Project No: 608855
Project Acronym: ROBO-PARTNER
Project Full Name: Seamless Human-Robot Cooperation for Intelligent, Flexible and Safe Operations in the Assembly Factories of the Future

Final Report

Period covered: from 01/11/2013 to 30/04/2017
Date of preparation:
Start date of project: 01/11/2013
Date of submission (SESAM):
Project coordinator name:
Mr. Onder Tokcalar
Project coordinator organisation name:
TOFAS TURK OTOMOBIL FABRIKASI ANONIM SIRKETI
Version: 1

Grant Agreement number:	608855
Project acronym:	ROBO-PARTNER
Project title:	Seamless Human-Robot Cooperation for Intelligent, Flexible and Safe Operations in the Assembly Factories of the Future
Funding Scheme:	FP7-CP-IP
Project starting date:	01/11/2013
Project end date:	30/04/2017
Name of the scientific representative of the project's coordinator and organisation:	Mr. Onder Tokcalar TOFAS TURK OTOMOBIL FABRIKASI ANONIM SIRKETI
Tel:	+90 224 2610350
Fax:	
E-mail:	onder.tokcalar@tofas.com.tr
Project website address:	http://www.robo-partner.eu/

4.1 Final publishable summary report

Executive Summary of the project

Today's European industry faces the challenge to achieve flexibility and efficiency in order to improve its competitive position in the world market. There are numerous industrial applications where the assembly process is mainly performed by human operators due to the fact that

a) operations require a human like sensitivity,
b) handled materials are different and often show a compliant, unpredictable behaviour (upholstery, rubber, fabric etc.)
c) often more than one operators are active in each station to perform cooperative or parallel operations.

Nevertheless, the automation of operations in manual assembly stations and lines is highly demanded so that quality levels are increased mainly in terms of precision and repeatability, throughput time is decreased in assembly stations, traceability of the performed operations is allowed and in the meanwhile the ergonomic workload for the operators is reduced.

Rather than using a brute force approach to automate the relevant assembly processes, ROBO-PARTNER promotes a hybrid solution involving the safe cooperation of human operators with autonomous and self-learning/adapting robotic systems through a user-friendly interaction. The synergy effect of the robot's precision, repeatability and strength with the human's intelligence and flexibility will be much greater especially for the case of small scale production where reconfigurability and adaptability are of great importance. In this direction ROBO-PARTNER will work towards achieving the following objectives:

- **Highly intuitive interfaces for safe human-robot cooperation**
- **Development and introduction of advanced safety strategies and equipment** allowing fenceless human robot assembly cells
- **Robust methods and software tools for determining the optimal planning** of assembly/disassembly operations using a multi-criteria, simulation enabled approach
- **Simplified and user-friendly robot programming** by means of: a) Programming by Demonstration (PbD) and b) Robot instructions libraries
- **Introduction of mobile robots (ground and overhead)** acting as assistants to the human operators
- **Introduction of more flexible integration and communication system** for the shared data (both control and sensor).

Summary description of project context and objectives

Human skills are the main driver that enables producing high added value products in Europe. Thus, the manufacturing processes are based on utilizing these skills. ROBO-PARTNER investigated the integration of the latest industrial automation systems for assembly operations in combination with human capabilities, combining robot strength, velocity, predictability, repeatability and precision with human intelligence and skills. Thus, a hybrid solution involving the safe cooperation of operators with autonomous and adapting robotic systems through a user-friendly interaction was presented. The focus was given in the following directions:

- Development of highly intuitive interfaces for safe human-robot cooperation during assembly by using sensors, visual servoing, speech recognition, advanced control algorithms
- Development of advanced safety strategies and equipment allowing fenceless human robot assembly cells
- Introduction of robust methods and software tools for determining the optimal planning of assembly/disassembly operations using a multi-criteria, simulation enabled approach
- Adaption of simplified robot programming by means of: a) Programming by demonstration & b) Robot instructions libraries
- Introduction of mobile robots acting as assistants to the human operators (e.g. for supplying parts to the assembly line)
- Development of more flexible integration and communication architecture by utilizing a distributed computing model and ontology services.

