

**Workshop "ECHORD - scientific results and tech transfer opportunities"
Vilamoura, October 11, 2012**

HUROBIN experiment (Call II)

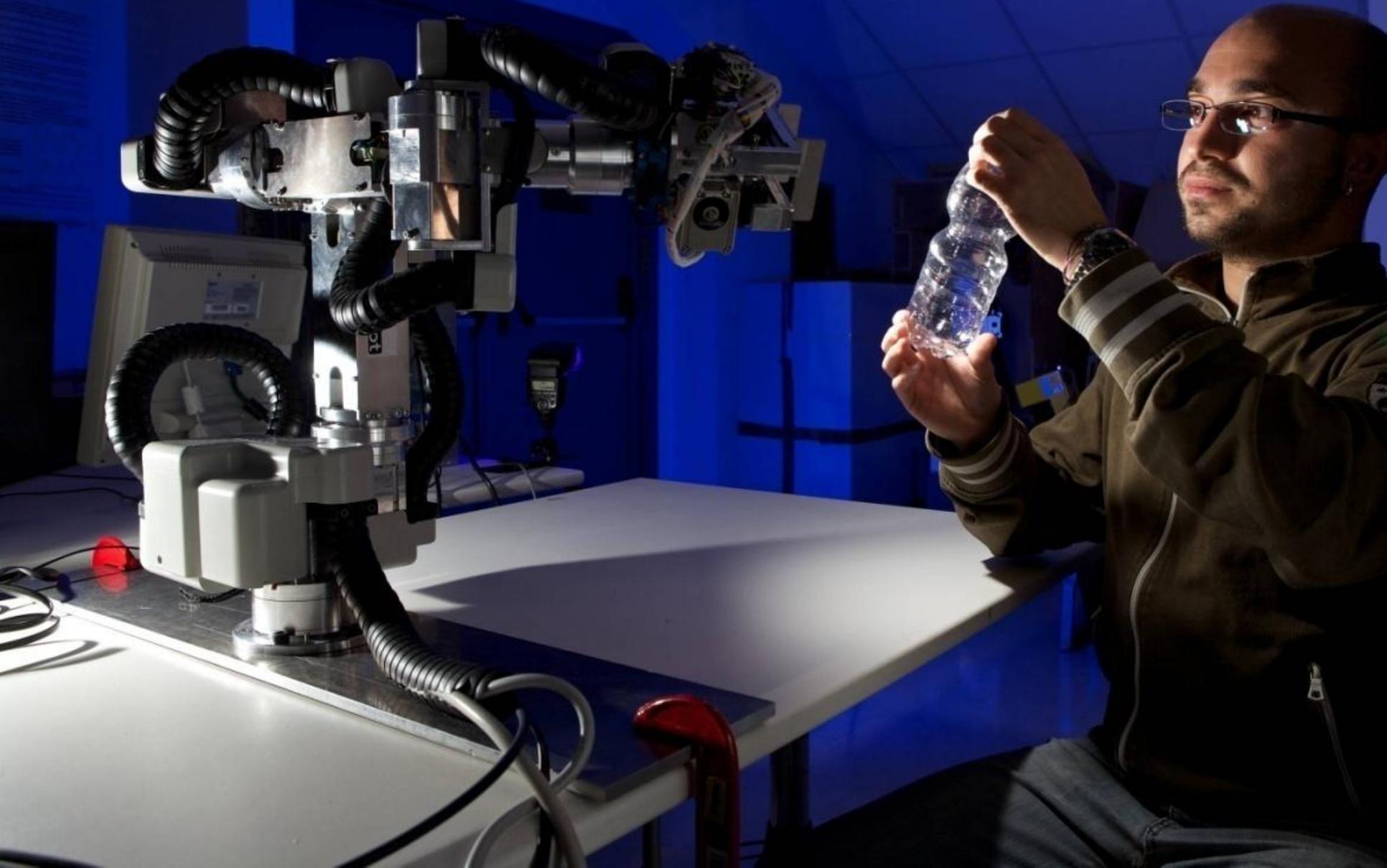
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The BioRobotics Institute – Scuola Superiore Sant'Anna

IEEE/RAS co-Chair of Technical Committee on Rehabilitation & Assisitive Robotics

HUROBIN experiment (Amendment 2)

Human-Robot Object Interaction

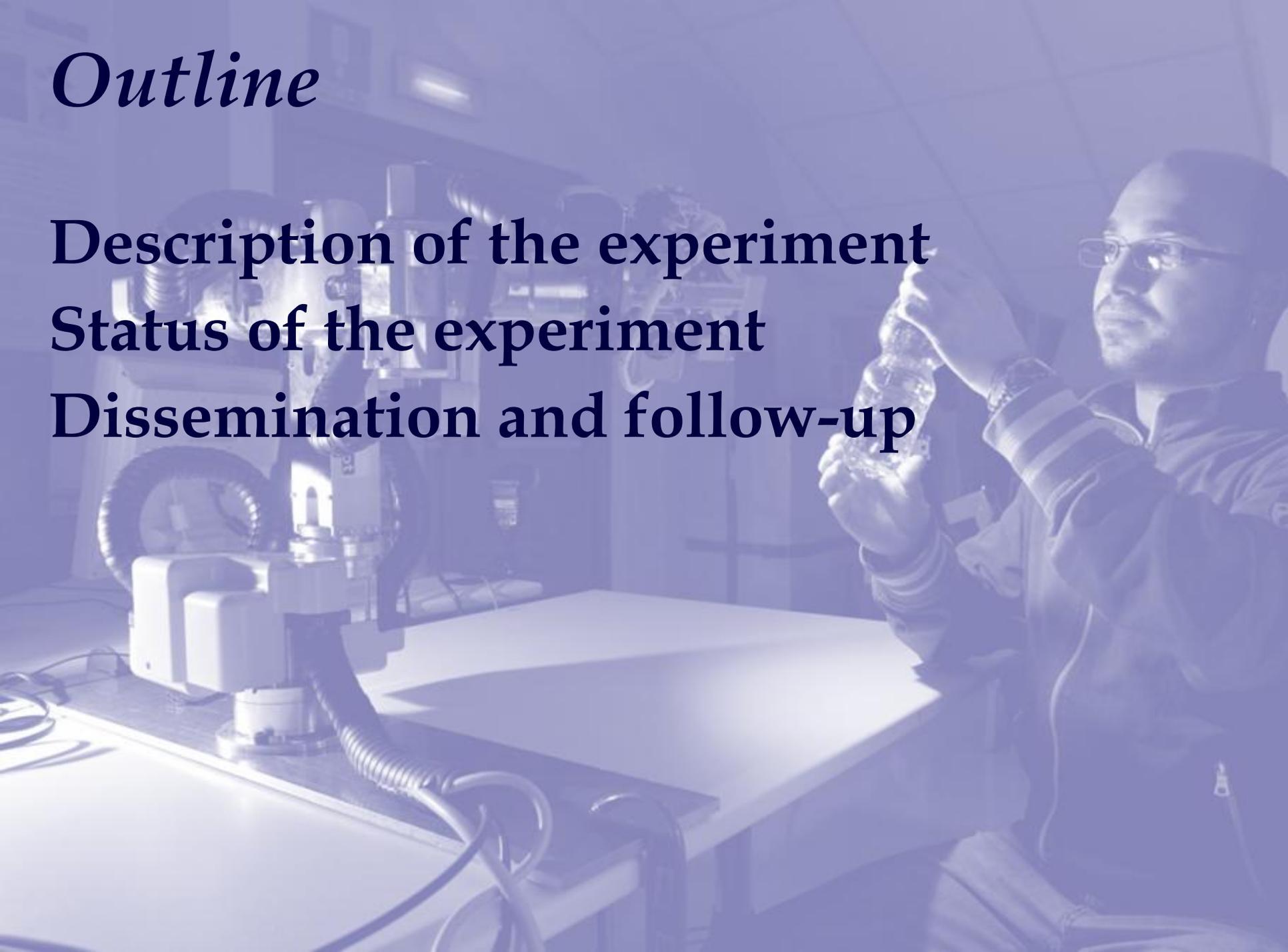


Outline

Description of the experiment

Status of the experiment

Dissemination and follow-up



Outline

Description of the experiment

Status of the experiment

Dissemination and follow-up



Objectives:

- Safe human-robot cooperative manipulation tasks
- Human operator interacts with the robot for manipulating shared objects
- The robot adapts its configuration and dynamics to the conditions imposed by the human operator
- 7 DoFs manipulator and a gripper used in combination with a dataglove (as HMI) and a motion tracker
- Objects characterized by different shared, length and weight
 - n. 2 cylinders (*cyl_1*, *cyl_2*), external diameter 60 [mm] and bore 56 [mm]; *cyl_1*: 1000 [mm] length and 1.092 [Kg], *cyl_2* : 500 [mm] length and 0.544 [Kg];
 - n. 2 bars (*bar_1*, *bar_2*) square section, external side 50 [mm], internal side 40 [mm]; *bar_1*: 1000 [mm] length and 2.439 [Kg]; *bar_2*: 500 [mm] length and 1.219 [Kg];
 - n. 2 plates (*plt_1*, *plt_2*): 1000 [mm] and 500 [mm] length, 70 [mm] width and 10[mm] thickness; *plt_1* :1.897 [Kg]; *plt_2*: 0.949 [Kg].

Assumptions

- Sensor failures and adverse conditions considered to test the safety of the human-robot cooperative tasks
- Motion tracker used by the human agent to track the trajectory of the shared object during simulation of position sensor failures
- The robot is expected to adapt the trajectory using the load cell
- Tracker connected to the object to check kinematical data: to provide redundancy (safe conditions to the human operator)
- Dataglove used as command interface for the robot gripper and as emergency button

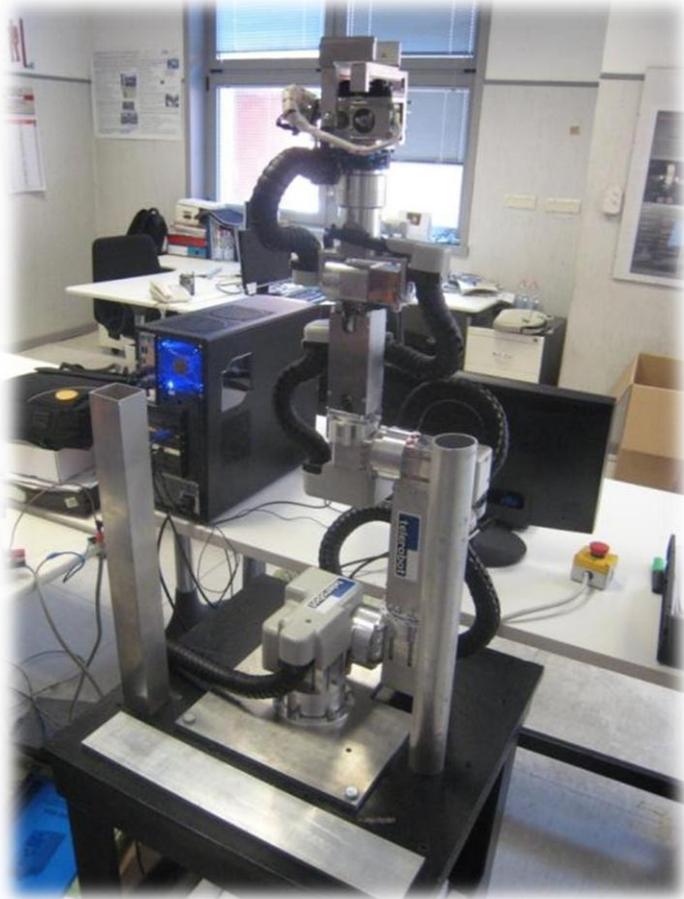
Participants

- The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa – Italy (*SSSA*): experiment's coordinator
- Humanware Srl, Pisa –Italy (*HMW*): experiment's partner, spin-off company specialized in the design and development of advanced hardware and software for HMIs



