Research for SME

Grant agreement **nº: 606363**

Call identifier: FP7-SME-2013-1

CooperAtive Robot for Large Spaces manufacturing

CARLoS

Final Report

Publishable Summary

"This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 606363".

Table of Contents

1 Summary description of project context and objectives

Large semi-structured manufacturing spaces present serious challenges for robot mobility, safety and reliability. This is clearly the case of shipbuilding environments. Shipyards exhibit unique features that challenge but also make of major interest the deployment of mobile robots able to take on arduous repetitive tasks in which productivity may not be improved but at the expense of worker wages.

The problems at hand in CARLoS project are the fit-out operations inside blocks of ship superstructures. Currently, these tasks require arduous manual works. There is no available solution to automate the targeted works in a complex environment such as shipbuilding.

The final goal of the CARLoS project is to get a prototype of a robot co-worker for fit-out operations inside blocks of ship superstructures. The specific operations targeted by CARLoS are stud welding and marking based on information from a CAD model that are necessary for posterior fit-out operations. This includes:

- Semiautonomous navigation inside ship blocks.
- Performing the necessary stud welding process completely automatic based on CAD descriptions.
- Marking pre-outfitting information from the CAD model onto bulkheads to aid fit-out operations by the human worker.
- Skills-based robot programming in order to be easily controlled by an ordinary shipyard worker.

2 Description of work performed and main results

2.1 First period

During this first period, the specification of industrial and functional requirements has been done, and a 3D scenario was selected based on a real block of ship superstructure. The main components of the robot (i.e. platform, arm, sensors, and tools) have been selected, designed and assembled, and partially tested.

Important requirements in the design of the platform were the size (compliant with hatchways width), the payload (enough for the manipulator, welding equipment, batteries, and sensors). Regarding the manipulator, the ratio payload/weight and the possibility to tailor the control system were determinant aspects. The selection of sensors and devices for robot navigation, bulkhead sensing, process control, and human robot interaction was also done based on the functional requirements of the robot. Visual clutter, pin distribution requirements, safety requirements were taken into account for such selection. Besides, cost of components was taken into account in order to achieve a cost effective solution. As well, simulations of robot movements and sensors were used to guide the selection of components.

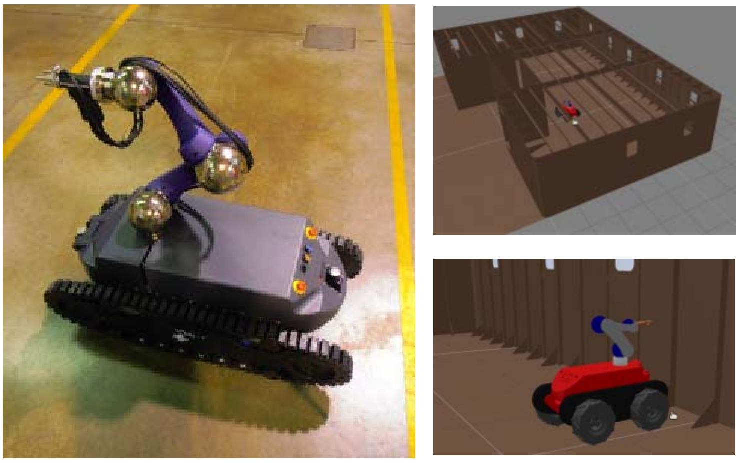

Figure 1 CARLoS Robot with the welding gun (left); Simulations on a 3D model of the block selected

Preliminary stud welding trials have shown positive results, using the selected manipulator and a commercial welding gun tailored to be attached to the wrist. These trials have served to demonstrate a good weldability of pins using the manipulator. Besides, specific requirements on process sensing (e.g. accurate orientation of the tool) have been assessed; confirming the adequacy of the components selected for sensing and process control.

Figure 2 Welding trials using the manipulator

The architecture and major components of the robot control software have been defined. Initial versions of software modules for autonomous robot navigation, bulkhead sensing, and process execution have been implemented.

Navigation software is being developed based on ROS move_base package, with satisfactory results, and further efforts will focus on optimizing performance and minimizing manoeuvres.

A manipulator control is being developed based on MoveIt!, and a vision system to sense bulkhead and deciding the distribution of pins has been developed to work in an embedded plaftorm using OpenCV.

A three layer architecture comprising of primitives, skills, and tasks is beneficial for more intuitive and safe robot programming for mobile manipulators. This is the starting point for implementing the robot skills concept on the CARLoS robot, since this approach has some obvious advantages compared to traditional robot programming. The approach allows the operator to focus on the task instead of complex robot programming.

