CogLaboration

Collaborative Project

FP7 – 287888

D5.7 Report on Human robot interaction safety

Lead Author: Mildred Puerto (TECNALIA)

Reviewer: [Marco Controzzi (SSSA), Anthony Remazeilles(TEC)]

Deliverable nature:	<Report (R) >
Dissemination level: (Confidentiality)	<Public (PU) >
Contractual delivery date:	M33
Actual delivery date:	M33
Version:	2 digits separated by a dot (First digit is 0 for “draft”, 1 for “project approved”, 2 for “further revisions” e.g. when the EC rejected version 1
Total number of pages:	17
Keywords:	Robotics, human robot interaction, safety

Abstract

Vision systems are a fundamental component in robotic interactive systems. In CogLaboration's testbench, the safety of the human is entrusted to a Kinect XBOX 360, a real time controller and to the intrinsic properties of the Light Weight Robot arm (LWR), specifically designed for interact with humans. Properties like the force feedback provided by the LWR assure the redundancy of the safety during the interaction, since the robot is able to detect potential collisions and stop its movement.

The main achievement for the safety monitoring and human interaction in this project is to adapt human detection techniques to the object-exchange scenario. CogLaboration requires physical human-robot interaction and because of that, the activation of different safety states was introduced in the interaction mode of each stage of the human-robot object exchange.

Executive summary

The summary below resumes the activities addressed within the Task 5.7 during CogLaboration. The objectives of the Task have been successfully reached:

Objective 1: Scene understanding and situation understanding for safety: Work done in WP3 to understand the situation will be handled from a safety-for-user point of view. Particularly development done in task T3.3 Human motion tracking will be used to guide a safe robot control system.

Human detection is performed by different methods implemented in ROS. Those are used for different purposes as following described:

- Human safety inside the robot workspace: Octomaps for human pre-collision detection and force threshold for post-collision detection were implemented and successfully tested.

- Object exchange, hand-positioning: Hand and head location are localized using color-skin detection techniques in order to retrieve/plan the hand location for object exchange. It is used for human-robot interaction and it has been developed in Task 3.3.

The final integration of human detection techniques requires the definition of allowed and not allowed contact states. The definition of areas and states during the object exchange (including planning and execution) permit a better utilization of CogLaboration resources, at the same time that priorizes the human safety, due to possible collisions.

Objective 2: Collision detection and reaction for safety: Collision detection and reaction strategies will be implemented to ensure a safe-for-user operation of the robot arm. They'll enable the robot to react against collisions while preserving as much as possible the execution of the task.

Regarding how to deal with collisions, two different and complementary strategies must to be combined to assure human safety: pre-collision detection and post-collision response. In CogLaboration both strategies were implemented using different information sources (mechanical contact by force sensors and computer vision), improving by this way the redundancy and robustness of the system.

Pre collision strategy: It is using the Octomaps functionality provided by ROS, the implementation of the pre-collision strategy monitors the robot's workspace. The occupancy map generated by this function is configured, processed and analysed. If the result is a human detection, the algorithm publishes a message used by the robot controller.

Post collision strategy: Force sensor threshold by physical contact. When no camera information is available (if the object handover is taking place and thus reducing the camera visibility, or if there is a camera malfunction or a delay introduced by the image processing load), specific thresholds in the robot force sensors have been fixed to detect collisions. The post collision strategy utilizes the force sensors located in the LWR joints to detect not allowed contacts (those outside the area occupied by the human and robot hand during the `assess grasping mode`); the system response after a collision is stopping the robot by software's emergency stop.

Document Information

IST Project Number	FP7 - 287888	**Acronym**	CogLaboration
Full Title	Successful Real World Human-Robot Collaboration: From the Cognition of Human-Human Collaboration to the Cognition of Fluent Human-Robot Collaboration		
Project URL	http://www.coglaboration.eu/		
Document URL			
EU Project Officer	Juha Heikkilä		

Deliverable	**Number**	D5.7	**Title**	**Report on Human robot interaction safety**
Work Package	**Number**	WP5	**Title**	Artificial Cognitive Systems Integration

Date of Delivery	**Contractual**	M33	**Actual**	M33
Status	version 1.0		final x	
Nature	prototype □ report x demonstrator □ other □			
Dissemination level	public x restricted □			

Authors (Partner)				
Responsible Author	**Name**	Puerto	**E-mail**	mildred.puerto@tecnalia.com
	Partner	Tecnalia	**Phone**	

