF (**→ simplicity)
- Static and dynamic models to maximize the poly-robot **margin of stability**
- **Perception** and **control** to guarantee efficient **connections** m-bot/m-bot and p-bot/payload
- Optimal **reconfiguration** of the m-bots for the task (number, poses, cooperation strategies)

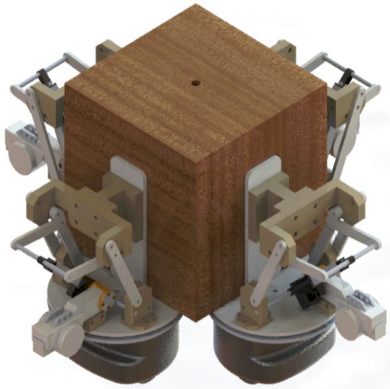
The mechatronic architecture was developed in previous works: [Hichri, 2014]

M-bot with lifting mechanism



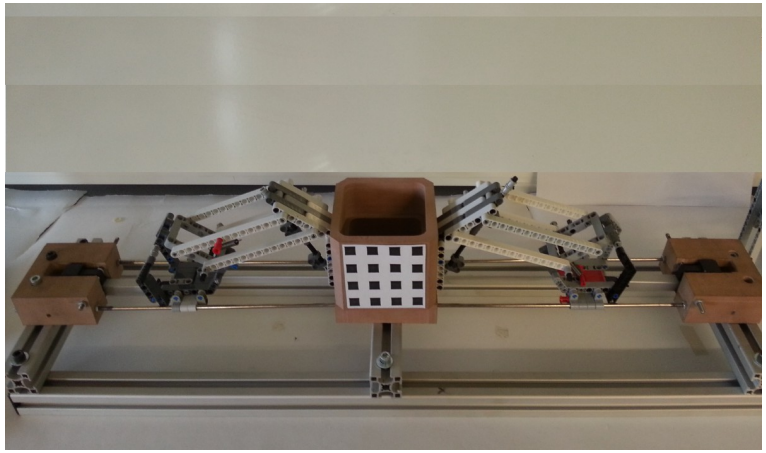


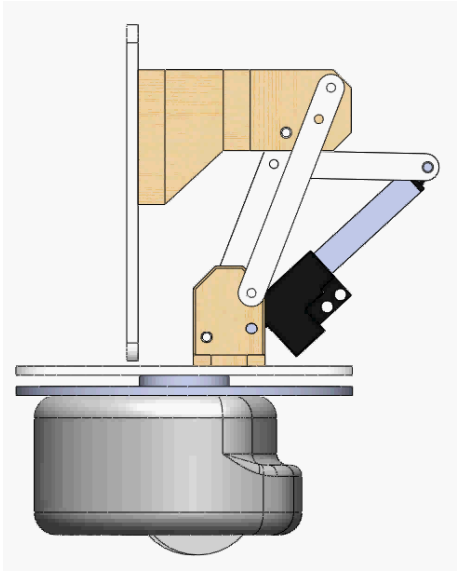
P-bot lifting a box



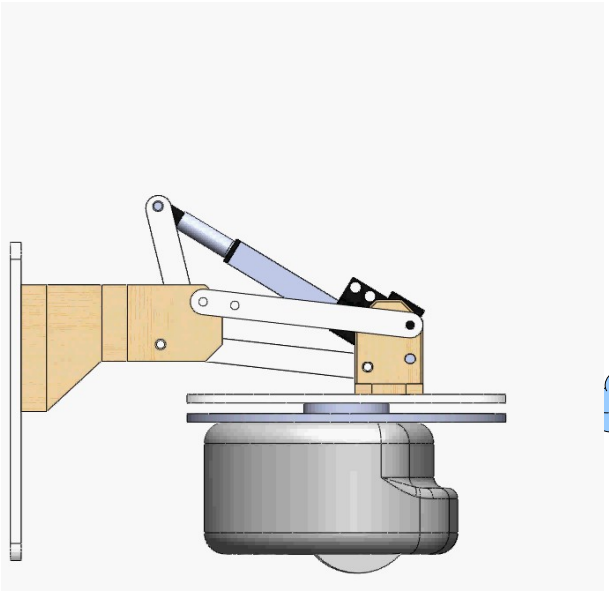
Prototypes based on Khepera robots

Lifting testbench