The project was based on industrial applications, bringing its development to a maturity level that allows the introduction in industry, as well proven production technologies. Two demonstrations in automotive involved the assembly of the rear wheel group and the execution of logistics tasks. A second demonstration focused on handling of large parts by overhead robots for measurement applications and the last one on the white goods industry for the inner liner assembly.

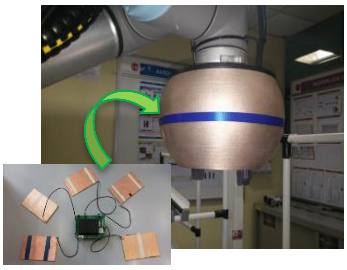
Description of main S & T results/foregrounds

During the project activities, the following S/T results were extracted:

ER1 - SAFETY TOOLS FOR HUMAN ROBOT COLLABORATION	
Owner COMAU	
Description of exploitable solution • HRC safety tools (h/w devices, s/w, integrated solutions) in manual assembly scenario • Fenceless approach for cost and space saving	
Open problem • Increase of flexibility at affordable cost • Respect of ergonomic rules for operator working area • Respect of safety constraints	
Value proposition • New logistics application with human-robot collaboration approach • Replacement of complex and expensive safety fence systems with cost saving • Improvements on ergonomic requirements for users • Reduction of the costs compared to the totally automatic solutions for complex assembly tasks • Increased reliability and flexibility due to simplified structure	
Potential customers • OEM car builders • Small, Medium and Large manufacturing enterprises • Tier 1 suppliers • White goods	
Investments needed for exploitation • Costs for testing, engineering, customization, industrialization • H/w and s/w licenses • Further developments to improve cost effectiveness of solution	
Exploitation activity • First application in a testing/lab environment • Identification of target customers • Preliminary application in actual industrial scenario, evaluation of benefits • Feedback collection, customization for specific implementations, industrialization, further industrial implementations	**Timeline** • During the project (from M24) • During the project (from M30) • Final phase of project (from M36)

• Large-scale application	• 1-2 years after end of project • 3-5 years after end of project

Pictures



Capacitive sensors and pressure sensitive skin

ER2 - DYNAMIC SAFETY ZONES FOR ROBOTIZED APPLICATIONS

Owner

PILZ

Description of exploitable solution

- Dynamic safety zones switching for robotized applications
- Human-Robot collaboration for Speed and Separation Method according to ISO/TS 15066
- Replacement of fences or fixed virtual safety zones
- Safety zones are switched using the real robot position
- Needed communication between PILZ systems and Robot controller.

Open problem

- Until now fixed robotic cells
- With the use of S-Eye we create more flexible cells without physical fencing are feasible,
- With Human Robot Collaboration methods, the cell flexibility is improved. But until now the virtual fences are fix, can be switched but according to other signals (i.e. Operator input), not according to the process

Value proposition

- With Dynamic Safety Zones, it is possible to switch different safety zones (which monitors the separation between robot and operator) according to the process
- Knowing the Robot position, different safety zones of S-Eye System can be activated/deactivated

- This gives to the cell a high flexibility modifying the safety zones according to the process and robot position, which could directly impact the cycle time and reduces downtimes of the cell

Potential customers

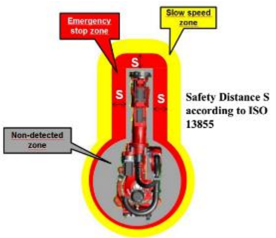
- OEM car builders
- Medium and large manufacturing enterprises

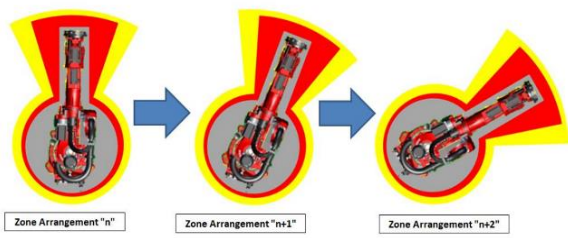
Investments needed for exploitation

- First test and implementation
- Improve Robot controller – PILZ communication
- Costs for testing, engineering, customization, industrialization
- Further developments to improve the solution