Abstract (for dissemination)	Vision systems are a fundamental component in robotic interactive systems. In CogLaboration's testbench, the safety of the human is entrusted to a Kinect XBOX 360, a real time controller and to the intrinsic properties of the Light Weight Robot arm (LWR), specifically designed for interact with humans. Properties like the force feedback provided by the LWR assure the redundancy of the safety during the interaction, since the robot is able to detect potential collisions and stop its movement. The main achievement for the safety monitoring and human interaction in this project is to adapt human detection techniques to the object-exchange scenario. CogLaboration requires physical human-robot interaction and because of that, the activation of different safety states was introduced in the interaction mode of each stage of the human-robot object exchange.
Keywords	Robotics, human robot interaction, safety

Version Log			
Issue Date	**Rev. No.**	**Author**	**Change**
	0.1	M.J. Puerto	Template preparation & outline definition
16/07/14	0.2	A. Remazeilles	First section draft
25/07/2014	0.3	M. Controzzi	Second section draft
31/07/2014	1.0	M.J. Puerto	Complete document

Table of Contents

Table of Figures

Abbreviations

ROS: Robot Operating System

KUKA LWR: Light Weight Robot built by KUKA.

LWR: Light Weight Robot built by KUKA.

FRI: Fast Research Interface of the LWR.

rviz: ROS integrated visualizer.

pHRI: physical Human-Robot Interaction.

1 Introduction

To ensure operation safety during the interaction of the humans within the robot workspaces, it was implemented a collision detection strategy that comprises of two blocks working in parallel: the first is a pre-collision strategy exploiting the vision system of the robot and the second is a trajectory monitoring with post-collision strategy using a threshold on the force acquired by the sensors embedded in the LWR joints.

Adaptation and definition of the requirements for human-robot interaction based on object exchange have been analysed on the first demonstration scenario. The main source of information is a Kinect camera located on top of the object exchange area, due to only one camera is used, the camera resources for human detection and safety monitoring must to be ensured and optimized due to the low frequency obtained from the data analysis (only 30 Hz). Several strategies and safety modes have been combined in order to achieve a high level of human-robot interaction, maximizing the use of the information provided by the camera.

The document is structured based on the states where contact is allowed or not, it is based on the robot controller states (refer to Deliverable 4.62). Inside each subsection have been included and explained the algorithms and techniques used to implement the safety strategies in the selected moment of the object exchange.

2 Safety interaction

The design of collaborative tasks, as it is proposed in CogLaboration [1], requires providing some specific mechanisms to monitor the safety of the human partner, while the person is within the operation space of the arm, and in particular when potential contact can occur outside of the physical interaction protocol.
The implementation of safety mechanism is naturally dependent on the robotic arm being used and on the tasks being realized with this arm.

CogLaboration project is using the Kuka Light Weight Arm (LWR [5]) that is provided with a per-construction compliance property through variable impedance actuators, thanks to which is possible to minimize the damages due to collisions. Nevertheless, considering that such mechanisms are not implemented on all robotic arms, and that potential collisions should be avoided as much as possible, we considered important to investigate how, through perception of the human location to the arm, the system can identify potential collisions out of the exchange procedure, and adjust accordingly to that its behaviour.

2.1. Safety implementation a using dedicated camera

The hardware of the system is composed by a Kinect XBOX 360 camera [6], ROS functionalities [7] and a dedicated PC with Ubuntu 12.04, 64-bits, GNOME 3.4.2, Intel Xeon @3.2 GHzx8.

Since the CogLaboration testbench uses two cameras (Figure 1), one for the object recognition and one for monitoring the human-robot interaction, only one camera is available for safety algorithms.