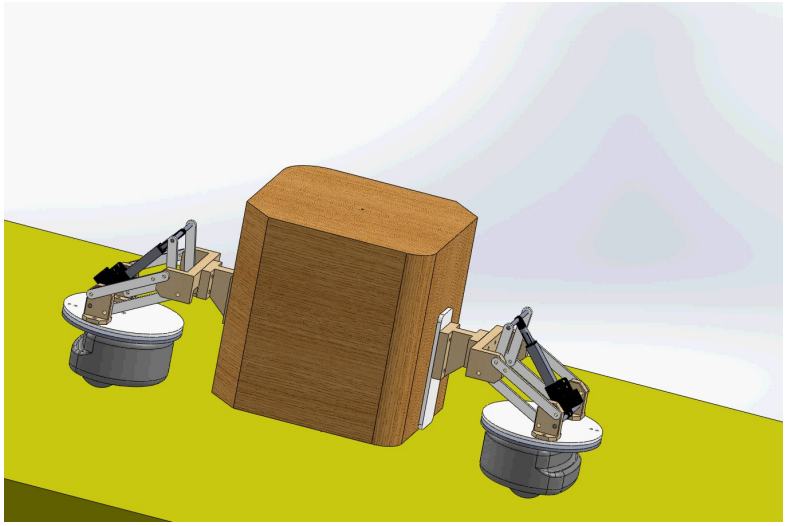




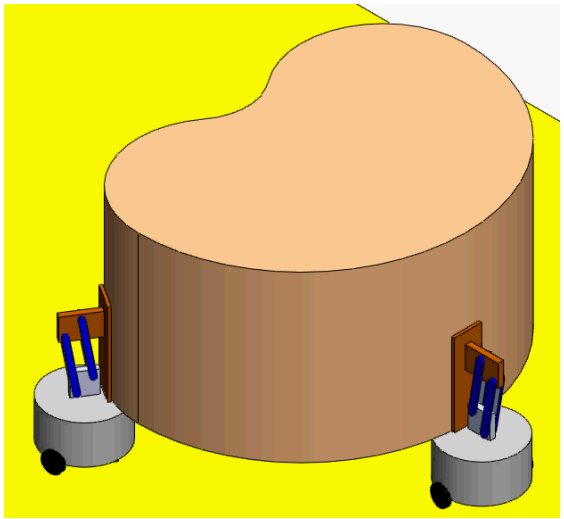
Mobile platform free steering motion



Lifting Mechanism



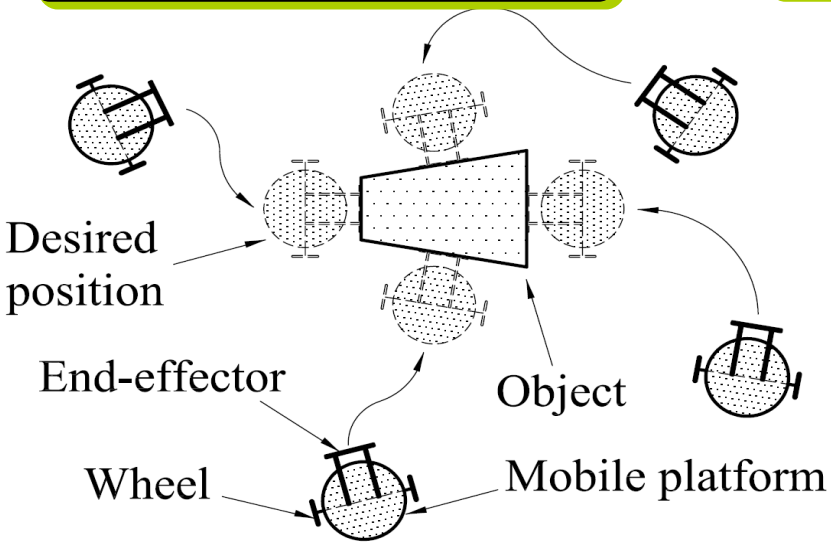
Cubic payload lifting



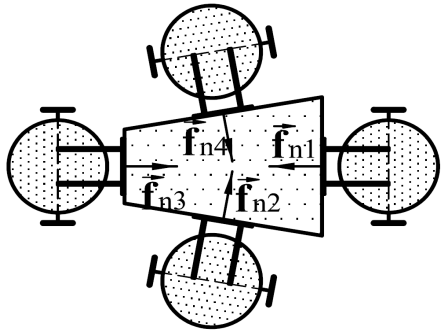
General payload lifting

Co-manipulation and transportation method

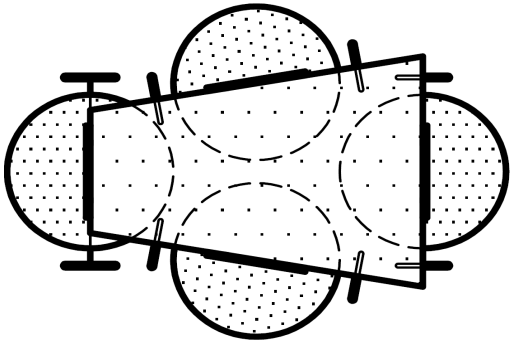
1- M-bot positioning



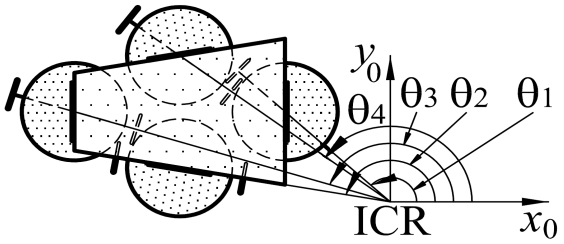
2- Payload tightening for lifting



3- Payload posing for transport



4- Collaborative transport



Input parameters

- The payload curve *(B)*
- The number of used m-bots
- The center of mass position G_{pl}