- Team
 - Stefano Mazzoleni, PhD, Control engineer (*SSSA*)
 - Nicola Di Lecce, Control engineer (*SSSA*)
 - Andrea Scoglio, CEO, Electronic engineer (*HMW*)
 - Giovanni Cappiello, PhD, Mechanical engineer (*HMW*)
 - Zoran Curto, Electrical engineer (*HMW*)

Experiment setup



7 DoFs robotic arm
(TLR LightArm, TeleRobot, Italy)



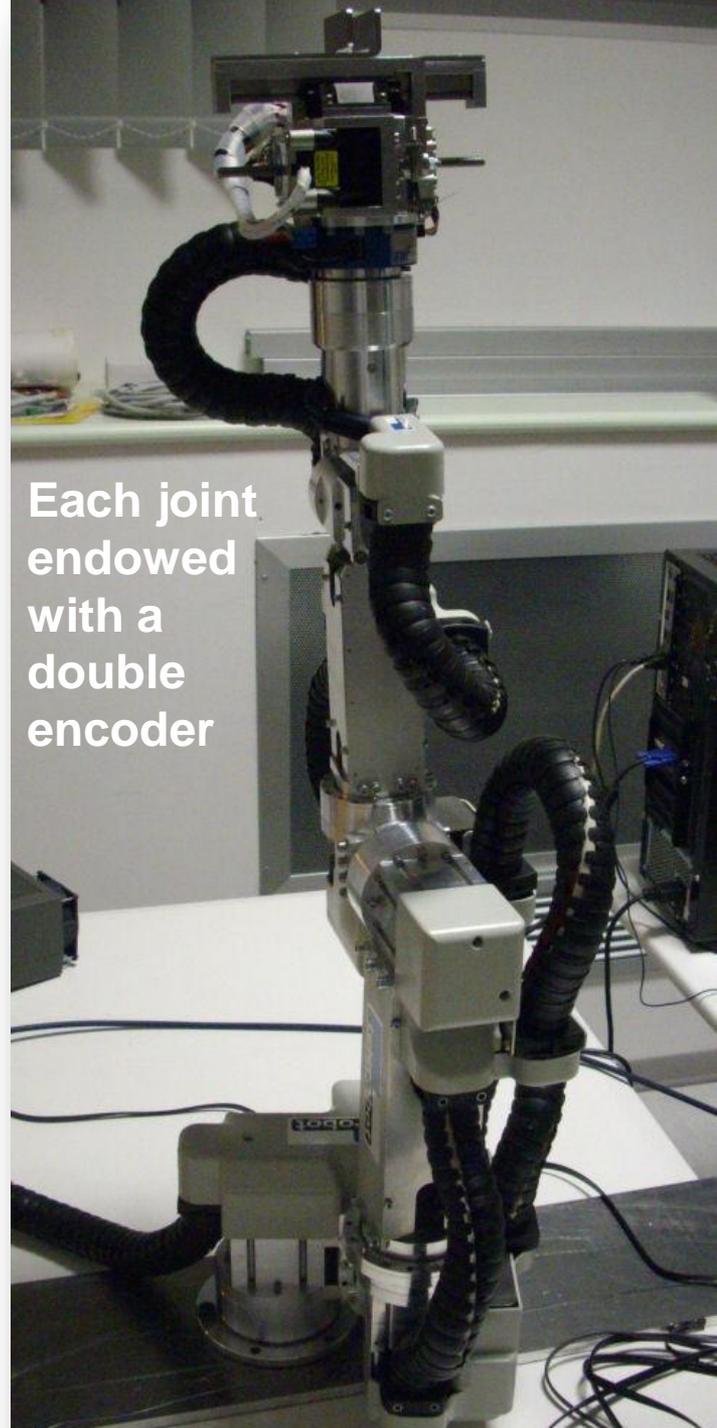
Motion tracker
(Humanware, Italy)



Dataglove
(Humanware, Italy)

Robotic arm

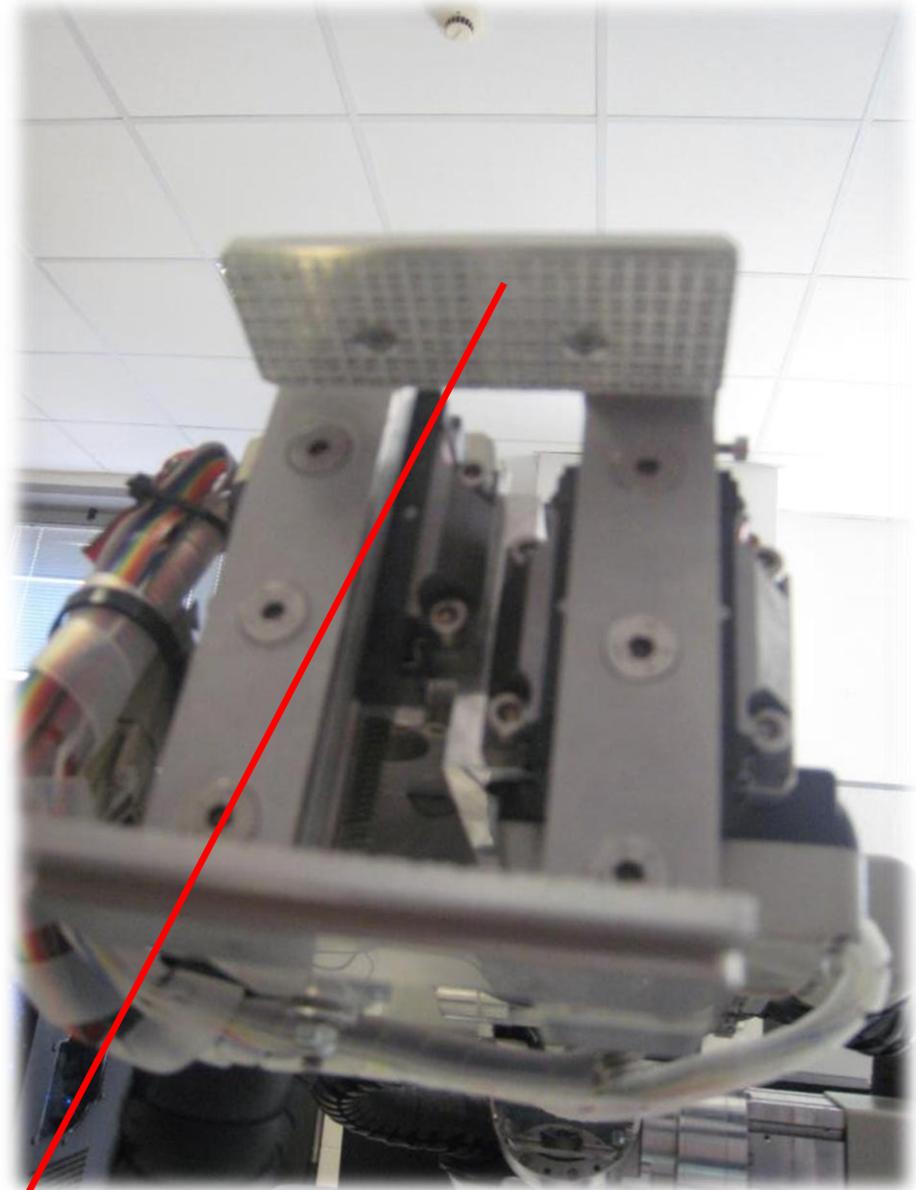
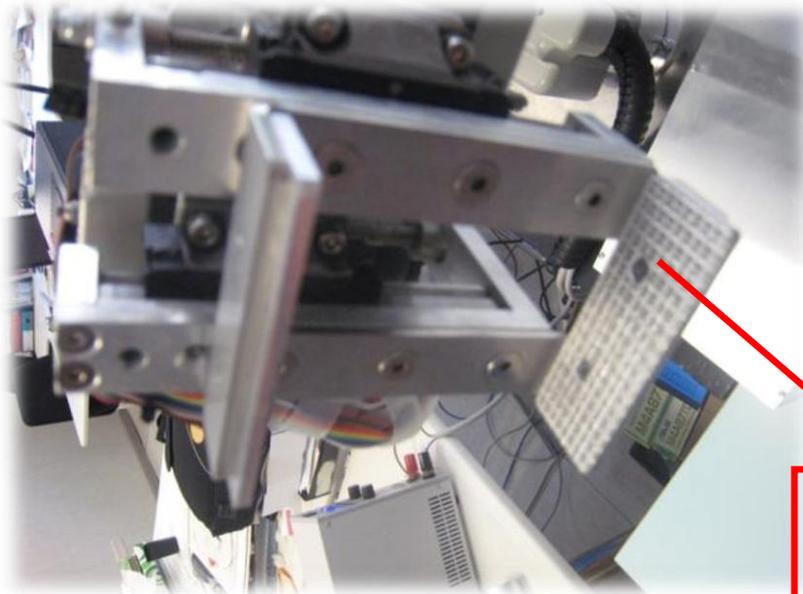
- Harmonic drive gearboxes with frameless brushless motors;
- 7 controlled axis;
- Nominal arm max length: 850 mm;
- 12 bit absolute encoder on all axis;
- Repeatability +/- 0.5 mm;
- Rough weight: 15 Kg;
- Maximum speed: 90 deg/s for each joint with 48 VDC supply;
- Max Payload: 7.5 Kg;
- DSP and motor amplifier on board at each modular joint and CANopen connection;
- Position, speed and torque direct joint control available;
- Modular design
- 6 DoF load cell on the wrist joint;
- 24/48 VDC power supply



Each joint
endowed
with a
double
encoder

Gripper

- Max Payload: 5 kg;
- Maximum opening: 80 mm;
- Max applied force: 30 N;
- Actuation: 2 stepper motors (MH2-1713);
- Transmission: worm system



**Manufactured at SSSA
precision machine shop**

Motion tracker

Its end-effector can be placed on the handled object in order to track the trajectory of this rigid body during co-manipulation task



- 6 DoFs
- Angular sensor on each joint.
- Resolution: 0.2 mm
- Linearity: $\pm 1\%$
- Working Space: Spherical, $\varnothing 1700$ mm
- Data rate: 1.5Mbit/sec
- Power supply: USB port
- Dimensions: 160x195x580mm
- Weight: 1.5 Kg

Dataglove

Its end-effector is placed on the handled object in order to track the trajectory of this rigid body during co-manipulation task

- 6 DoFs
- Angular sensor on each joint.
- Resolution: 0.2 mm
- Linearity: $\pm 1\%$
- Working Space: Spherical, $\varnothing 1700$ mm
- Data rate: 1.5Mbit/sec
- Power supply: USB port
- Dimensions: 160x195x580mm
- Weight: 1.5 Kg