Exploitation activity	Timeline
• First concept design in ROBO-PARTNER project	• During the project (from M24)
• First implementation and test	• During the project (from M30)
• Feedback collection to PILZ headquarters → S-Eye improvements?	• Final phase of project (from M36)
• Feedback collection, customization for specific implementations, industrialization, further industrial implementations	• Final phase of project (from M36)
• Tests in industrial environment with a Pilot Case	• After Project execution

Pictures





ER3 - HAND GUIDANCE PACKAGE FOR COMAU ROBOTS

Owner

IPK

Description of exploitable solution

- Control S/W modules and interfaces for integrating the manual guidance into industrial robots
- Intuitive, modular, and safe physical HRI devices, sensors and interfaces (for both hands-on-control and hands-on-payload)

- Safety-Sensors and human-detection interfaces and tools for calibration and integration into interactive controller

Open problem

- Integrated manual guidance solutions and products
- Embedded interfaces and safety according to ISO 10218 and TS-15066
- Complex commissioning, operation (calibration, operation)

Value proposition

- Modularity
- Embedded H/W, S/W and processing
- Communication middleware and networking
- Automatic calibration
- Improved haptics.

Potential customers

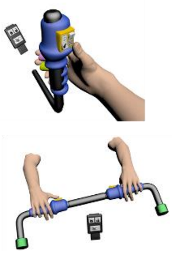
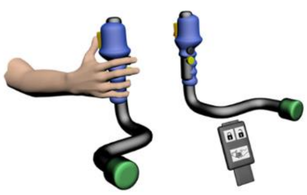
- Robotic systems providers and integrators
- Various scale manufacturing enterprises and service sectors
- Robotic/Cobotic end-users
- Sensors producers (ME-Messsysteme)

Investments needed for exploitation

- Following-on public founded projects
- Industrial projects and investments

Exploitation activity	**Timeline**
• Prototype applications tests • Development of variants • Preparation for marketing	• During the project (development phase) • During the project (demonstration) • After the project (1-2 years)

Pictures

ER4 - OVERHEAD COOPERATIVE ROBOT FOR HANDLING LARGE PARTS
Owner JATORMAN, TRIMEK, TEKNIKER
Description of exploitable solution Overhead automatic handling robot with exchangeable jaw, allowing handling of heavy loads up to 3.000 kg and achieving a wide range of 5.450 mm maximum. It can be coupled to crane or other overhead systems Safety and autonomous assistive functions will enhance robot operation
Open problem • Respect of operator safety constraints: standards and normatives • Industrial environments may affect and condition the performance of the 3D measuring systems due to hits, vibrations or movements
Value proposition • Enables highly freedom movements of heavy or bulky loads handling with the required precision • Enables remote handling in hazard or risky areas • Robot can work automatically following a given program or by an operator using a joystick • Easy exchange of gripper by a coupling-decoupling device that transmits from the robot all electrical and hydraulic signals to the gripper • Safety solution integrated in large parts handling robots enabling the integration and collaboration with high accuracy digitalization systems • Reduction of human errors • Increased efficiency during operation due to robot endowed with improved functionalities for autonomous and safe operation
Potential customers • TRIMEK or other customers with high accuracy digitalization needs (CMM): Automotive (bumpers, engine bodies, car structure, doors), windmills, airplane wings • OEM car manufacturers and TIER 2 car suppliers • Aircraft manufacturers and their main suppliers • Subcontractors that need to automate work pieces load and/or heavy tooling load • Engineering companies integrating robotics • Overhead equipment manufacturers • Wind turbine industry and its supply chain • Machine tools makers to complement portfolio