Objective

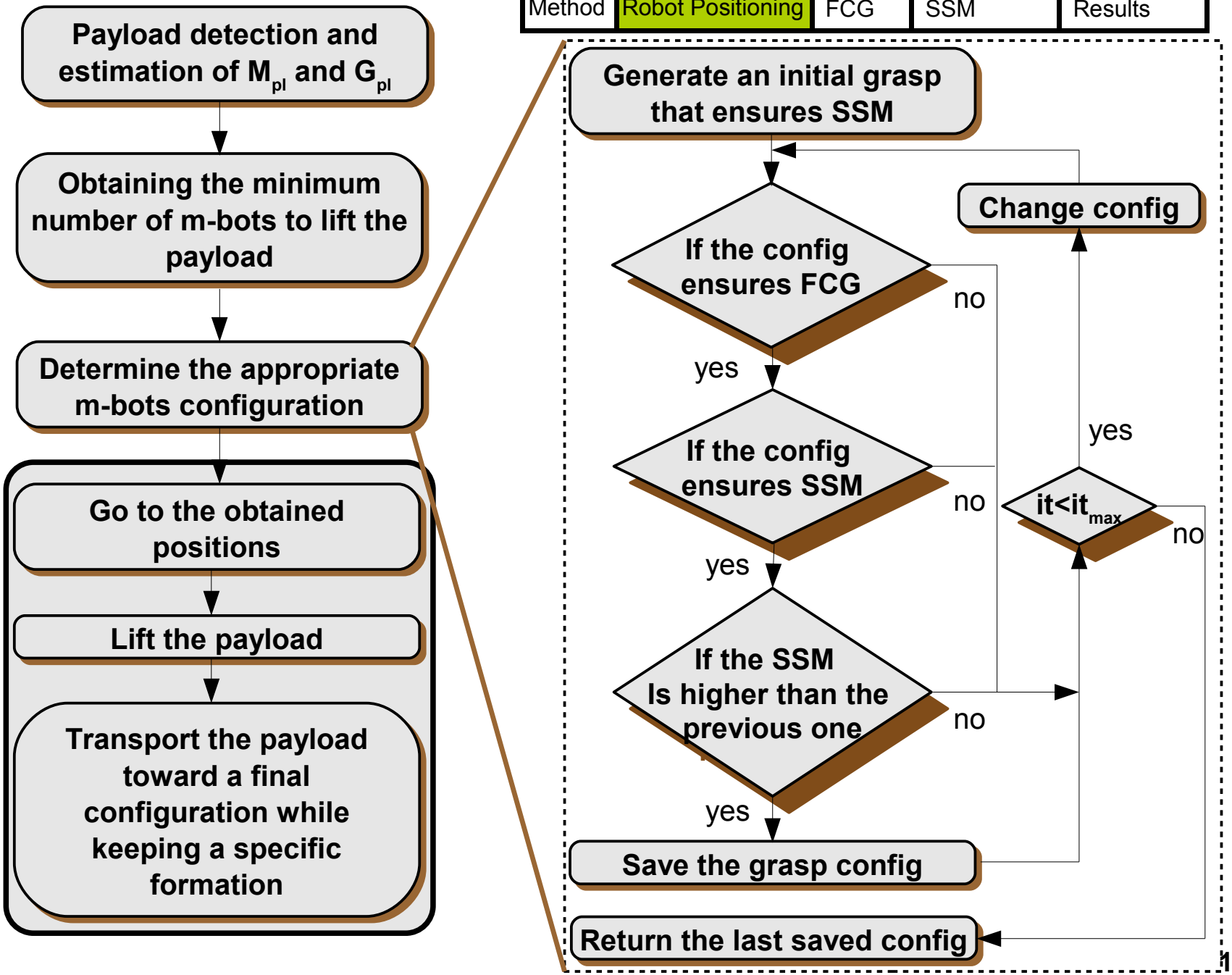
- Ensuring the payload prehension without slipping
- Ensuring stability of the whole system (m-bots+payload)