An early mock-up of a user-interface has been realized. With the user-interface the operator will be able to connect to and configure the robot, get essential information about the status of the robot system, jog the mobile platform and robot arm around the workspace, and set up a skill sequence.

Besides, the preliminary software architecture for the HRI integration into the central software architecture of the CARLoS robot has been defined.

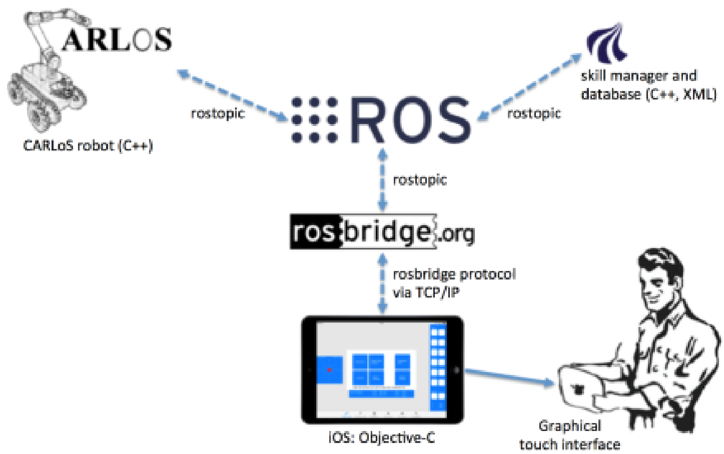

Figure 3 HRI software architecture

Laboratory trials and metrics for benchmarking have been defined at the main relevant component levels. Namely:

1. The mobile robot platform for navigation and coarse positioning
2. The manipulator and tool for fine positioning and process execution
3. The human robot interaction system for cooperative robot operation and skills-based programming

Bulkhead samples to be used in trials have been designed based on real designs of a block of ship superstructure. Two samples will be built to be available for laboratory trials in the second year of the project.

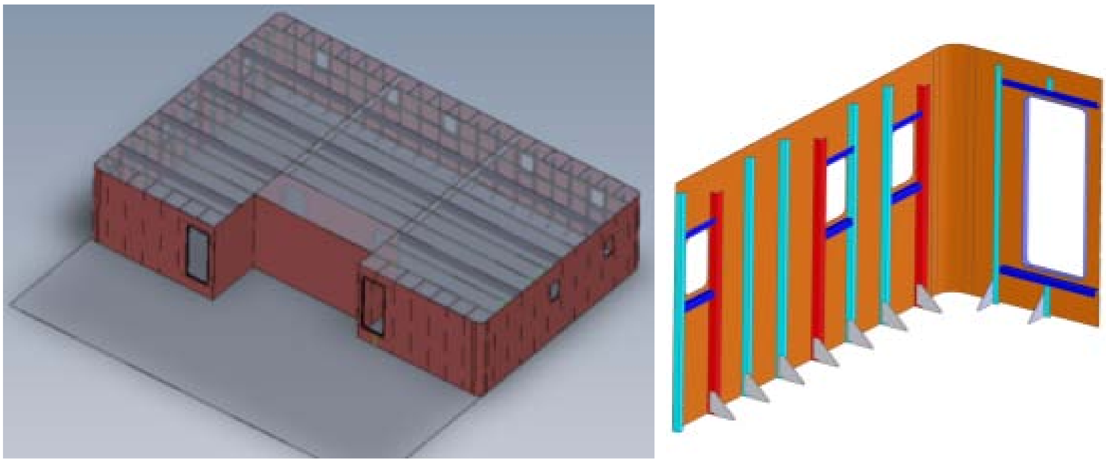

Figure 4 3D model of a real block (left) and Initial design of bulkhead for trials (right)

2.2 Second period

During this period, integration entailed an important amount of efforts with different integration workshops organised at DELTA, INES, and AIMEN. An important effort focused on the electrical and mechanical integration of the fit out system into the mobile platform. As a result the CARLoS robot prototype was delivered.