**Hall effect
sensors**

**Bluetooth
device**

Objects (1/2)

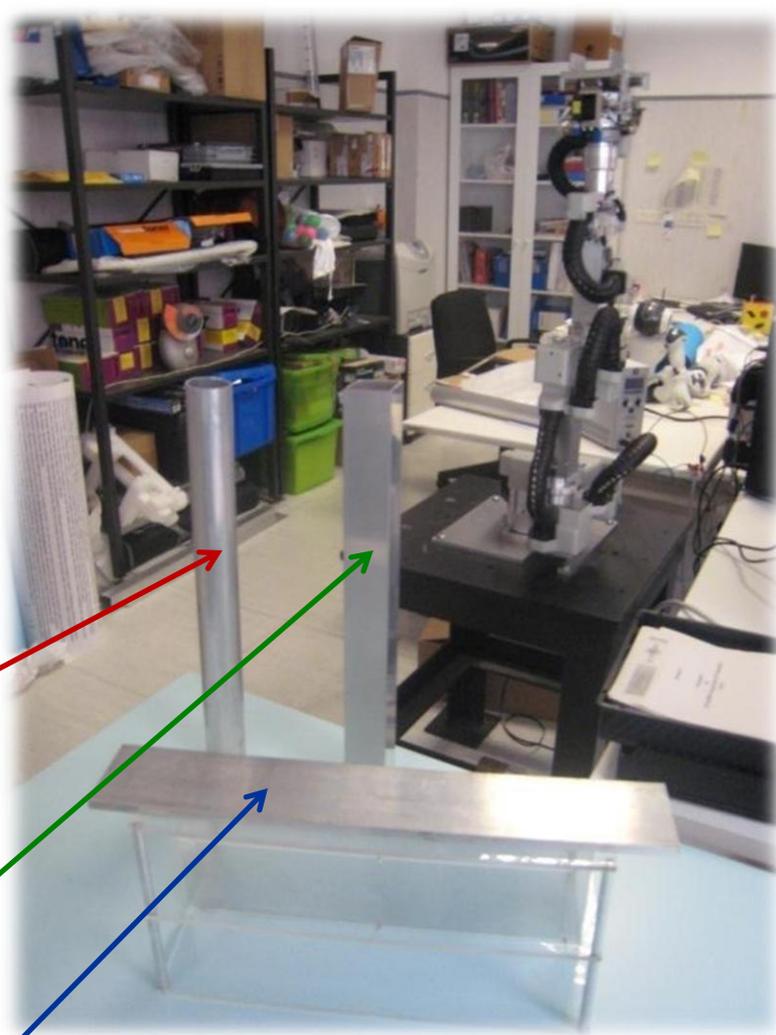
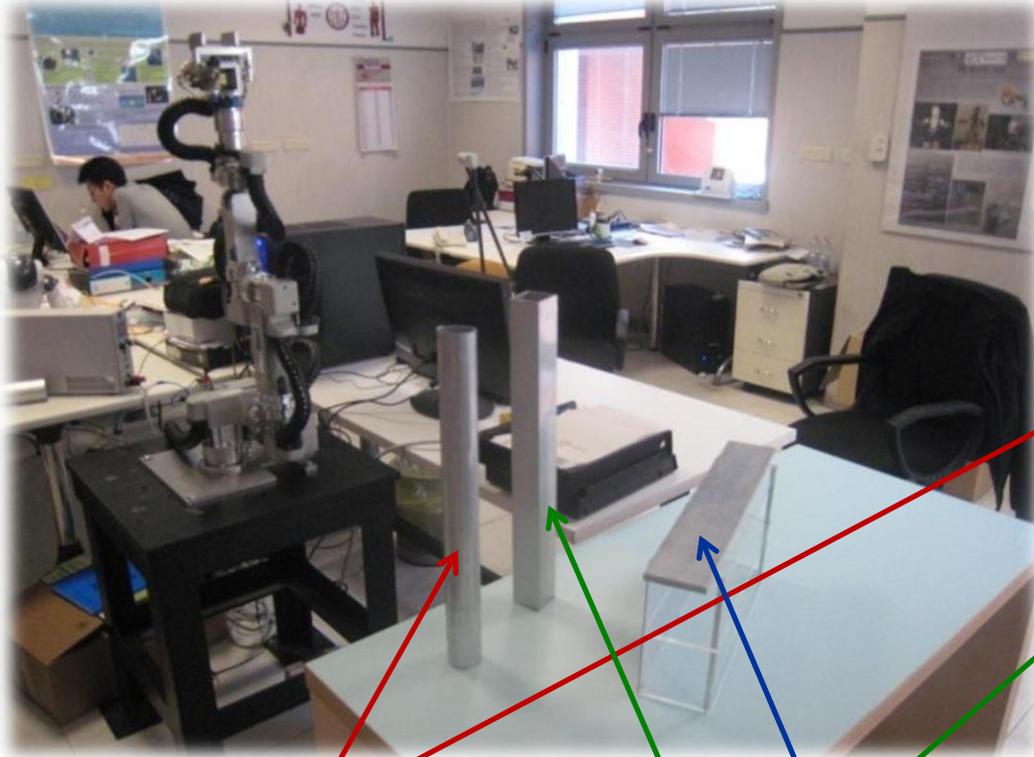


Cyl_1

Bar_1

Plate_1

Objects (2/2)