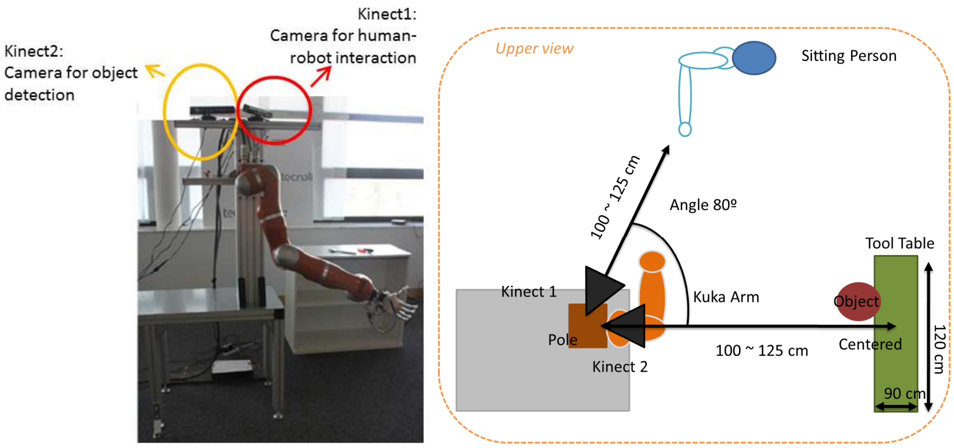


Figure 1: Testbench of CogLaboration (real and scheme): Kinect2 for object detection in the tool-panel and Kinect1 for human interaction (safety and hand-object detection).

The Kinect1 provides data about the human robot interaction taking place in the robot's workspace (see measures on Figure 1). It is mainly used to estimate the human location for object exchange, it is also intended to monitor the human during the exchange and during the automatic motions of the robotic arm ensuring a safety interaction. Since the camera data processing consumes a large quantity of resources in human detection techniques (see Deliverable 3.3), it has been decided to split the execution of those techniques according to the state of the exchange (Figure 2), activating the safety mode when any contact human-robot is expected.

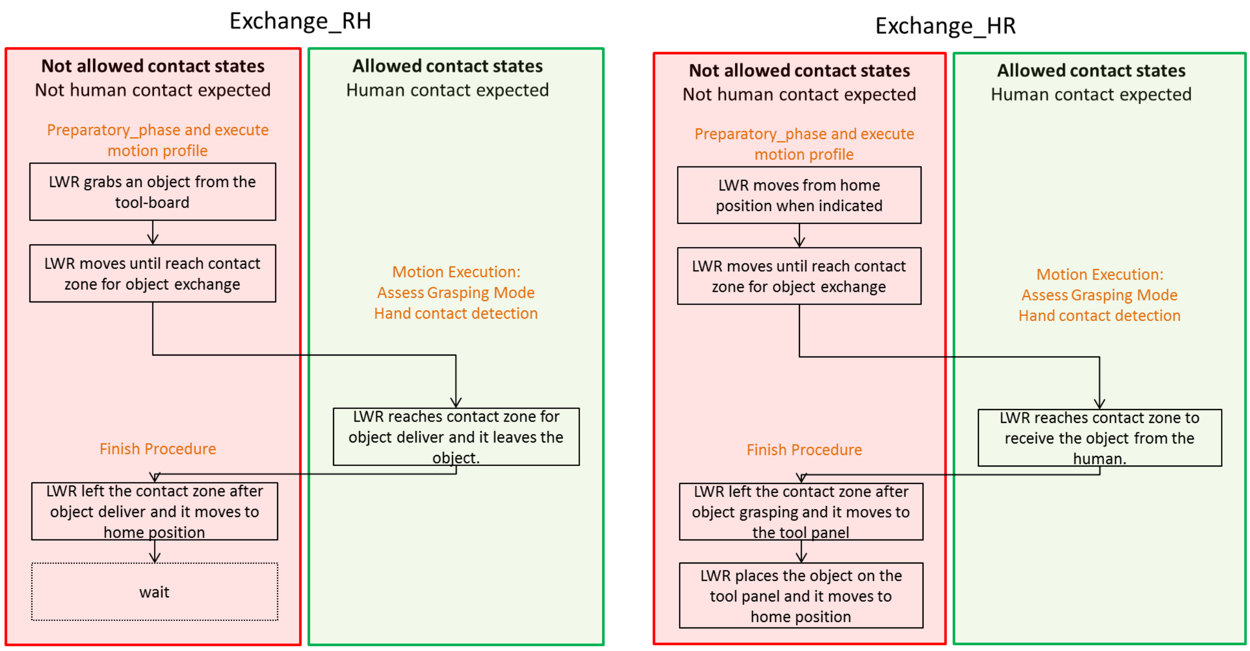


Figure 2. Safety mode activation flowchart.

The ***Not allowed contact states*** (market in red) activates the human detection using *octomaps* and its output is given to the CogLaboration's integrated controller. The response to a not allowed human presence is the immediate stop of the robot movements; the arm is locked until the presence of the human in the close vicinity of the arm disappears. Then, the arm either goes back in its rest mode or continues the action it was taking place.