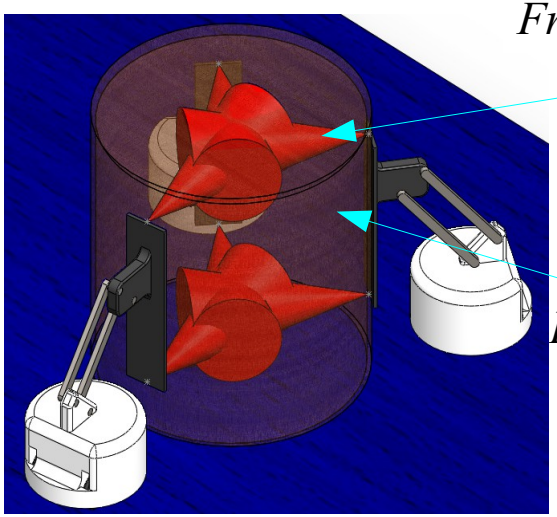
Force Closure Grasping FCG

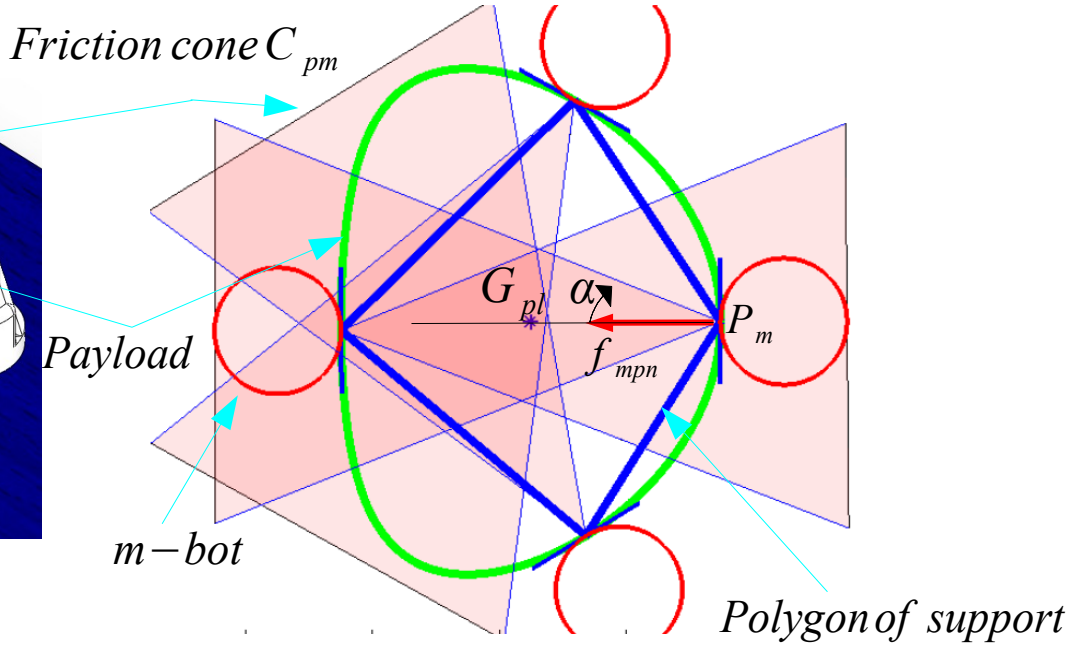
- Common concept for **manipulation**
- Used here for ensuring the **stable contact payload/end-effector**

Static Stability Margin SSM

- Common concept generally used for **stability** during **locomotion**
- Used here for ensuring a **stable contact wheel/ground**


Payload detection and estimation of M_{pl} and G_{pl}
Obtaining the minimum number of m-bots to lift the payload
Determine the appropriate m-bots configuration
Go to the obtained positions
Lift the payload
Transport the payload toward a final configuration while keeping a specific formation
Generate an initial grasp that ensures SSM
If the config ensures FCG
no
yes
Change config
If the config ensures SSM
no
yes
it<it$_{max}$
yes
no
If the SSM Is higher than the previous one
no
yes
Save the grasp config
Return the last saved config





$$\sum_{m=1}^{m_{min}} (P_m G_{pl} \otimes f_{m,p,n}) = 0$$

$$\sum_{m=1}^{m_{min}} f_{m,p,n} = 0$$

$$G_{pl} \in Convexhull(\cap C_{pm}) \mid m = 1..m_{min}$$

Assumptions

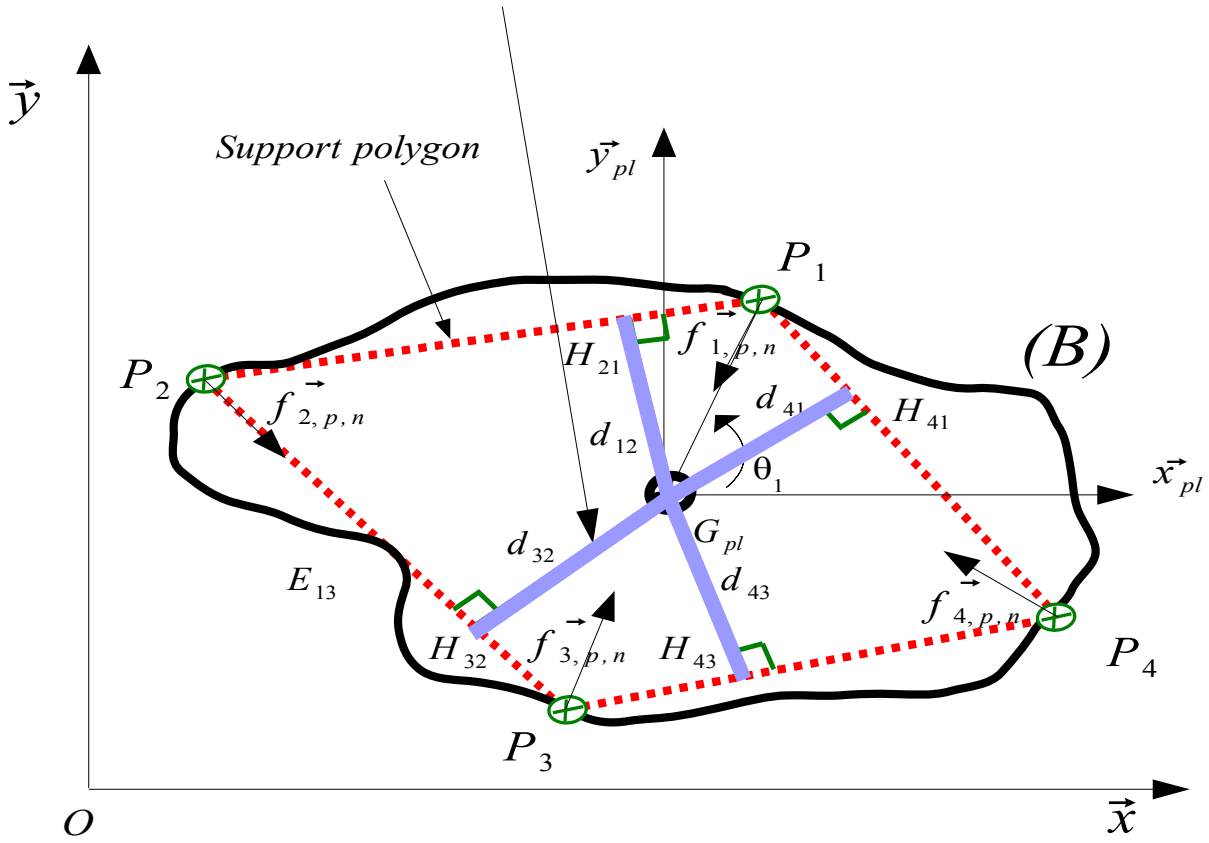
- A contact force lies inside the friction cone centred about the normal direction to the contact surface with half angle α.
- Tan(α) represents the friction coefficient.
- The friction cone of the mth contact is denoted Cpm.