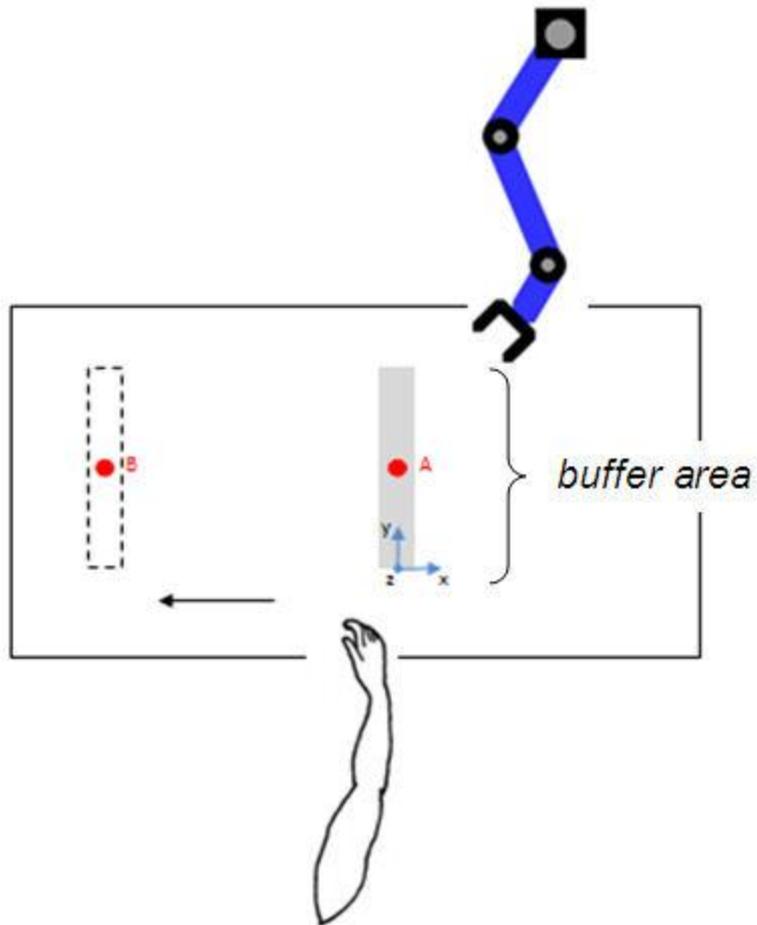


Cyl_2

Bar_2

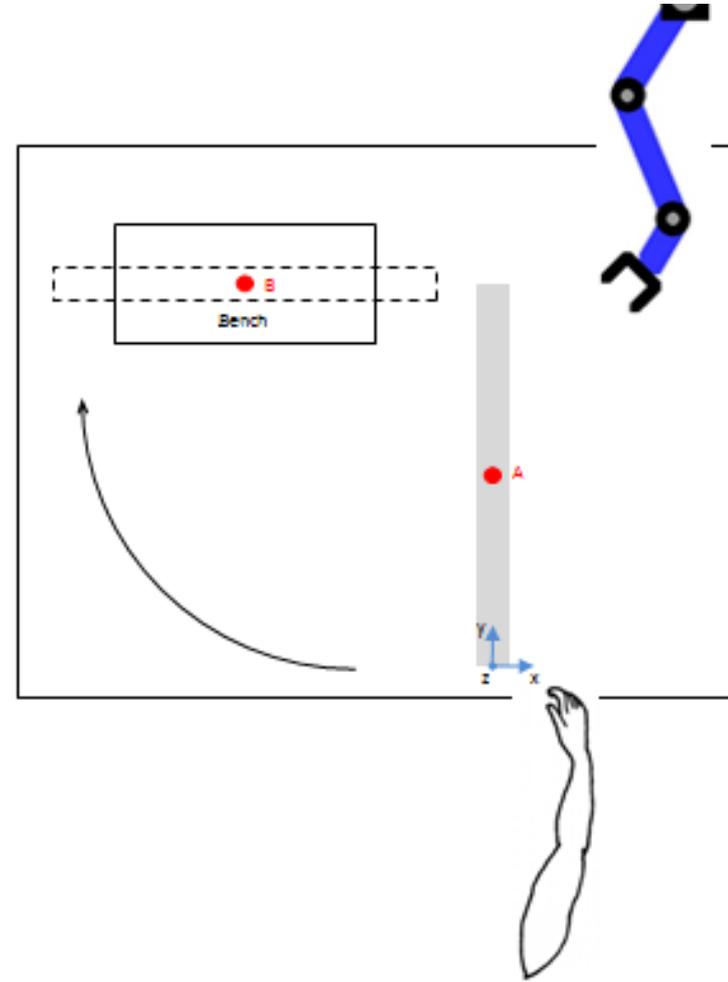
Plate_2

Scenario #1



cylinder 500 [mm] length

Scenario #2



cylinder 1000 [mm] length

Scenario #3

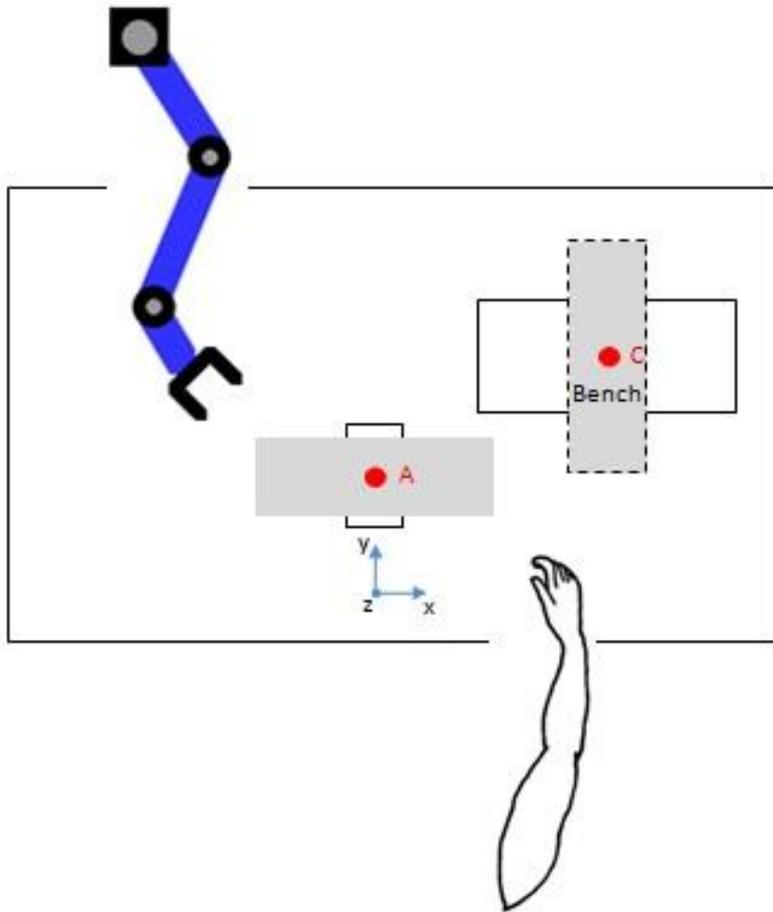


plate 500 [mm] length

Scenario #4

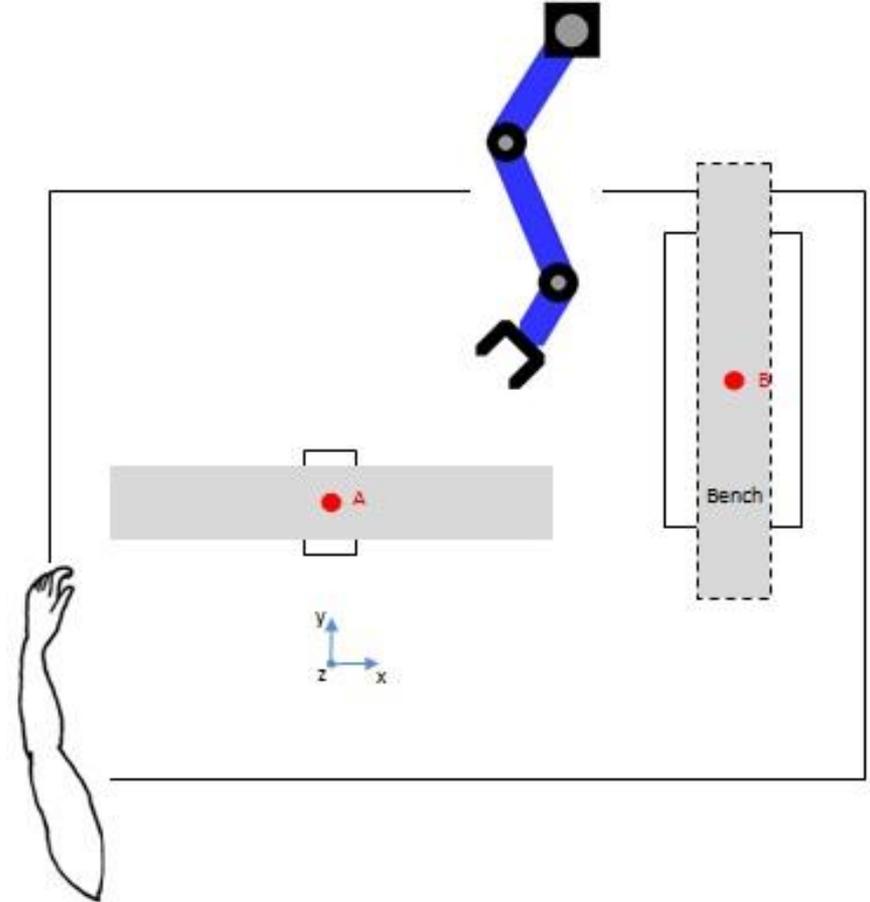
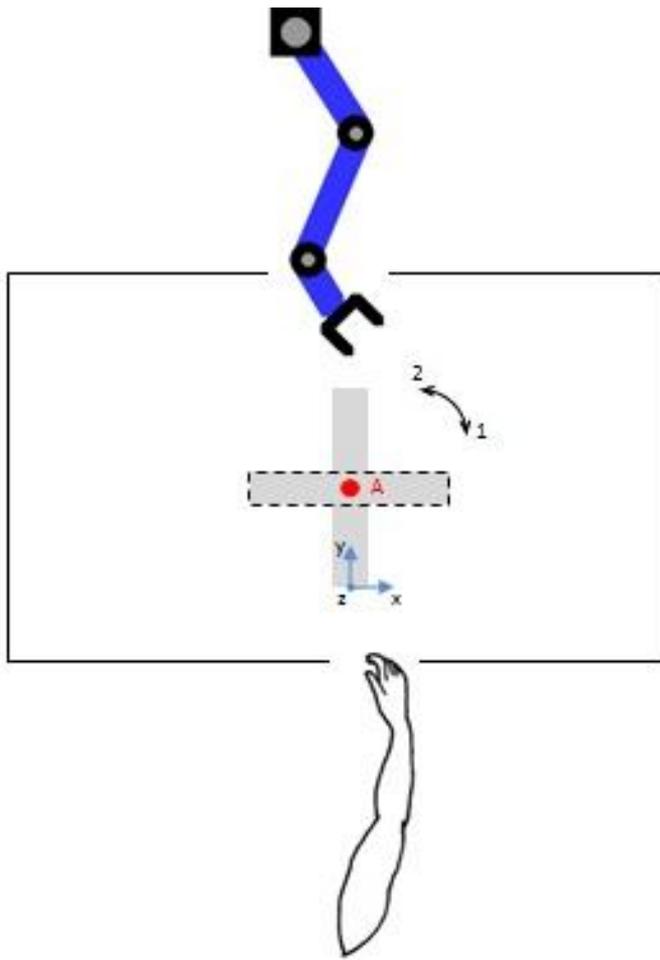


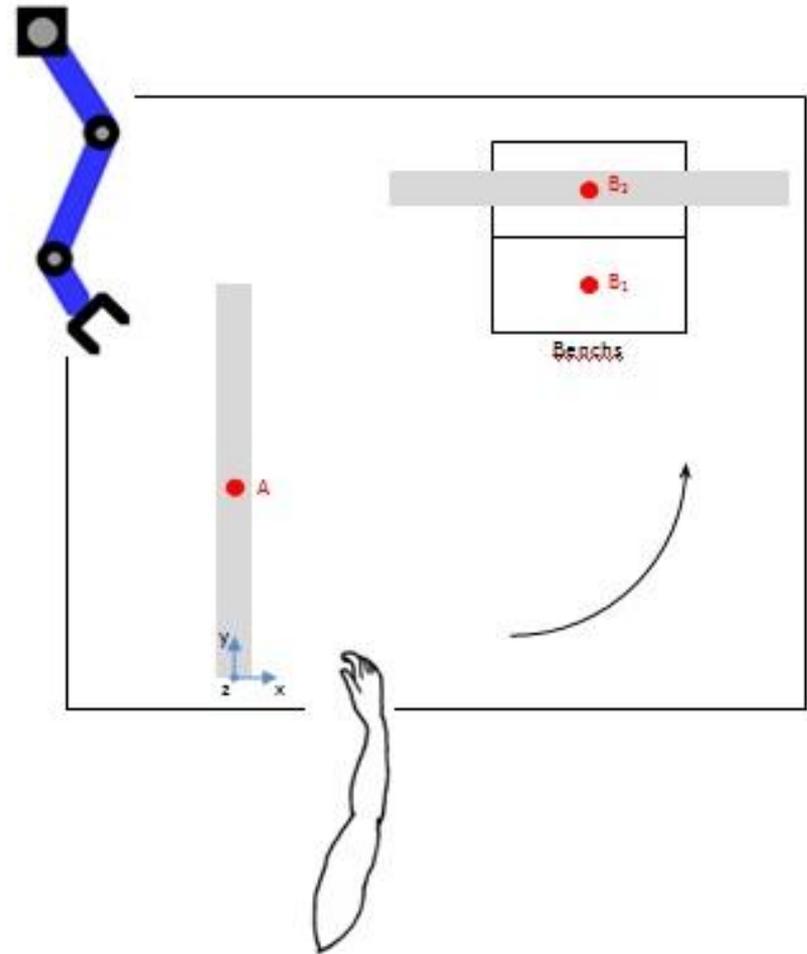
plate 1000 [mm] length

Scenario #5



bar 500 [mm] length

Scenario #6



bar 1000 [mm] length

Types of position sensor failures addressed:

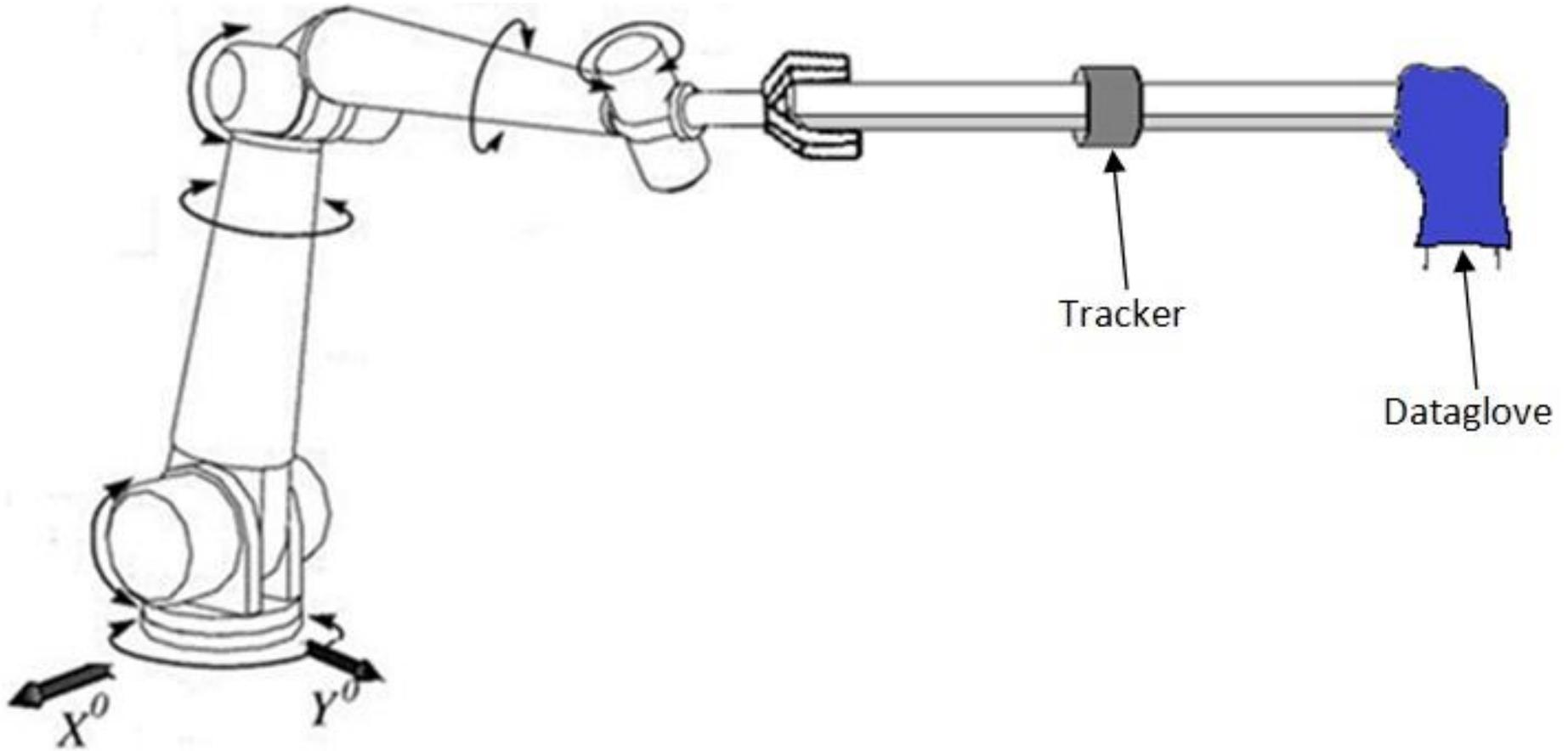
1. Mechanical failure (*e.g. the axis of the encoder and the axis of the joint are disconnected*)
2. Electrical failure (*e.g. cable unplugging or breaking*)
3. Electromagnetic interferences (*e.g. spike losses, noise introducing false spikes*)