The ***Allowed contact state*** (market in green) is activated when the robot reaches the exchange object zone, then, only the robot hand is allowed to physically touch the human. With the activation of *assess grasping mode*, no large movements are expected for the object exchanged, then, the camera focuses on the hand location and on the detection of the object, deactivating the safety mode for not allowed contact states.

2.1. Not allowed contact States

We have started implementing this safety aspect by considering control modes where the desired trajectory is defined through a planning mechanism that could be put in relation with the automatic generation of the encoded motion pattern as if it was to be reproduced by the robot. Specific ROS nodes have been developed to execute that trajectory in the free space of the environment, as illustrated on the general diagram presented on Figure 3.

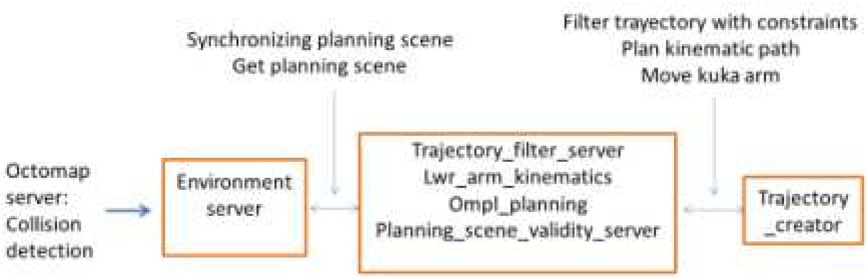
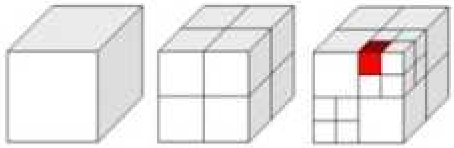
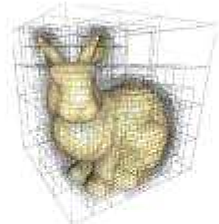


Figure 3. Components involved in the execution of a trajectory free of collision.

The detection of the location of potential collision in the operation space is performed through the description of the operational space with an octomap, as illustrated on
Figure 4.



Octrees basic representation. Any figure can be surrounded by an octomap.



Example. Stanford bunny represented with octrees.

Figure 4. Octree visual definition. It is very useful for collision detection since it decreases the complexity of the scene representation.

An octomap is able to model arbitrary environments without any prior assumption about it [10]. The representation models occupied areas as well as free space. Unknown areas of the environment are implicitly encoded in the map. On the software side, an octomap server is populated and permanently updated by receiving the point cloud generated by the Kinect1 sensor (cloud of depth points) and converting each point in an entity with specific volume and collision characteristics. The size of each octree can be adjusted to decrease the processing time of the collision detection.

The high priority areas (potential contact zones) are detected by proximity using the octomap server. The safety procedure is then straightforward: the trajectory planning detects the obstacle in the calculated trajectory, stops the motion taking place and then recalculates an alternative path in the actualized free zone. When the obstacle moves (in Figure 5, the person moves the arm at the same time that the robot) the robot algorithms repeats the calculations searching a free trajectory. The detection includes the object in the human or robot hand. The number of cubes is lower that the elements in the point cloud.