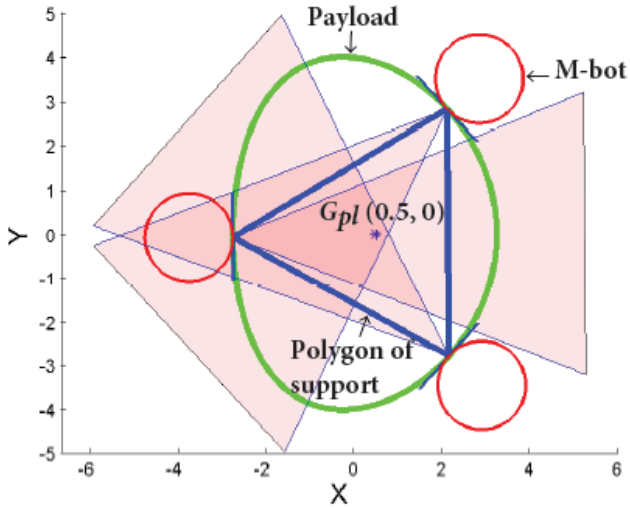
Goal: maximize the objective function f :

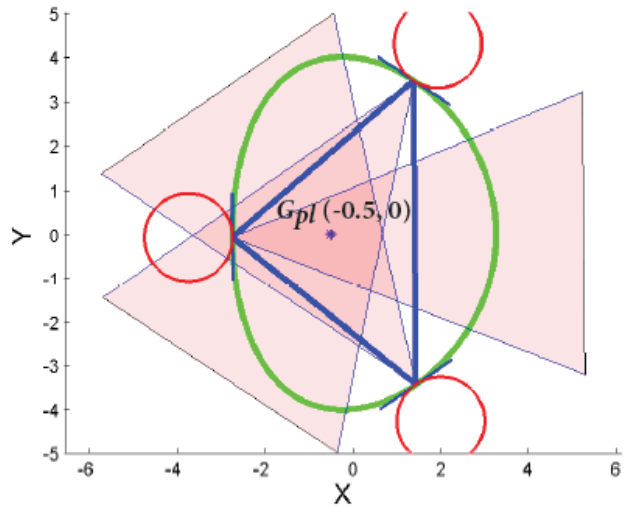
$$f(\theta_m, ..\theta_{m_{min}}) = \text{Min}(d_{m,m+1}) \mid m = 1..m_{min}$$