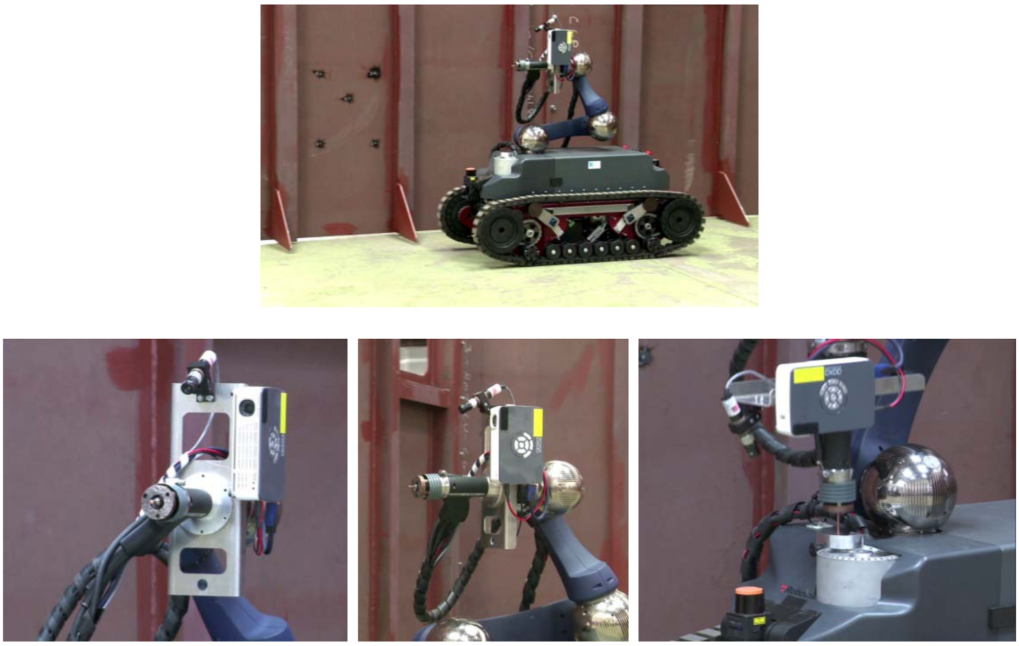

Figure 5. CARLoS mobile manipulator in its final form.

Laboratory demonstrator for SLAM, navigation and planning was realized during this period. The deliverable consisted in a 6 minute video comprising several trials. The navigation system was demonstrated in VALIÑA shipyards environment in the final demonstration.

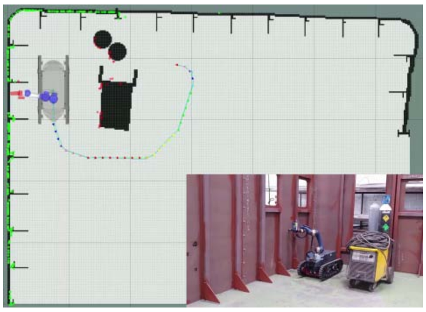

Figure 6. Navigation and welding in Valiña shipyards.

A large number of trials was performed, which were used to address different issues related to e.g. integration (communication signals, supply source), electromagnetic shielding, applied force. Different patterns in different sections were repeated in a large number of runs, removing the pins and welding again. During these tests process parameters were registered and many tests were recorded for further analysis (e.g. measurement of speed or time to failure). Moreover, these tests served to optimize process parameters, like force of the tool against the bulkhead. Kinematics issues were also identified during this process.

Figure 7 Welding tests were recorded all along the trials.

Integration of the visual feedback system (projector) and development of projection mapping functionality has been further improved since the last reporting period. It is now faster (less latency in the projected information) and more versatile in the teaching phase e.g. in relation to different objects that can be projected onto the ship wall such as fire extinguishers. This enables the operator in a safe way to instruct the task with all available environment information hence reducing the risk of errors. Extensive trials on the HRI has been carried evaluating the human robot cooperation.

Additionally, a high level mission controller was designed in order to communicate to all the subsystems of the CARLoS robot i.e. platform, arm, and user interface. This proved very useful and successful during the trials and final demo.

Finally, intensive demonstration of the robot in a real shipyard workshop from VALIÑA was performed. Navigation, stud welding and human-robot interaction were demonstrated in realistic conditions.