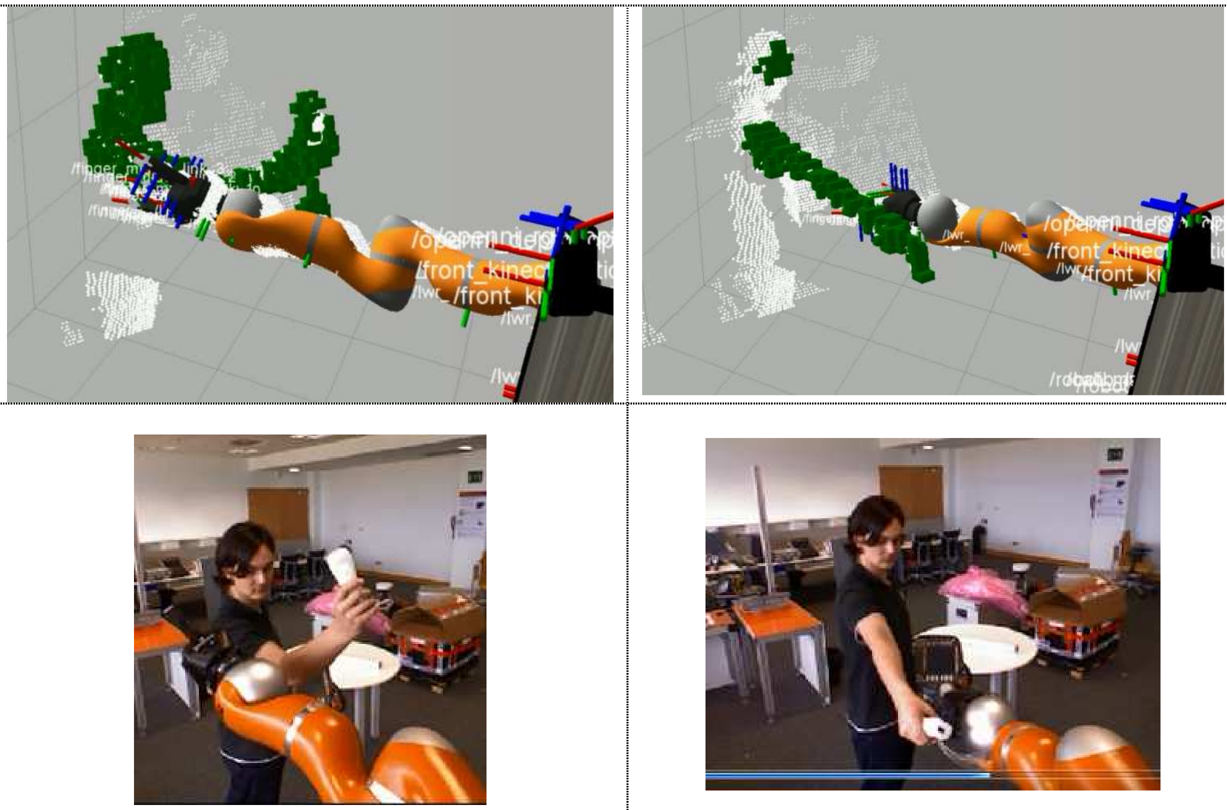


Figure 5. Obstacle avoidance: Green blocks correspond to the so-called high priority areas the KUKA LWR needs to avoid to anticipate a collision. The robot approaches from different directions, in both directions the collisions are detected with octomaps.

Human detection was implemented with octomaps in order to prevent collision with the LWR. The octomap library of ROS implements a 3D occupancy grid mapping approach, providing data structures and mapping algorithms. The map implementation is based on an octree. Preliminary trials in ROS detected the human presence based on the total surface of the octomaps, then the algorithm analyse the octomap_binary service in order to find the size of the occupancy map, if the result is a human detection (Figure 6), then the node publishes a message. The platform used to visualize the pHRI interaction is rviz. The message is read by the robot to be integrated in the path planning controller [2,3].

Human recognition using octomaps detects the proximity to the robot, even when not the whole human body is observed (Figure 6 it was a disadvantage detected from use the openni tracker [8] for safety supervision (refer to Deliverable 3.3).

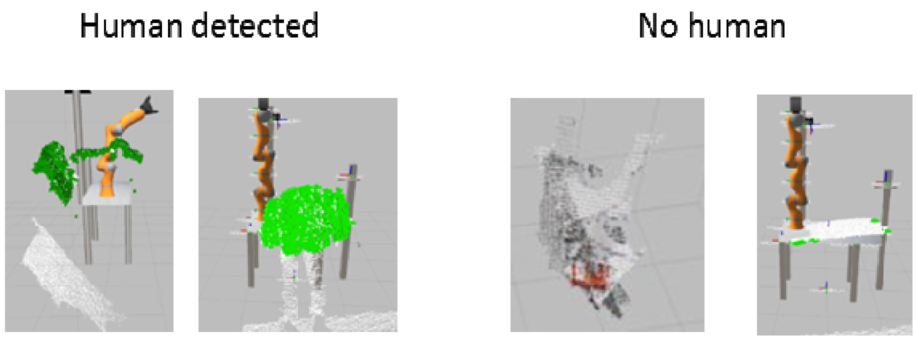


Figure 6. Octomaps detection: The octomap_binary occupancy grid is used to detecting human presence in the ***not allowed contact states.***