Stability margin

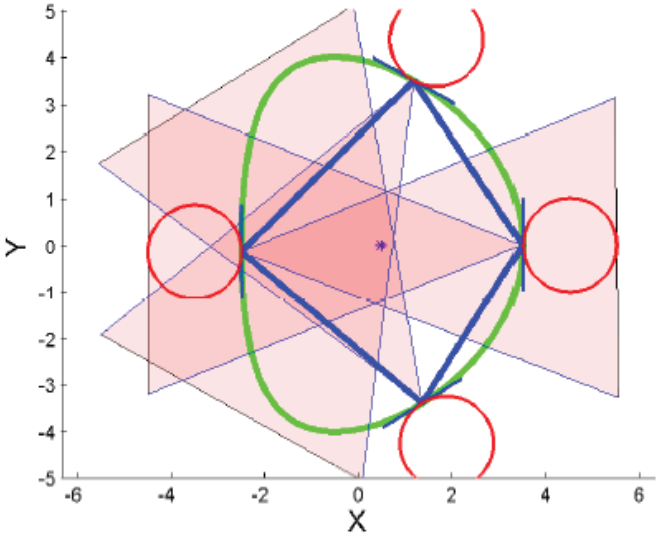
$$d_{m,m+1} = d(G, (P_m P_{m+1}))$$

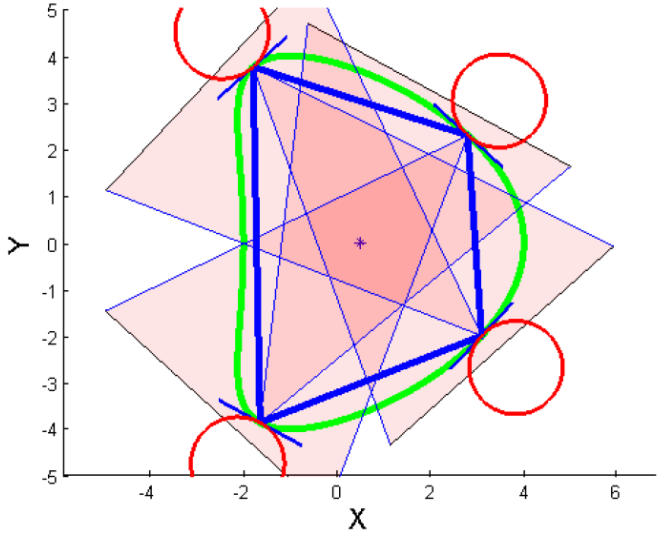






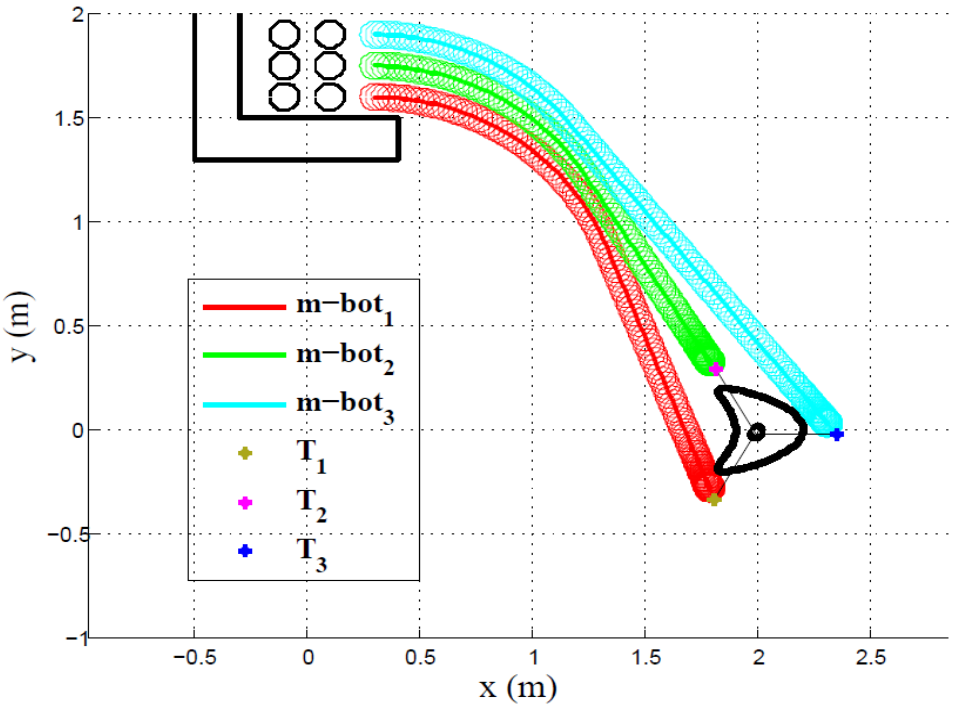
Positioning 3 m-bots according to differents positions of G_{pl}



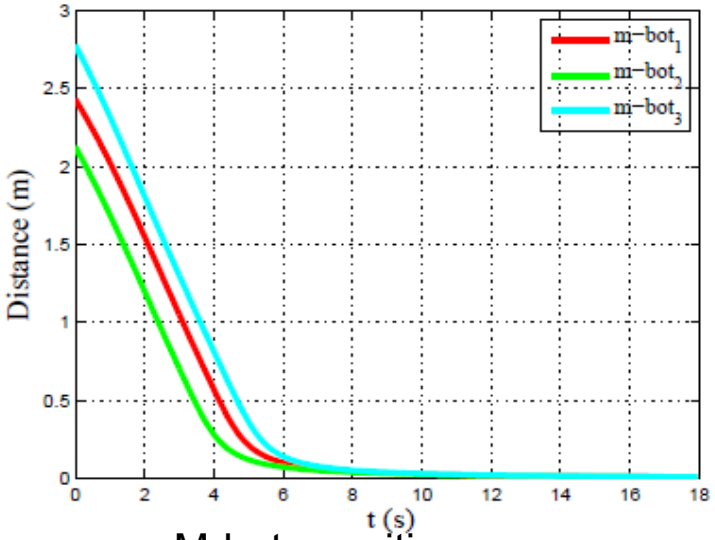


Positioning 4 m-bots according to object shape

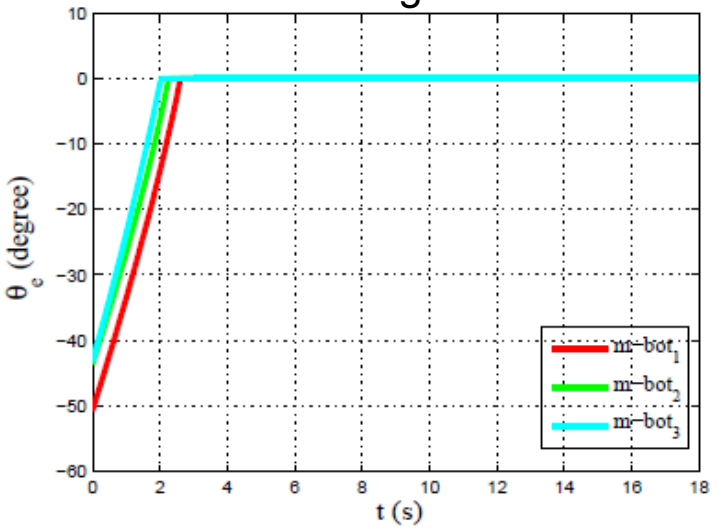
[8]