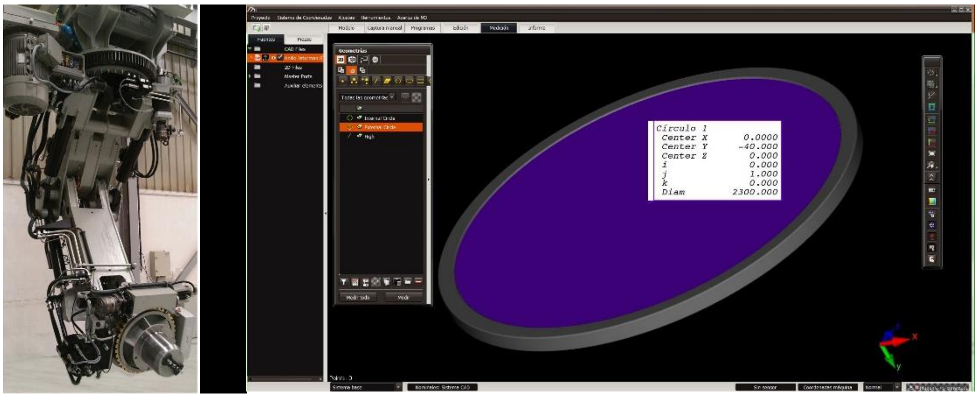
- Chemical, nuclear industry or other industries having hazards or operators risks that need to improve safety or use remote handling means
- And any other with intensive handling needs and variety of movements to be automated

Investments needed for exploitation

- Special overhead crane
- Further tests and trials, engineering, customization, industrialization and commercialisation activities

Exploitation activity	**Timeline**
• Tests and demonstrations • Public presentations • Marketing campaigning • Presentation to visitors	• 1 year after CE certification

Pictures



ER5 - MOBILE ROBOT FOR INTELLIGENT INTRA-LOGISTICS / PLANNING ALGORITHMS FOR MOBILE LOGISTICS

Owner

UNINOVA

Description of exploitable solution

- Robotic base platform adapted for shop floor environments;
- Needed communication between PILZ systems and robot hardware controller
- Novel dynamic navigation strategy for intra-logistics operations
- Integrated solution of ROBOSOFT's mobile platform with a built-in storage area and its management system – Intralogistics Mobile Assistant Unit (IMAU)

Open problem

- AGV solutions **cannot load/unload** materials to the assembly line stations by themselves, relying on human workers to perform such tasks;
- Human workforce health can suffer from **ergonomic issues** from daily intra-logistic operations

Value proposition

- Fully ROS compliant (de facto standard on robotics) IMAU with a built-in storage area capable of load/unload material boxes and equipped with multimodal sensors to operate in the shop floor
- This robot will assist the human operators by timely supplying material parts to assembly line stations
- This solution will improve the cycle time of intra-factory logistic routines and, thus, reducing the downtime of assembly operations

Potential customers

- Small, medium and large manufacturing enterprises that need smart logistics solutions

Investments needed for exploitation

- First test and implementation
- Adaptation of mobile robot controller to be safety certified by PILZ
- Costs for testing, engineering, customization, industrialization of the IMAU
- Possible further developments to improve the solution

Exploitation activity	**Timeline**
• First concept design in ROBO-PARTNER project	• During the project (from M12)
• First implementation and test	• During the project (from M33)
• Feedback collection, customization for specific implementations, industrialization, further industrial implementations	• Final phase of project (from M37)
• Tests in industrial environment with a Pilot Case	• Final phase of project (from M37)

Pictures

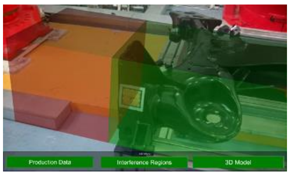
ER 6 - AUGMENTED REALITY (AR) PACKAGE FOR HUMAN-ROBOT
Owner LMS

Description of exploitable solution
 	
• Wearable solution using AR glasses to:
    • Visualize robot's working volume
    • Show robot's end effector trajectory
    • Provide to the operator upon request:
        • 3D models and animations of the assembly process
        • informational text messages
        • alerts for increasing safety awareness

Open problem • Printed instructions for each model - time required to retrieve information • Line stoppages in case of new rare/products • No means of visualizing safe working areas • Operators uncomfortable to work with robots - no indication/alerts of the robot behaviour
Value proposition • Reduction of errors by onsite assistance - Enhanced product quality • Reduction of stoppages due to operator task uncertainty • Faster access to assistive information • Elimination of documentation - non-value adding activity • Enhanced safety during cooperation - higher alertness • Real time update of information with new products • Enhanced and more intuitive training for new production lines
Potential customers • Vehicle builders (FCA, PSA, DAIMLER, FORD, VOLVO etc.) • White goods industries (Electrolux, Bosch, Gorenje, Frigoglass etc.) • Shipbuilding (NEORION etc.) • Aeronautics (AIRBUS, BOMBARDIER etc.) • Small, Medium and Large manufacturing enterprises and suppliers of the above • Already demonstrated in: Samsung, HUAWEI, NVIDIA etc. during IROS 2015 - positive feedback
Investments needed for exploitation • Costs for testing, engineering, customization, industrialization • H/w and s/w licenses • Further developments to improve cost effectiveness of solution