The human operator grasps the target object using the **dataglove**: when the human hand is grasping the object, the robot securely grasps the same object

When the human operator suddenly opens the hand wearing the dataglove, the robot motion is immediately stopped

The **tracker** is used as “third” position sensor (triple sensor redundancy)

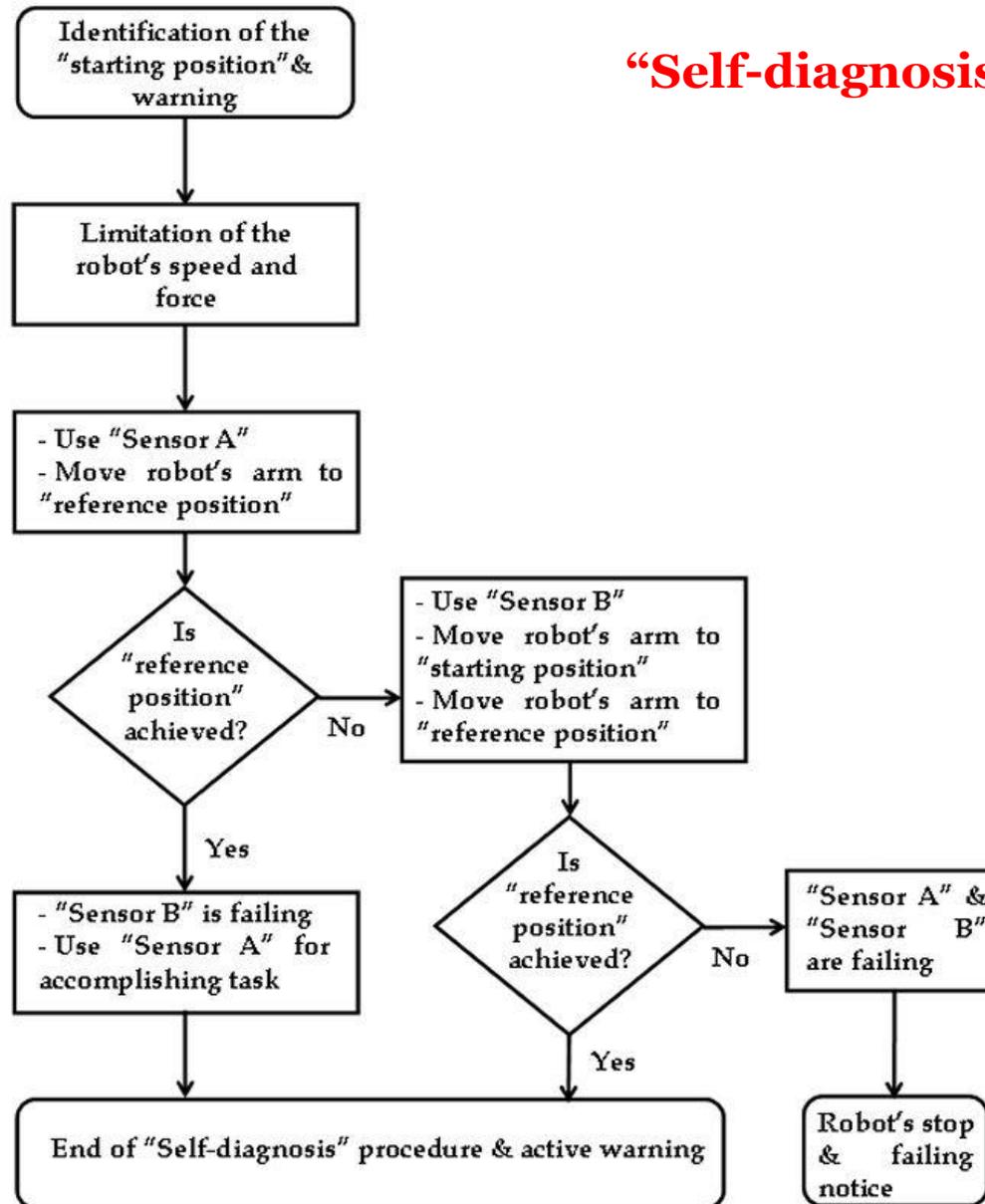
The operator intentions are extracted from information read by a load cell on the wrist joint



- Failure simulated by ignoring information from one or more **position sensors** (*e.g. encoders*)
- Control strategy to be implemented for **detecting inconsistency between encoders** on the same joint
- In case of **triple redundancy**, the task can still be accomplished: the inconsistency is detected by comparing the three signals (two coherent signals assumed as correct information)
- Usually triple redundancy is implemented only in critical applications (*e.g. avionics*): the experiment addresses the case of robot endowed with double redundancy
- Current safety procedures in manufacturing automatic cells prevent human-robot cooperation

Development of safe scenario for the human-robot cooperative manipulation, including sensor redundancy and implementation of a robust control strategy

“Self-diagnosis” procedure

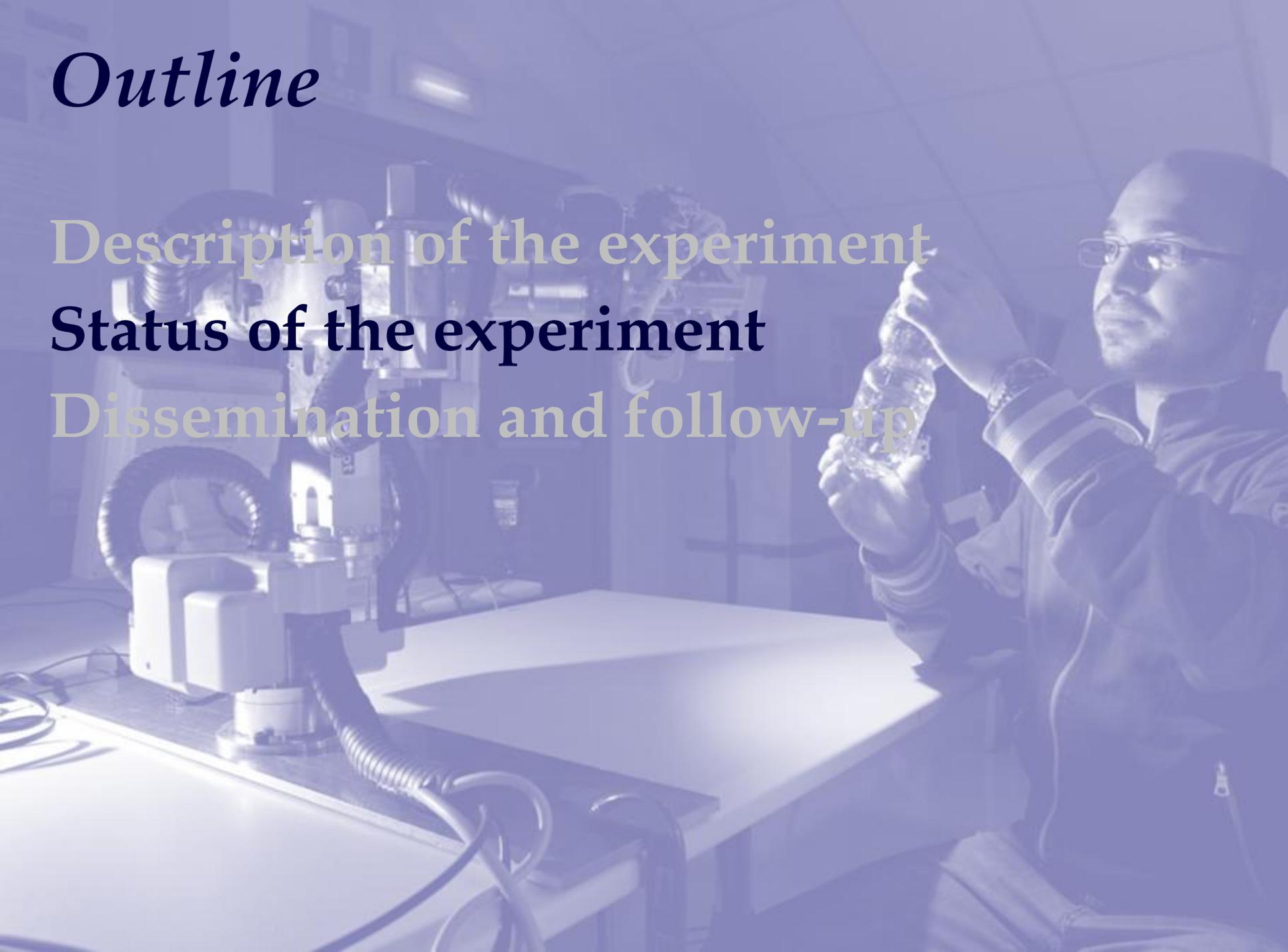


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Overall strategy of the workplan



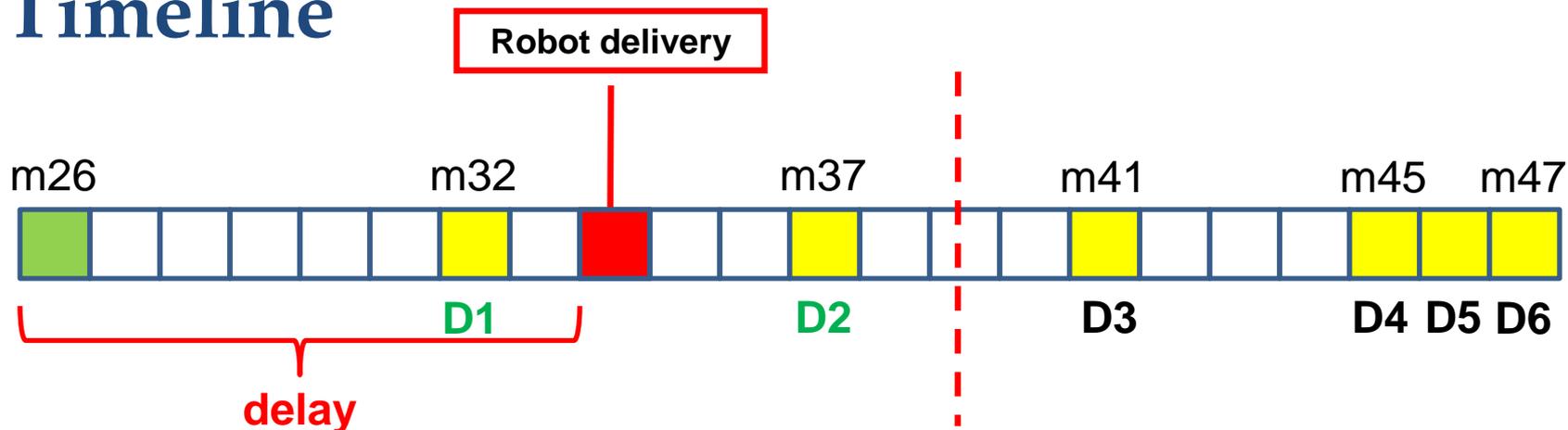
Task list

Task No	Task title	Lead participant Short Name
T1	State of the art and equipment setup	SSSA
T2	Dataglove and tracker integration with robotic arm	HMW
T3	Design and development of robust control strategies for the robotic manipulator	SSSA
T4	Experimental trials in the integrated scenario	SSSA
T5	Implementation of improved safe human-robot cooperation	HMW
T6	Dissemination	SSSA