The safety mode interacts with other ROS nodes, its basic functionality is the supervision of the robot workspace. Description of the ROS nodes is presented in the Figure 7:

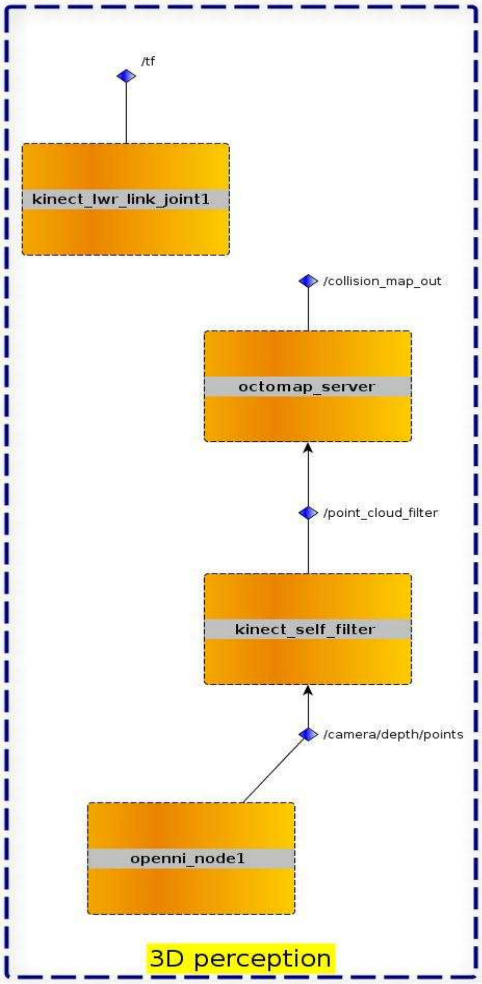


Figure 7. Perception of the LWR workspace. Nodes implemented in ROS.

Openni_node: Make the connection to hardware of kinect and publish a point cloud.

Kinect_self_filter: Take the points related to the robot arm out of the point cloud to avoid detecting them as collisions.

Octomap_server: Segment the point cloud into defined boxels and serve a collision map.

Kinect_lwr_link_joint1: Generates the /tf between the kinect and the base reference.

2.1. *Allowed contact States*

When object exchange mode is activated, the direct contact between human and robot is a **'must'** condition (In Figure 6 is shown how is the direct contact perceived from the vision system though a common object), here the octomaps strategy is seeing a collision, so, the advantages of this function are not applicable for direct human-robot contact. Also, as it has been mentioned before, the Kinect1 is used to locate the human hand. The result of having both algorithms running is very time consuming, limiting the frequency of the camera data to 3 Hz in average.

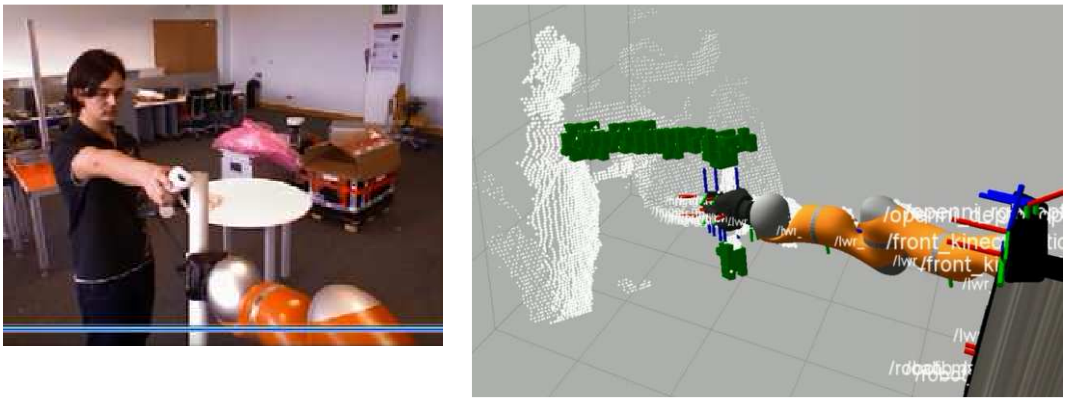


Figure 8: Octomaps detection when the robot and the human hold the same object: the contact though the object is perceived as a collision.

Because of that, overall safety by octomaps cannot be used, then, an area of not allowed contact during object exchange was defined (area marked in red in Figure 9, to the left). Due to Kinect2 is no longer analysing the octomaps, the detection of the contact is performed by a threshold of the force in the LWR joint's sensors.