Figure 8 Offline web-based interface

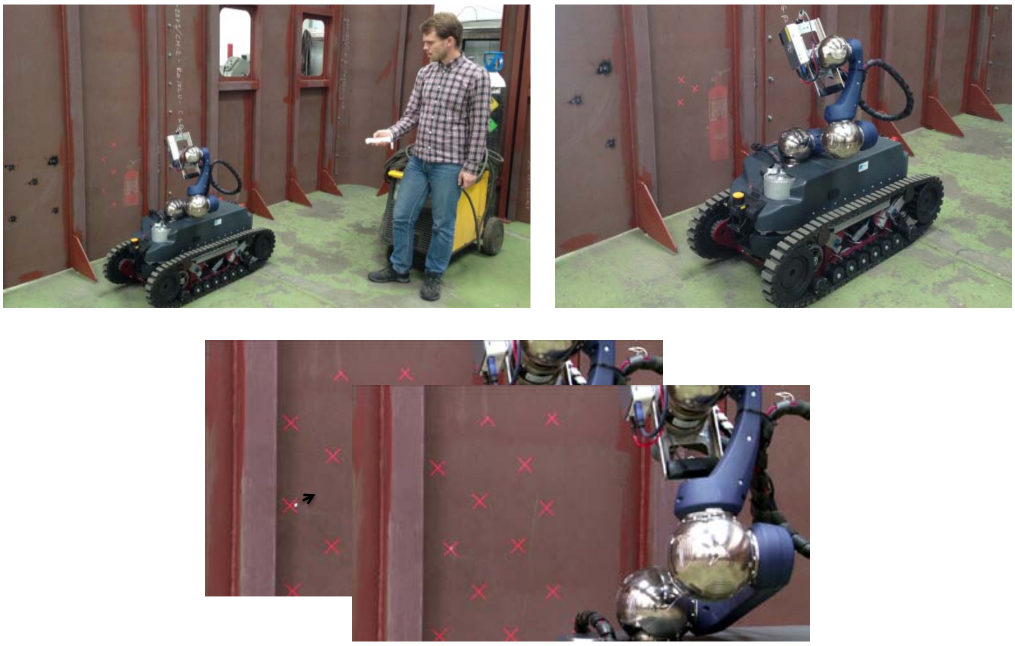

Figure 9 Projection-based interaction in the task space

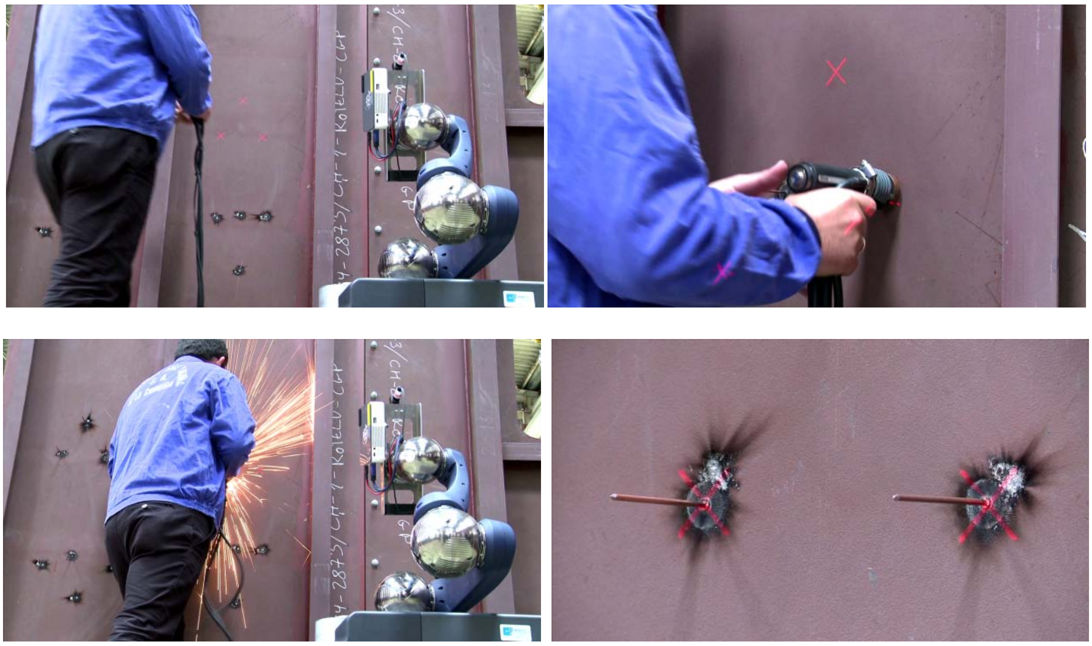

Figure 10 Welding assisted by projection maping

3 EXPECTED FINAL RESULTS AND POTENTIAL IMPACTS

CARLoS robot is expected to enable the automation of stud welding and marking in outfitting operations in shipbuilding, with an important increase of productivity, fault reduction, and competitiveness.

Besides, It will mean a step towards better (more reliable and agile) process management. In this regard, it will facilitate the implementation of innovative process management systems in shipbuilding and other sectors like industrial and civil construction based on metallic structures.

Otherwise, the CARLoS project is expected to contribute to strength the market position of European SMEs that develop, supply, and integrate mechatronic, sensing, and electronic technologies for industrial applications.

4 ADDRESS OF THE PROJECT PUBLIC WEBSITE.

Project website: www.carlosproject.eu