T1, T2: *completed*

T3, T6: *in progress*

Timeline



D1: Experiment description and setup (R, PU)

D2: Software development for dataglove and tracker systems (R, RE)

D3: Control strategies for the robotic platform (R+O, RE)

D4: Results from experimental trials on human-robot cooperative manipulation (R+O, PU)

D5: Integrated scenario for the human-robot cooperative manipulation (D, PU)

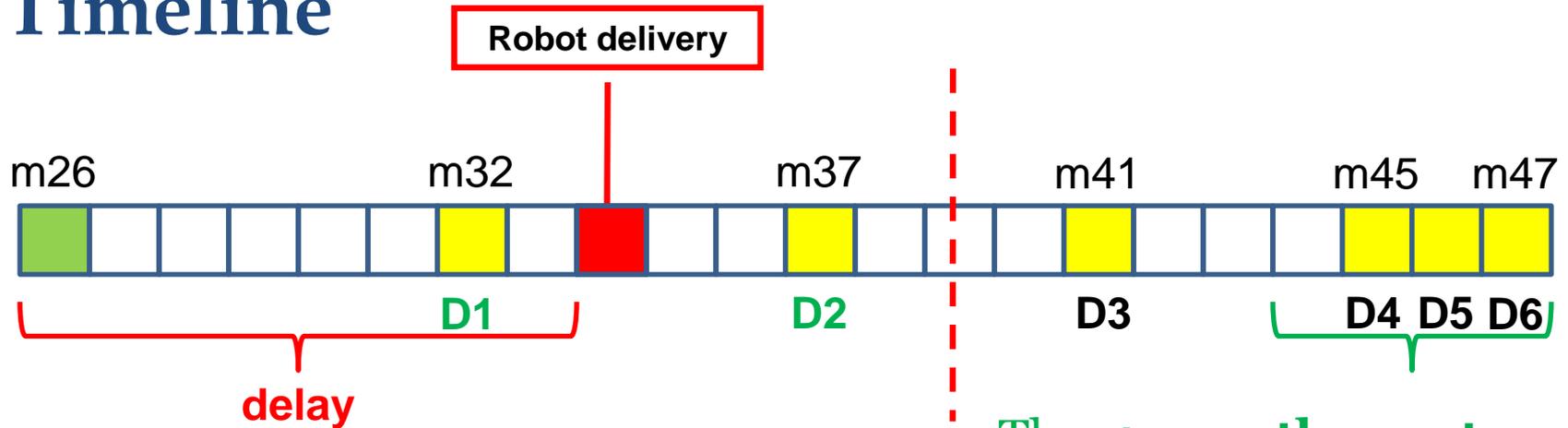
D6: Report on dissemination (R, PU)

R = Report, P = Prototype, D = Demonstrator, O = Other (video and pictures)

PU = Public

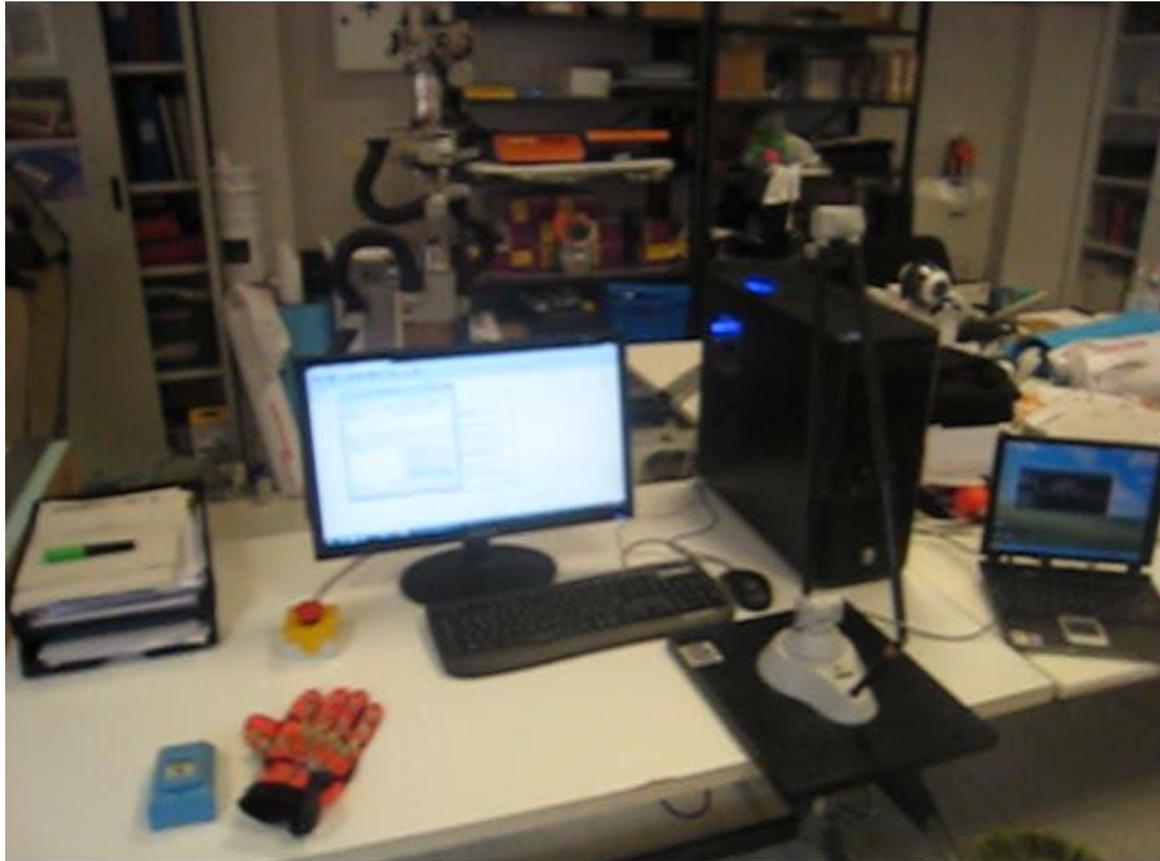
RE = Restricted to a group specified by the consortium (including the Commission Services)

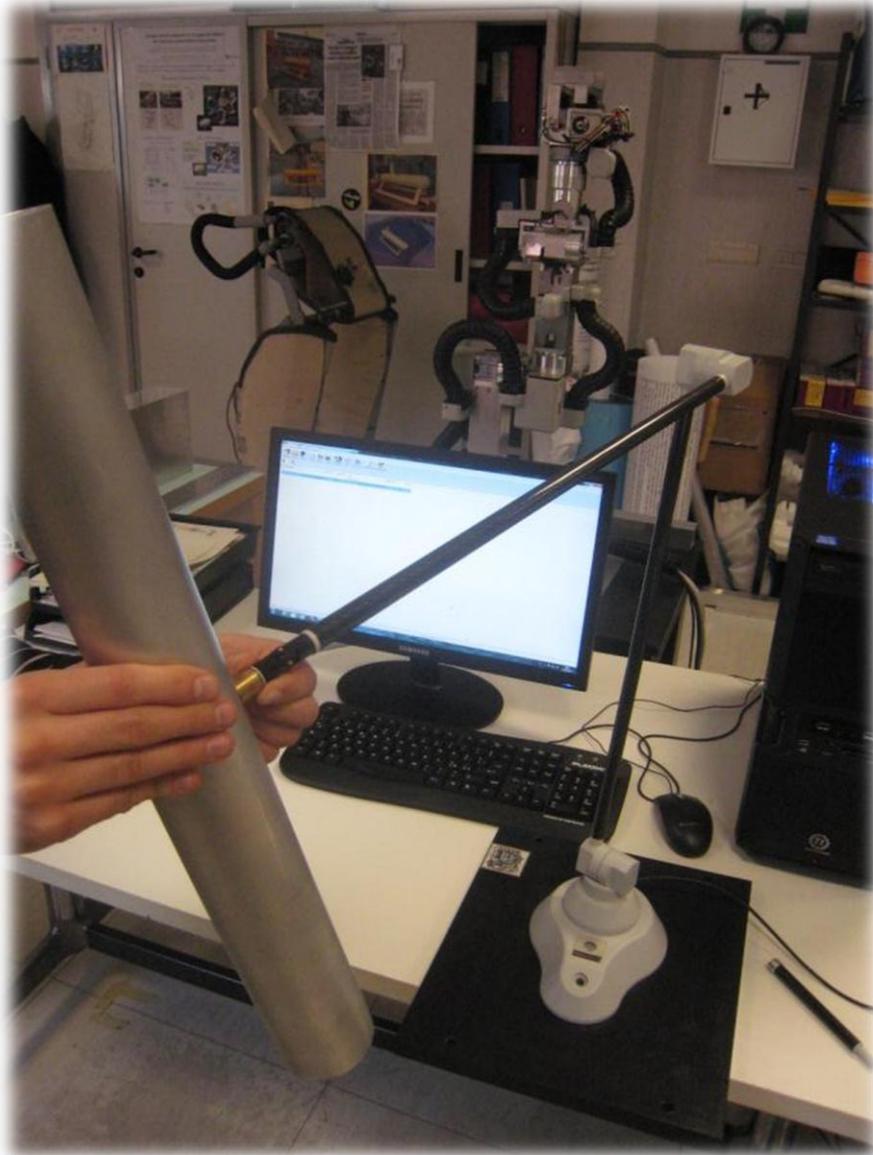
Timeline



The **4 months cost-neutral extension** allows the experiment to recover the delay caused by a late delivery of the robotic platform

Motion tracker





Motion tracker

Dataglove



Calibration phase

Dataglove



Power grasp:
cylindrical grasp

Dataglove



**Precision grasp:
*palmar pinch***

Scenario



Gripper closure

Activities completed

■ Setup of the robotic arm and tests

- Interface protocol using IXXAT USB-CAN compact device connected to the dedicated PC,
- driver installation,
- tests for operative steps.
- As integration platform, the Labview environment was used for collecting the different devices:
 - Joints actuators drivers (through IXXAT USB-CAN compact device);
 - JR3 force/torque sensor (through PCI card);
 - Gripper actuators drivers (through IXXAT USB-CAN compact device).