Exploitation activity	Timeline
• First application in a testing/lab environment • Selection of key suppliers to support further implementation phase • Identification of target customers • Preliminary application in actual industrial scenario, evaluation of benefits • Feedback collection, customization for specific implementations, industrialization, further industrial implementations • Large-scale application	• During the project (from M24) • During the project (from M27) • During the project (from M30) • Final phase of project (from M36) • 1-2 yrs. after end of project • 3-5 yrs. after end of project

Pictures



ER 7 - HUMAN ROBOT TASK PLANNING SOFTWARE (TASK PLANNER)
Owner GROBO

Description of exploitable solution
 	
• Tool for Human Robot Collaboration workplace layout generation:
  • based on multiple criteria evaluation for the alternative layouts evaluation
  • integration with 3D simulation tools
  • minimal user input
  • short time evaluation (3-4 minutes)
• Solution using the Siemens Process Simulate:
  • implementation of viewer within the simulation tool
  • visualization of the result including assembly tables, fixtures, robots, humans and parts
  • ergonomics evaluation

Open problem • Not available tool for assisting cell designers to decide for a good layout for Human and Robot workplaces

<table>
<tr><td colspan="2">• Long term procedure for generating a layout (1-6 months depending on application)</td></tr>
<tr><td colspan="2">Value proposition

• Reduce significantly the time for generating the layout alternatives for the Human Robot workplaces
• Evaluation of ergonomics and possibility to simulate solution for estimated cycle times in 3D simulation tools
• Minimal input from the user/ engineer/designer
• Proposal of a good layout generation based on the multiple criteria that the user defines</td></tr>
<tr><td colspan="2">Potential customers

• System integrators, system designers, engineering applications (COMAU, KUKA, EDAG etc.)
• Vehicle builders (FCA, PSA, DAIMLER, FORD, VOLVO etc.)
• White goods industries (Electrolux, Bosch, Gorenje, Frigoglass etc.)
• Shipbuilding (NEORION etc.)
• Aeronautics (AIRBUS, BOMBARDIER etc.)
• Small, Medium and Large manufacturing enterprises</td></tr>
<tr><td colspan="2">Investments needed for exploitation

• Costs for testing, engineering, customization, industrialization
• H/w and s/w licenses
• Further developments to improve cost effectiveness of solution
• Creating a service business model in cooperation with CAD providers to offer design services</td></tr>
<tr><td>Exploitation activity

• First application in a testing/lab environment– demonstration to SME
• Selection of key suppliers to support further implementation phase
• Identification of target customers
• Preliminary application in actual industrial scenario, evaluation of benefits
• Feedback collection, customization for specific implementations, industrialization, further industrial implementations
• Large-scale application</td><td>Timeline