Target Reaching (TR) of the 3 m-bots from initial position to optimal position around the payload

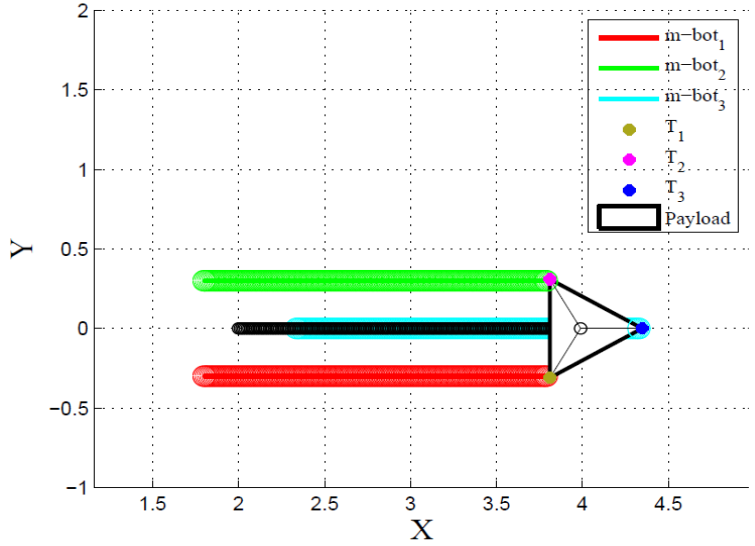


M-bots position errors during TR

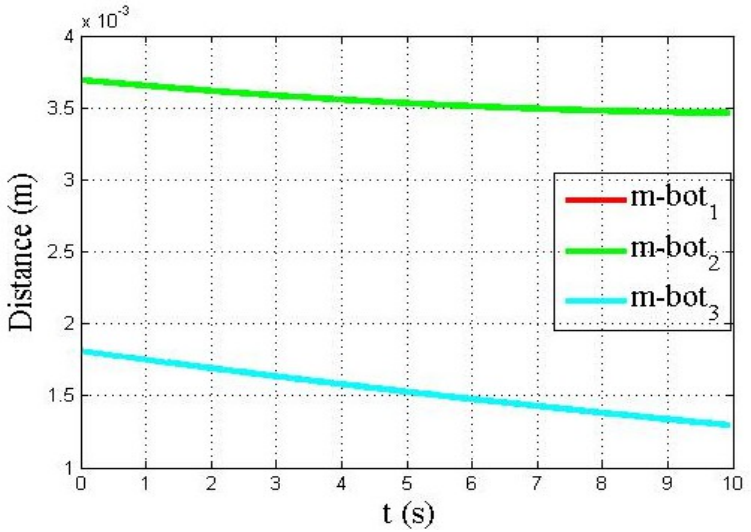


M-bots orientation errors During TR

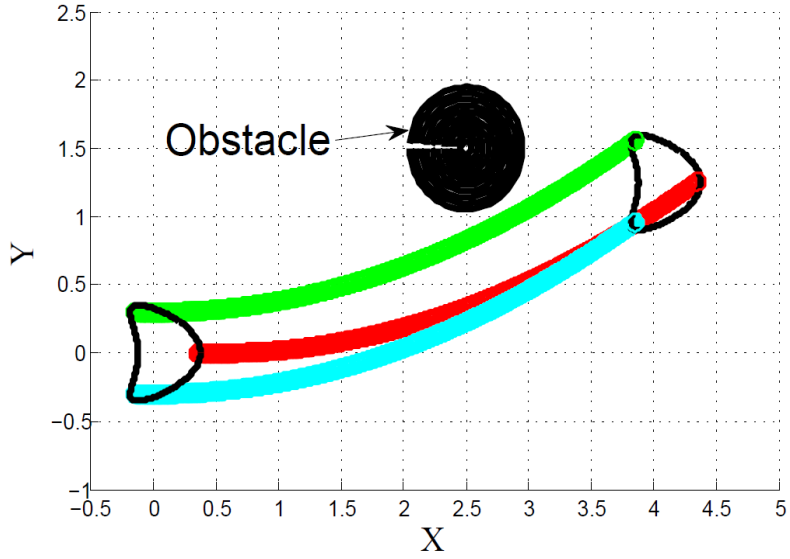
[8]

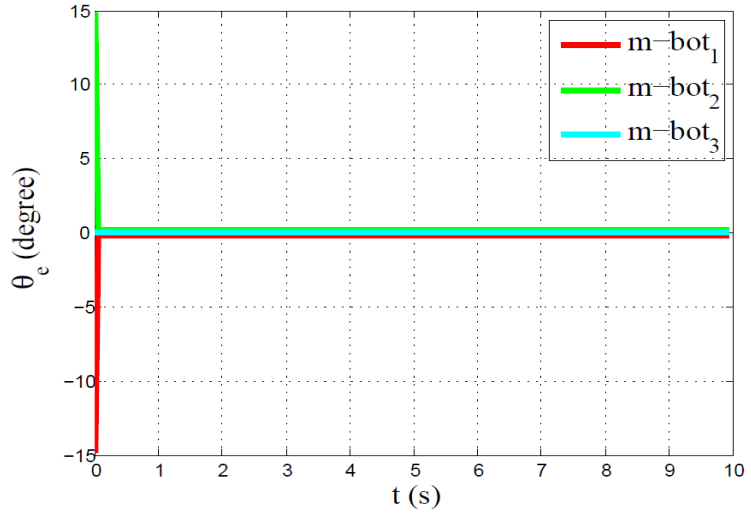


P-bot navigation as a rigid Virtual Structure (VS)