The following tests were carried out:

- a) Control of single joints;
- b) Control of the gripper;
- c) Validation of data transfer from JR3 force/torque sensor

Activities completed

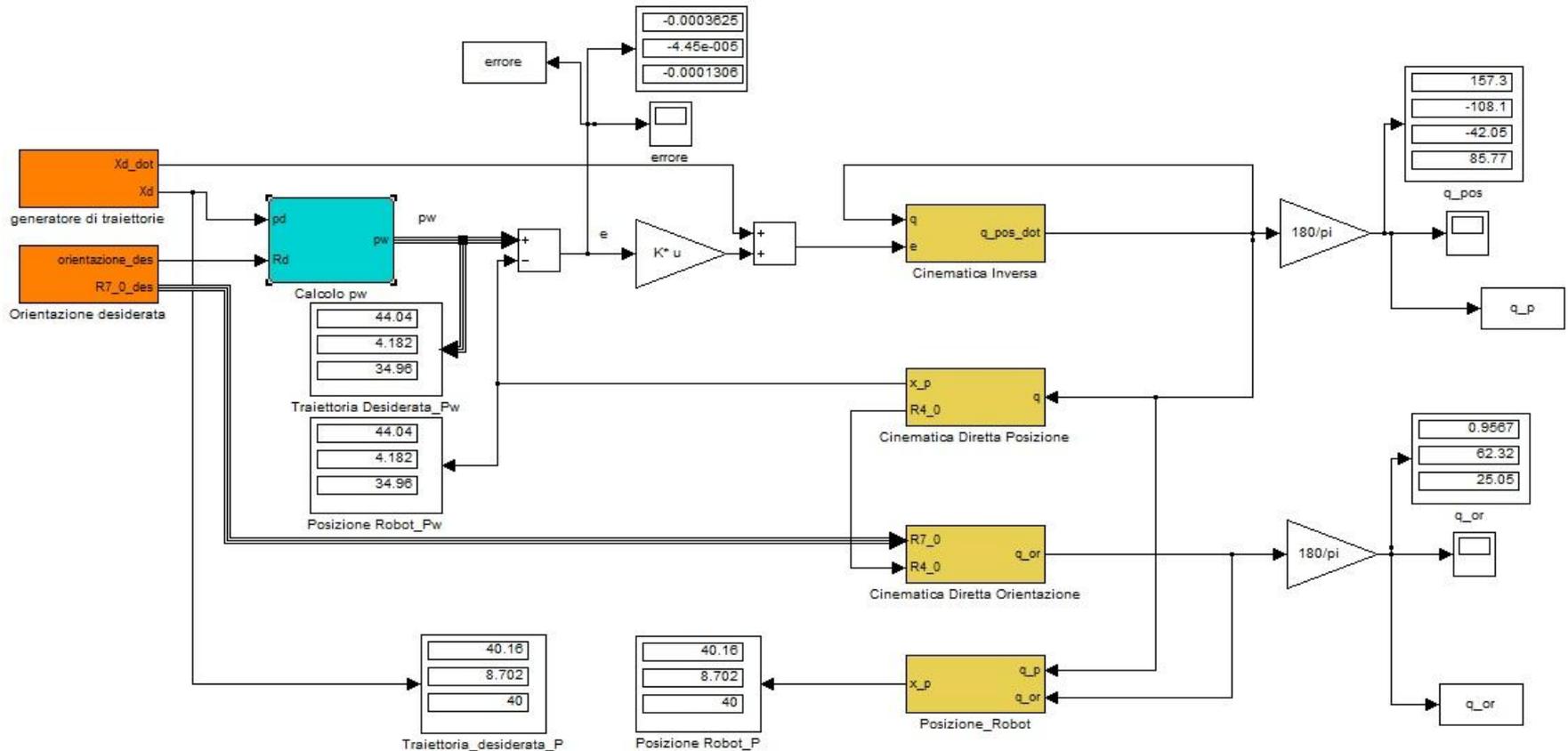
- **Implementation of control strategies for cooperative tasks**

- Development of Matlab S-function including embedding initialization commands for IXXAT USB-CAN compact device and the Process Data Objects (PDOs) sending commands to drivers.

The S-function provides the base interface module for the implementation of specific control strategies currently being designed.

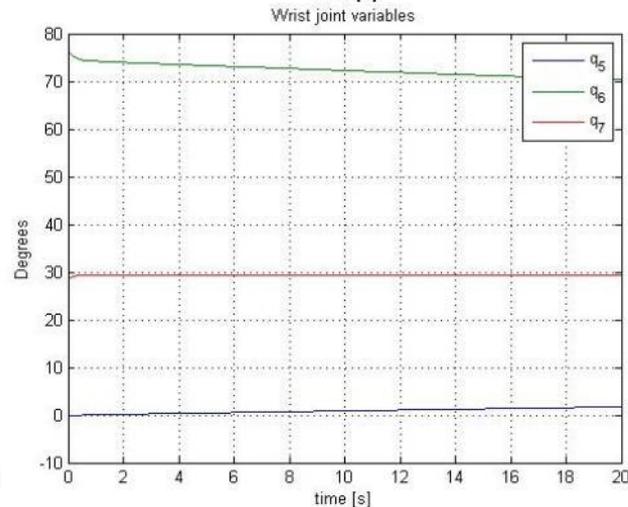
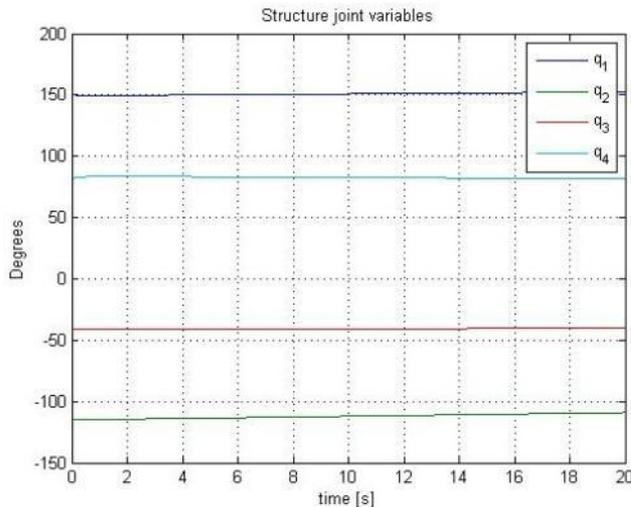
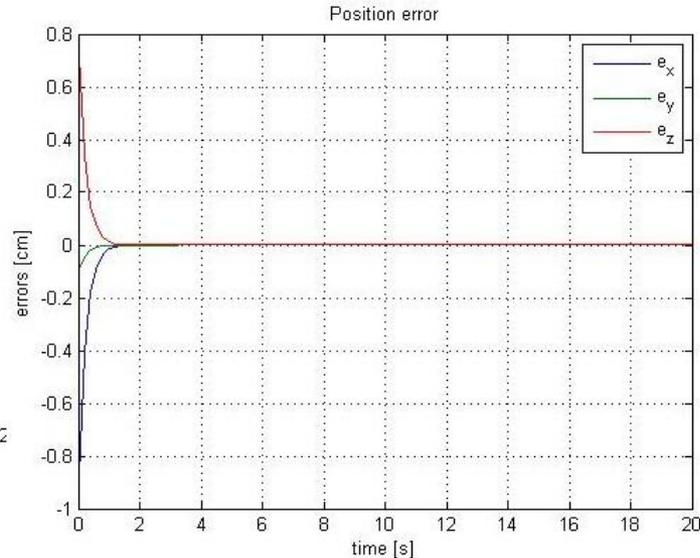
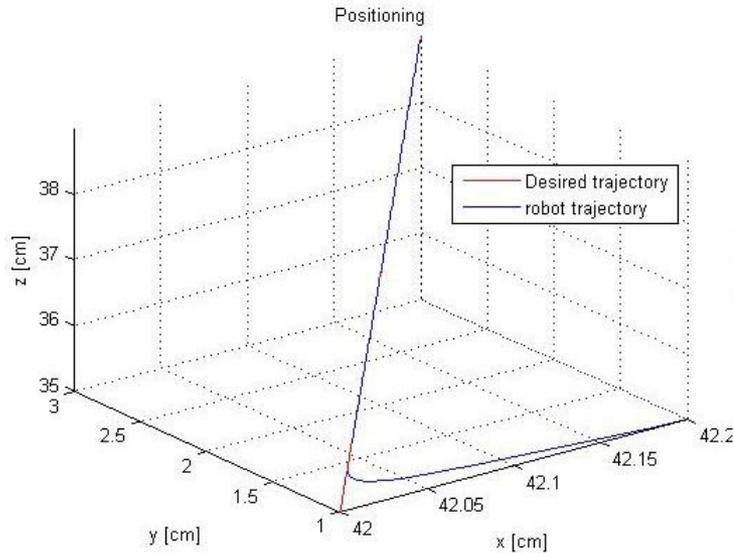
Activities completed

■ Matlab/Simulink trajectories tracking simulation



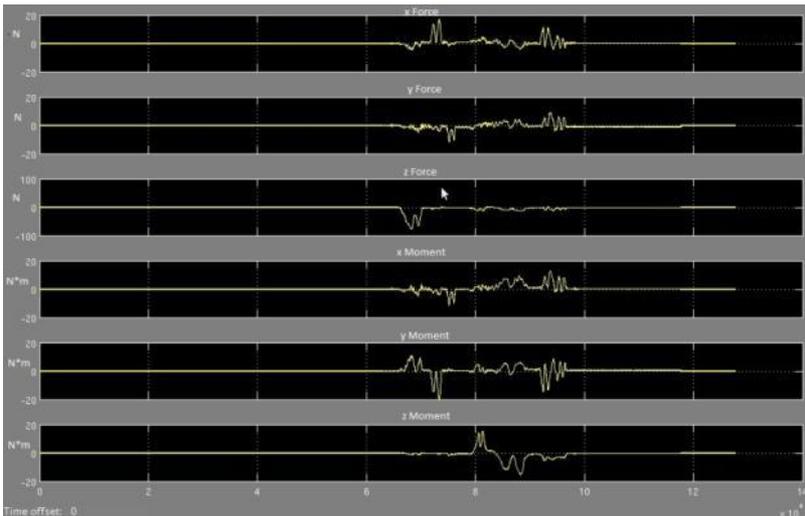
Activities completed

■ Matlab/Simulink trajectories tracking simulation



Activities completed

- Improvement of the ***MATLAB S-function*** for communication (open, initialize and close IXXAT USB-CAN compact device communication) and low level control of servo-motors (start motors, joints low level position control, motors stopping, motors braking);
- Implementation and integration of the ***JR3 force/torque sensor*** through dedicated MATLAB S-function;
- Implementation through embedded MATLAB function “***Damped Least Square for inverse kinematics***” for tuning parameters.