• During the project (from M24)
• During the project (from M27)
• During the project (from M30)
• Final phase of project (from M36)
• 1-2 yrs. after end of project
• 3-5 yrs. after end of project</td></tr>
<tr><td colspan="2">Pictures</td></tr>
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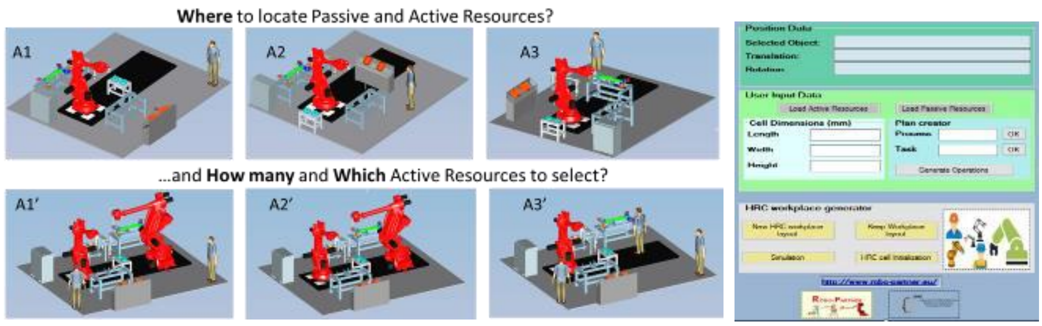
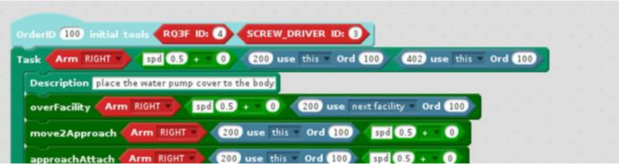
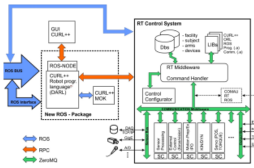
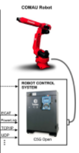


ER 8 - SIMPLIFIED ROBOT TOP PROGRAMMING SUITE AND APPLICATIONS	
Owner IPK	
Description of exploitable solution • TOP framework (high level language CURL++, MONGO-DB, ROS packages, libraries, multi-modal interfaces, graphical programming)	
Open problem • Low-level proprietary robot programming • Difficult integration of sensors and gesture programming devices, • Difficult integration and programming of interaction control.	
Value proposition • Easy, efficient, intuitive, instructive and interactive (I3) robot programming with less or without expert knowledge in robotics, interfaces to various robot control systems and ROS • Multi modal interfaces (speech, various gesture interfaces, vision etc.) • Improved human-robot communication and awareness • Middleware technology; ROS and DDS compatibility • Graphical programming interfaces (scratch); Task (skills) and behaviour oriented programming with independent program libraries, data and logic flows.	
Potential customers • Robot manufacturers and integrators (COMAU, KUKA, ABB) • Robot and cobot end-users	
Investments needed for exploitation • Following-on public projects • Internal Fraunhofer investments (start-ups) • Industrial projects and investments.	
Exploitation activity	**Timeline**

• ROS publication • Tests of applications libraries • Dissemination and preparation for marketing (start-up)	• During the project (development phase) • During the project (demonstration phase) • 1-2 years after the project

Pictures




ER9 - MULTI MODAL INTERFACES FOR HUMAN ROBOT INTERACTION

Owner

GROBO

Description of exploitable solution

- Wearable solution using headset to:
  - Send commands/ interact with the robot
  - Send instant feedback to the operator included audio/visual alerts
  - Simplified programming of the robot
- Solution using Kinect or similar sensors to:
  - Guide and interact with the robot during
    - Programming /setup
    - Production (coordinating

Open problem

- Non-intuitive robot programming
- Current practise needs a lot of experience and training
- Hardware buttons or HMIs needed to communicate with the robot- distracting humans from the task at hand

Value proposition

- Enhanced interaction by simple commands and smart wearable devices
- Shorter learning curve - less training required for operators
- Easy integration with different robot platforms as an external application

Potential customers

- Vehicle builders (FCA, PSA, DAIMLER, FORD, VOLVO etc.)
- White goods industries (Electrolux, Bosch, Gorenje, Frigoglass etc.)
- Aeronautics (AIRBUS, BOMBARDIER etc.)
- Consumer goods production (Bic, P&G, etc.)

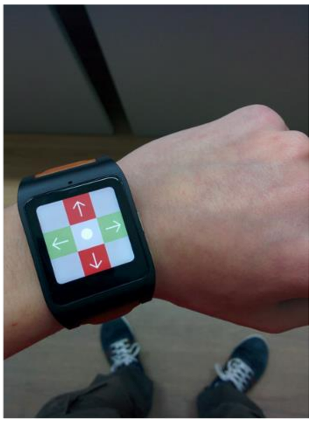
• Small, Medium and Large manufacturing enterprises

Investments needed for exploitation

- Costs for testing, engineering, customization, industrialization
- H/w and s/w licenses
- Further developments to improve cost effectiveness of solution