Post-collision detection is allowed in the area in red (mentioned before) because two reasons: the robot is not programmed to move large distances in the exchange zone and the LWR body is contact safe when velocity acceleration is limited [4].

In the programmed scenario, two nodes are in charge of the dynamic safety implementation of the human-lwr interaction: *Kinect_collision_detector* and *physical_collision_detector*, one for the robot structure with the programmed elements in the workspace and the other for the physical collision indicated by the force sensors. Those modules provide information to validate the LWR trajectory, if any collision occurs, then the robot stops.
In the Figure 9 is shown the scenario without Kinect vision (this consideration can be extended to a system where the camera vision could fail). In the pictures, the robot (with limited acceleration and velocity) collides with a person, the contact is not dangerous, but enough to be detected by the force sensors and stop the LWR in a safety configuration.

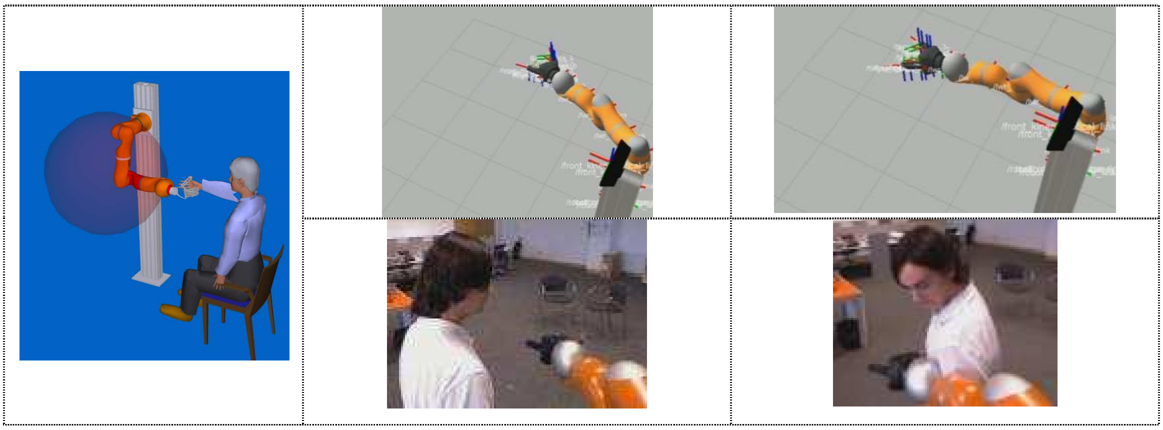
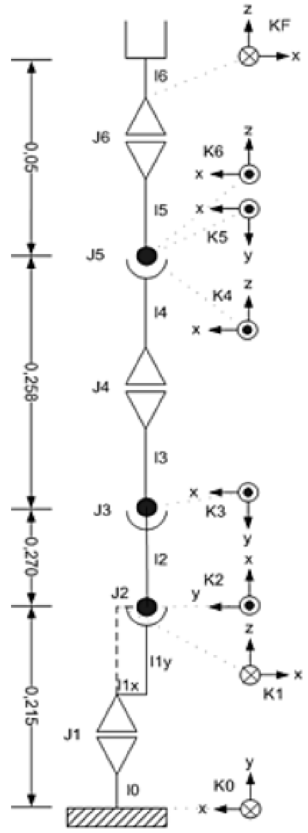


Figure 9. Area of not allowed interaction and example of collision detection using only the force sensors embedded in the LWR.

¡Error! No se encuentra el origen de la referencia. presents a typical signal provided by the force sensor of the LWR end effector, it has been produced by a direct contact when the robot moves slowly on a fixed linear trajectory. The threshold on the torque was fixed at 0.5 Nm and it is easily detected by reading the *physical_collision_detector* topic.

The detection is based on large variations of the commanded torques/motor currents in one joint (joint 4) due it is mainly involved in the LWR large movements in the testbench configuration. The collision is recognized, the reaction to not allowed contact is launched to the robot by stopping the motion reference generator.

It has been decided to not use the forces in the end effector; due it is deeply involved during the object exchange and contact forces are expected. The solution implemented in CogLaboration testbench that stop the robot proves to be functional, however, a manner to use the contact forces for all the joints located in the LWR is being explored recently (implementing reaction strategies to the contact and the dynamical model of the LWR, but it is outside the project scope).