Activities completed

- Tests on F/T sensor
- Initialization and calibration of motion tracker and dataglove
- Motion tracker and dataglove interfacing with robotic arm's control system under Linux - Ubuntu, using UDP functions
- Optimization of low level function for actuators control
- Additional Service Data Objects (SDO)
- Tests on direct and inverse kinematics and angles remapping (based on encoders data)
- Offsets on the encoders of actuators

Ongoing and future activities

- Tests on dynamics of robotic platform (T3)
- Implementation of position control scheme (T3)
- Dissemination (T6)

- Implementation of **impedance-based control scheme** for safe human-robot cooperative tasks (T3)
- Validation of proposed control strategy through experimental tests (T4)
- Implementation of improved safe human-robot cooperation (T5)
- Dissemination (T6)

Outline

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Follow-up

1) Further developments to be proposed under research European funding programmes

- Manunet 2012 (*proposal submitted, in collaboration with HMW and Asturian company*) → possible exploitation plan

2) Use of integrated platform for upper limb rehabilitation

- Stroke patients
- Pointing and grasping tasks
- Activities of Daily Living tasks (*drinking, moving a bottle*)
- Experimental trials at the **Laboratory of Rehabilitation Bioengineering**, “Auxilium Vitae” Rehabilitation Centre, Volterra

Dissemination activities

September 7-9, 2011

Automatica.it (Pisa, Italy):
poster presentation

www.convegnoautomaticaitaliana.org/

November 28-December 4, 2011

European Robotics Week:

permanent photo gallery (HUROBIN
experiment presented) and primary
school students' competition at SSSA

www.eurobotics-project.eu/eurobotics-week/events-calendar/

Introduction

Industrial robots find their application when the task execution requires a level of precision, accuracy and flexibility making which cannot be met manually in a cost-effective or robust way. However, even when tasks have to be executed manually because using robots is unfeasible or too expensive, there are some key demanding subjects which could still be carried out automatically. A safe and flexible co-operative human-robot and human operator may be a promising way to improve productivity. Safety issues are increasingly important in human robot systems and will be required to allow safe working area with a human operator. Human-robot cooperation is one of the most challenging field in the application of robotics. Previous studies have shown the effectiveness of different methods for human-robot cooperation [1][2]. Recently, different robotic platforms were developed for cooperative tasks [3][4]. One of the challenges of robotic technology is developing robots able to perform cooperative tasks. Our approach aims at contributing to increase knowledge in this field and offering control strategies for safe human-robot cooperative manipulation after position sensor failure.

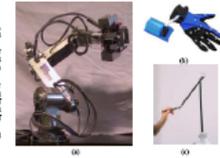


Figure 1. The experiment setup: 7-DOF robot platform (a), daignone (b), master (a) (b) (c)

Experiment Design

The main goal of this experiment is focused on safe human-robot cooperation. In the proposed experiment co-worker interacts with a human operator to achieve the common purpose of manipulating shared objects. The robot will have to adapt its configuration and dynamics to the conditions imposed by the human operator. Objects characterized by different shape, length and weight will be used. For this experiment, the following objects made of aluminum are chosen:

- o_1 cylinder (r_{o_1} , h_{o_1}) having external diameter 61 [mm] and has 69 [mm] (o_1 / h_{o_1}) length and 1.003 [kg] (o_1 , o_2) is characterized by 563 [mm] length and 5.164 [kg].
- o_2 bar (l_{o_2} , r_{o_2} , h_{o_2}) having square section, external side 30 [mm], internal side 40 [mm], bar l_{o_2} having 1003 [mm] length and 2.439 [kg]. Bar o_2 is characterized by 500 [mm] length and 2.227 [kg].
- o_3 plate (l_{o_3} , h_{o_3}) having 1003 [mm] and 500 [mm] length, 89 [mm] width and 3 [mm] thickness, o_3 is characterized by 4.334 [kg] and o_3 is characterized by 1.108 [kg].

The first aim of investigating the human-robot co-worker consists, defining the cases in which the human operator and the robot appear to be the same object in a co-operative task and those tasks the robot is required to force the hand with the human hand the movement of the object. The force of the second is the human robot interaction, co-handling and consequently the safety for the human operator.

The 7-DOF robot arm (Figure 1a) will be equipped with the human carrying the object. A daignone (Figure 1b), used by the human will act as a constant load for the robot gripper. A master tractor (Figure 1c) will be connected to the object to track the kinematic data during the experiments and to provide force redundancy, in each joint of the robot it already equipped with a 3D force sensor in order to measure sensor redundancy, and then safety.

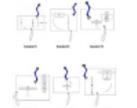
The human operator moves the daignone and gripper at one end of the object, while the robot arm on the other end. In order to highlight the redundancy and human safety, four most significant tasks have been selected:

- [1] The human operator carries the object from the initial position to the goal position (pick and place) at arbitrary speed, co-handling with the manipulator.
- [2] The human operator suddenly leaves handle and the robot arm because the grip force and stops each movement in order to ensure maximum degree of safety to the human operator.
- [3] The human operator carries robot arm moving. A feasible solution is the robot stops and then it carries when human operator ceases the manipulator. The second case is the human cooperation with the robot arm used for stable of the operating area. The end will be the robot arm side in the process.
- [4] Singularity management, arbitrary positions are reached taking advantage of the robot arm redundancy, in order to ensure human safety.

In these tasks, a failure to a joint occurred is simulated, impacting selectively one of the three modules on the joint or on the gripper, thus simulating force loss of the three modules on the joint. This failure is recovered by sensor redundancy (i.e. a 3D force sensor on each joint) or by inverse kinematic algorithm. This type of algorithm is the object position in the space obtained by the matrix inverse. The experimental scenario will also account the behavior of the different objects in order to highlight the critical strategies which will be implemented for safe human-robot cooperation (Figure 2).

Conclusions

The proposed experiment is focused on safe human-robot cooperation. The robot co-worker interacts with a human operator to achieve the common goal of manipulating shared objects. The robot adapts its configuration and dynamics to the conditions imposed by the human operator. A 7-DOF manipulator and a gripper will be used in combination with a daignone (a Human-Machine Interface - HMI) and a master tractor, to perform human-robot cooperative manipulation tasks.



Acknowledgments

The HUROBIN experiment is funded by the European Commission under the 7th Framework Programme - project ECHORD: European Clearing House for Open Robotics Development grant agreement n. 231146.

References

[1] Bardi, T. and Carrozza, M. C., "Human-Robot Cooperative Manipulation with Shared Control", in Proceedings of the IEEE Conference on Robotics and Automation, 2009, pp. 2041-2046.

[2] Bardi, T., Carrozza, M. C., and Cappiello, G., "Human-Robot Cooperative Manipulation with Shared Control", in Proceedings of the IEEE Conference on Robotics and Automation, 2009, pp. 2041-2046.

[3] Carrozza, M. C., Bardi, T., Frazzetta, F., and Cappiello, G., "Human-Robot Cooperative Manipulation with Shared Control", in Proceedings of the IEEE Conference on Robotics and Automation, 2009, pp. 2041-2046.

[4] Carrozza, M. C., Bardi, T., Frazzetta, F., and Cappiello, G., "Human-Robot Cooperative Manipulation with Shared Control", in Proceedings of the IEEE Conference on Robotics and Automation, 2009, pp. 2041-2046.



Dissemination activities: 2012-2013

IEEE target conferences

2013 IEEE International Conference on Robotics and Automation
(*deadline: Sept 16, 2012*)

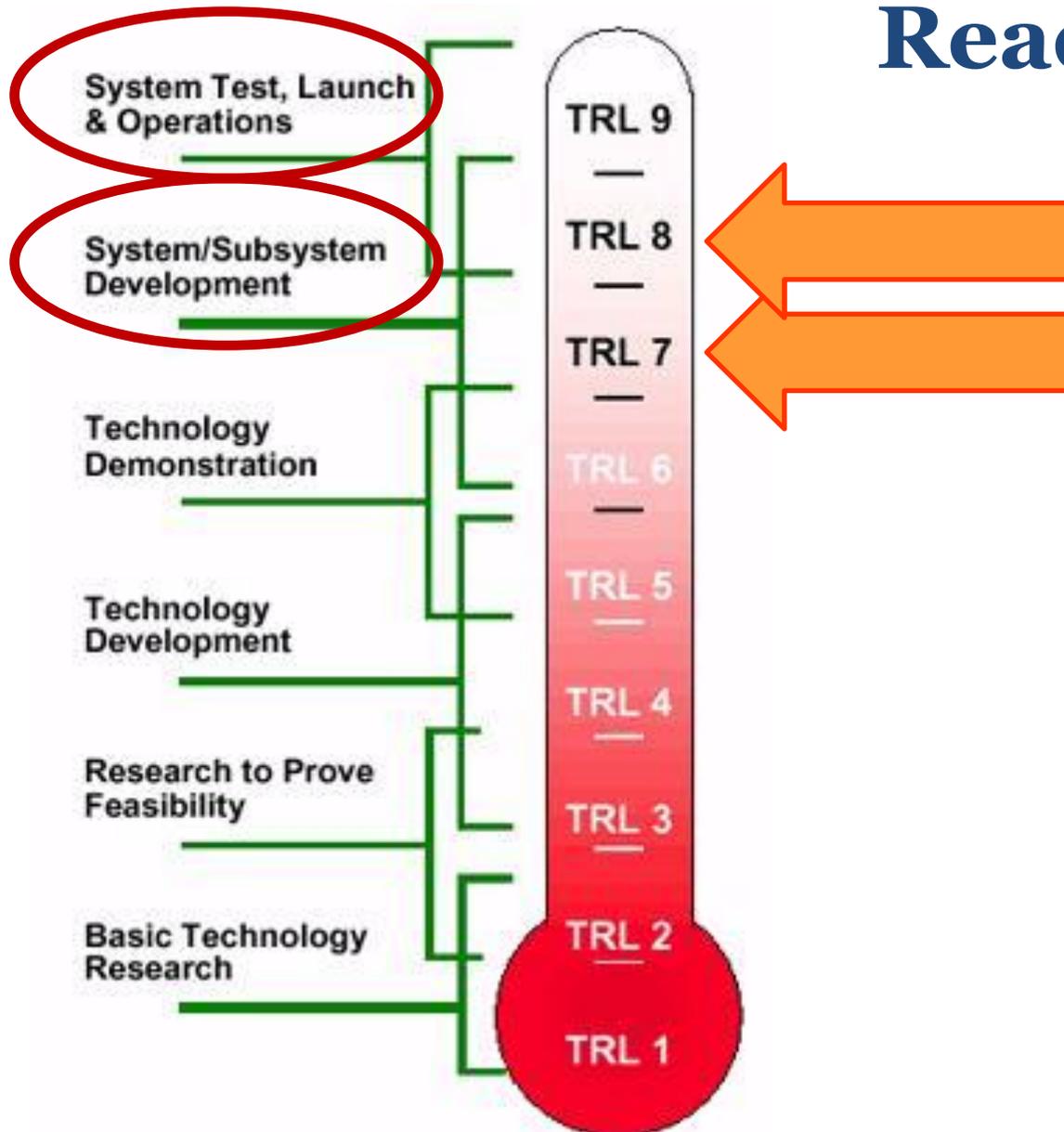
2013 IEEE International Conference on Mechatronics (ICM)

2012 IEEE/SICE International Symposium on System Integration
(*deadline: Sept 23, 2012*)

2012 12th International Conference on Control Automation Robotics & Vision
(*deadline: Apr 1, 2012*)

2012 IEEE International Conference on Mechatronics and Automation
(*deadline: Apr 15, 2012*)

Technology Readiness Level (TRL)



Thank you for your attention!



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