Exploitation activity	**Timeline**
First application in a testing/lab environment	During the project (from M24)
Selection of key suppliers to support further implementation phase	During the project (from M27)
Identification of target customers	During the project (from M30)
Preliminary application in actual industrial scenario, evaluation of benefits	Final phase of project (from M36)
Feedback collection, customization for specific implementations, industrialization, further industrial implementations	1-2 yrs. after end of project
Large-scale application	3-5 yrs. after end of project

Pictures



ER10 - INTEGRATION AND COMMUNICATION ARCHITECTURE AND REFERENCE SOFTWARE SYSTEM

Owner

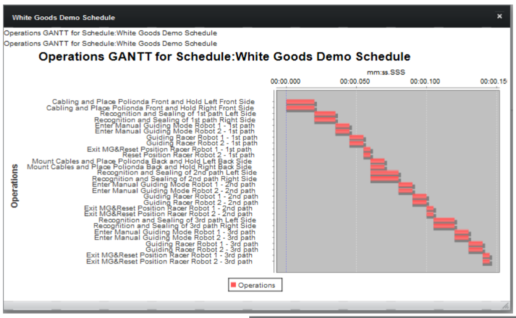
INTRASOFT

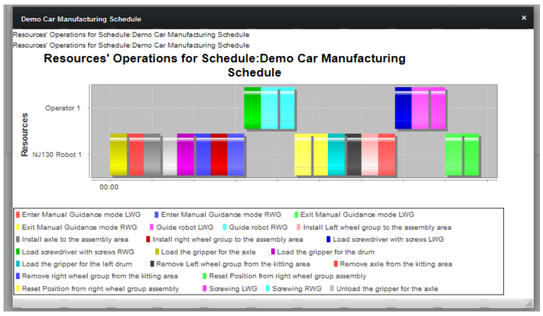
Description of exploitable solution

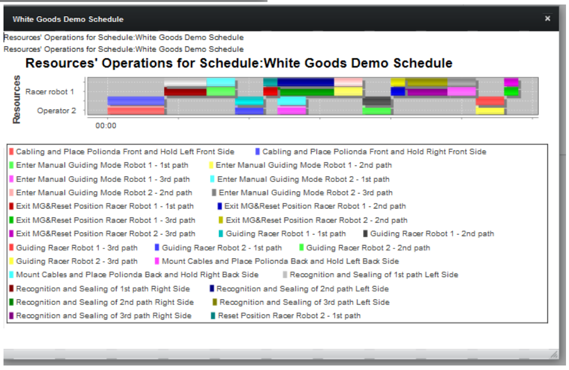
- Integrated communication software system that allows centralized control and peer-to-peer communication of manufacturing resources. The

<table>
<tr><td colspan="2">software system supports the message exchange, data sharing and coordination of autonomous and human robot collaborative operation.</td></tr>
<tr><td colspan="2">Open problem
Currently no fenceless human robot-cooperation solutions have been applied in industry yet. At the same time, no standard integration framework has been developed. Integration is either not implemented or it is being done using custom isolated interfaces of robotic resources.</td></tr>
<tr><td colspan="2">Value proposition
Software system that enables the integration of systems in workshops with assembly lines that include human-robot cooperation. Offers:
Centralized coordination of resources
Service oriented architecture.
Includes Shared Data repository, messaging and communication mechanisms</td></tr>
<tr><td colspan="2">Potential customers
Manufacturers that intend to utilize assembly lines that include human-robot cooperation.
OEMs such as (car builders and white goods manufacturers)
Medium and large manufacturing enterprises
Tier 1 suppliers
SMEs
Universities and research labs
Research Performing Organisations (RPOs)</td></tr>
<tr><td colspan="2">Investments needed for exploitation
Cost Structure
Engineering costs (personnel)
Software License Costs
Hardware Costs
Data Centre Costs
Cost of further development and improvement. (Improve cost effectiveness of product and evolve product)
Cost of product industrialization</td></tr>
<tr><td>Exploitation activity
Potential Channels:
Direct sales
Industry events and manufacturing exhibitions
Publications
Inbound marketing
Social Media
Technology Brokerage Events</td><td>Timeline
M36</td></tr>
</table>

• Multi-Side industrial platforms	
Pictures	







Results achieved regarding the demonstrators

The project is based on industrial applications, bringing innovative human robot collaborative work cells to a maturity level that allows the introduction in industry, not as experimental equipment but as well proven and reliable production technologies.