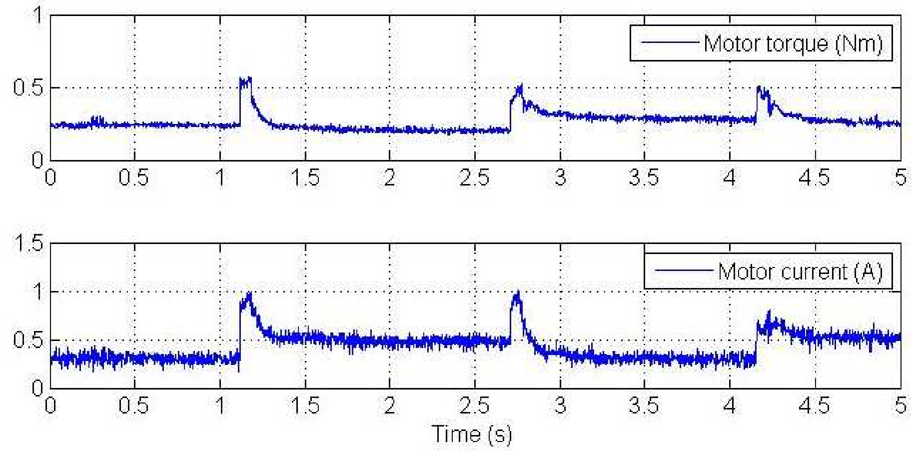


Figure 10: Above: Contact effect in the force sensors of the LWR joint 4. In the left is shown the kinematic chain of the Kuka LWR where the joint position is depicted.

The area of allowed interaction is located by the human detection algorithm designed in Task 3.3 (hand location), the robot approaches to the person in order to interact with his/her through the object exchange. This zone covers hand exchange area (Figure 11) and the activation of the *motion execution* state.

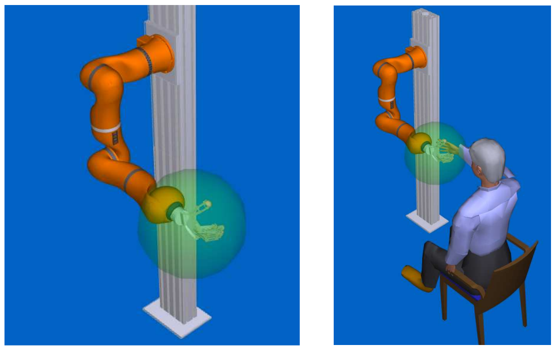


Figure 11: Area of allowed contact during *allowed contact state*.

3 Conclusions

- A combination of techniques has been required to explore the best manner to implement safety human-robot interaction for object exchange. Safety was implemented in two different but complementary techniques, First focused to hand detection (refer to Deliverable 3.3 Human motion tracking) and later for pre-collision strategies
- Classical approach to collision detection has been programmed and its implementation was adapted for the particular characteristics of the CogLaboration testbench. When no contact was allowed, the robot workspace was supervised by a pre-collision strategy using octomaps. When object interchange was needed, then post-collision strategy was activated and combined with human location developed in task 3.3.

References

[1] http://www.coglaboration.eu

[2] A. Haddadin, Albu-Schaffer, A. De Luca and G. Hirzinger. Collision detection and reaction: A contribution to safe physical human-robot interaction. In Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, Nice, France, Septiembre 2008. Pág: 3356-3363.

[3] F. Flacco, T. Kroger, A. De Luca and O. Khatib. A depth space approach to human-robot collision avoidance. In Proc. IEEE Int. Conf. on Robotics and Automation, St. Paul, USA. Mayo 2012.

[4] S. Haddadin, A. Albu-Schäffer and G. Hirzinger. Safety Evaluation of Physical Human-Robot Interaction via Crash-Testing. In Robotics: Science and Systems Conf. 2007.

[5] http://www.kuka-labs.com/en/medical_robotics/lightweight_robotics/

[6] http://www.xbox.com/en-US/xbox360/accessories/kinect/KinectForXbox360 Kinect sensor for Xbox 360

[7] http://wiki.ros.org/ Robotic Operating System (ROS) wiki

[8] https://github.com/OpenNI/OpenNI OpenNI framework

[9] http://wiki.ros.org/ROS/Technical%20Overview ROS technical overview

[10] http://wiki.ros.org/octomap