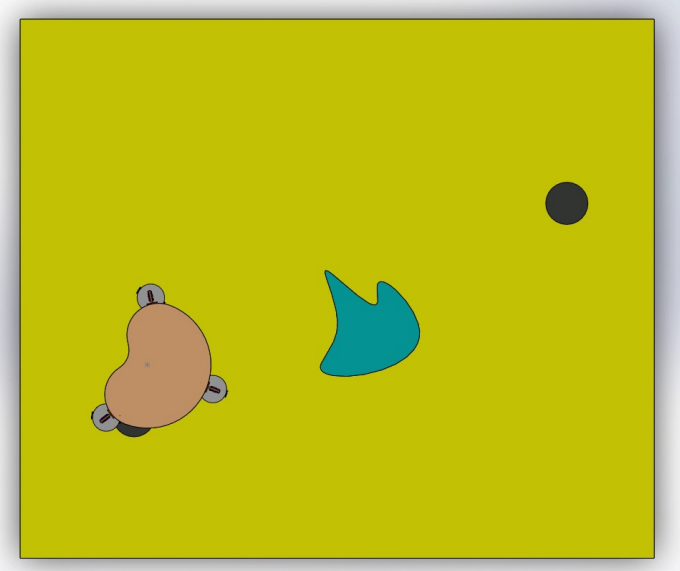


M-bots position errors during VS navigation

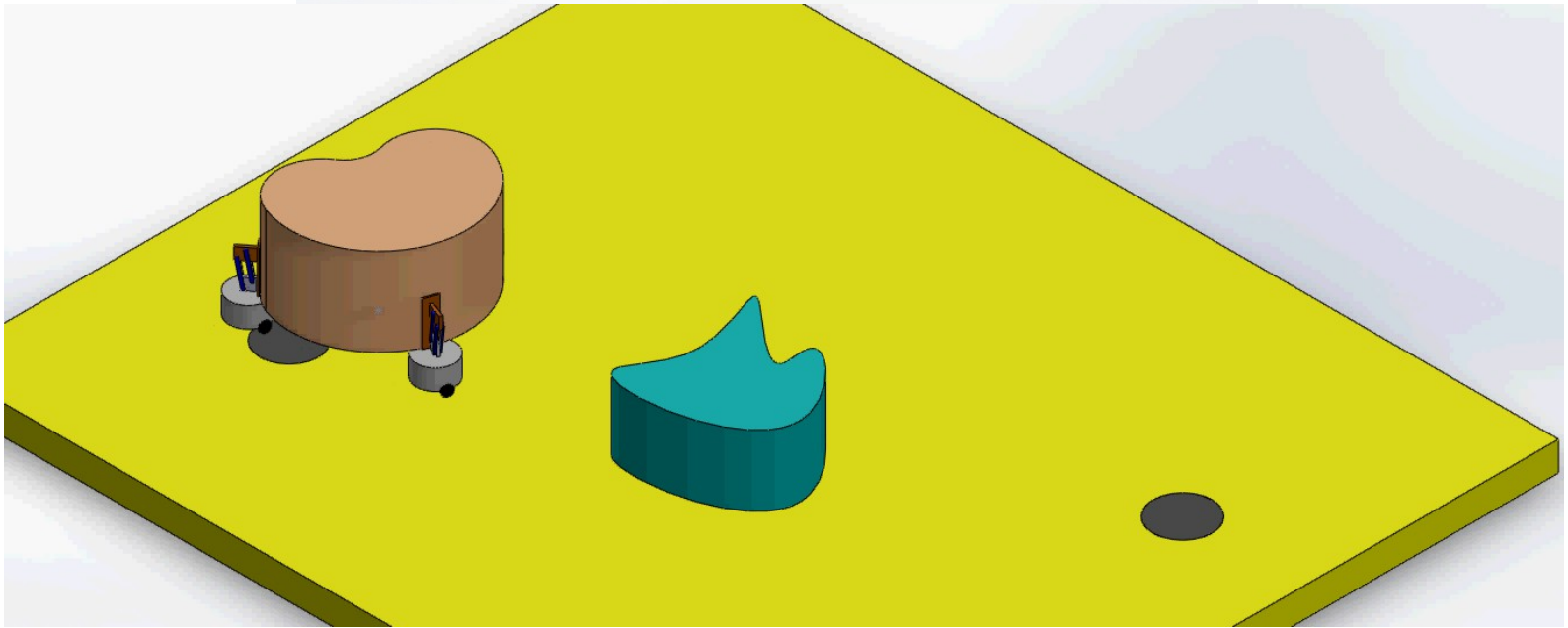




M-bots orientation errors during VS navigation



video



Conclusion

- Topic: **transporting** any shape payloads in structured environments with collaborative mono-robots
- An algorithm for m-bot **positioning** respecting both **FCG** and **SSM**
- **Multibody dynamics** modelling for the overall system **stability** evaluation
- Experiments with testbench to validate **lifting**

Future work

- Develop an all-terrain platform for obstacle-crossing & exploration of unstructured environments
- Experimental validation of p-bot stability

Thank you for your attention