Automotive Industry. TOFAS pilot consists of two major components: the human robot collaborative cell for the assembly of the rear wheel group and the intralogistics mobile assistant unit.

"Rear wheel group pre-assembly": Rear wheel group assembly case includes the manipulation of heavy parts such as the rear axle (around 30 kg) and the two drums (around 12 kg each), flexible parts such as cable and small sized parts such as screws. The heavy and difficult tasks of this assembly scenario were assigned to COMAU NJ130 robot, due to its advanced manipulation and control capabilities, as well as its payload (130 kg). The flexible part (cable) and small part manipulation and assembly were assigned to human due to its dexterity and flexibility in assembly. Under this collaborative cell, novel communication and interaction mechanisms have been implemented and integrated under the service oriented ROBO-PARTNER Integration and Communication platform. Augmented Reality applications interfacing in wearable devices (AR glasses, tablets, smartwatches etc.) have been used for increasing human safety feeling while including him in the execution in a non-intrusive way. Moreover, human

robot direct interaction techniques such as manual guidance have been realized in order to reduce operator’s fatigue and physical strain. In order to ensure the safe human robot collaboration while producing a certifiable solution according to European standards, a safety architecture has been implemented based on the outcome of the first version of Risk Assessment for the automotive pilot. A dedicated Safety Controller (Safe PLC) has been introduced, integrating all the safety devices (B&R PLC – PILZ SafetyEye, push buttons, indicator lamps, enabling devices etc.) involved in the scenario while handling all the generated signals and distributing the requests for the required actions. The cell for this case is illustrated in Figure 1.

Figure 1: Rear Axle Collaborative Assembly cell at LMS premises

“Intralogistics Mobile Assistant Unit (IMAU)”: Under ROBO-PARTNER, a novel autonomous mobile robot has been designed in order to carry out the intra-logistics operations inside the industrial shop floor of TOFAS end user. The Intralogistics Mobile Assistant Unit (IMAU) was designed to fulfil the needs of an automotive company in terms of autonomously loading, unloading and transporting material boxes from the warehouses to the assembly stations. The final version of the IMAU is visualized in Figure 2. Concerning the software architecture, it was designed to be a context–aware modular distributed architecture. The complexity of operating in a dynamic environment is dealt with by associating the surrounding context with predefined operation profiles, i.e., sets of software and hardware behaviours and energy consumption strategies. When loading a box from a station, for example, the majority of the IMAUs sensors will focus on retrieving the necessary information for a correct box identification while the navigation module will remain in a quasi-dormant state.

Such behaviours reduce the energy consumption while maintaining the system's performance. The defined architecture is divided into three major groups, low-level hardware interfaces, mid-level modules and, finally, higher-level reasoning modules. The hardware layer interfaces all sensors and actuators of the IMAU. The mid-level group is divided into three modules manipulation, perception and navigation. While, the top-tier is divided in two with a supervisory module and human-robot interface.

Figure 2: Intralogistics Mobile Assistance Unit (IMAU)

Large Parts Inspection Industry. The main outcome of the ROBO-PARTNER project was the design and creation of the HERCULES robot, a 10 tones payload robot integrated on a crane, able to detect, pick and place large parts. Using cameras and sensors (ENSENSO camera, laser scanners, ASUS 3D sensor) the robot is able to detect the part before handling it, as well as its environment, either humans or obstacles, and adapt its behaviour accordingly. In addition to this, a 3D measuring system was also installed in the area, able to inspect the large parts and make a point cloud based on their shape and size. After that, an advanced algorithm, compared this point cloud with the CAD design of the part, extracting different types of information (dimensions, shape, position etc.) and helping the robot better manipulate it. Lastly, from the hardware side, a remote controller was created for the robot, including an interactive GUI as well as haptic feedback, allowing the operators to easily interact with the robot. The final version of the Hercules robot is visualized in Figure 3.

Figure 3: Hercules Robot

White Goods Industry. Following the Electrolux requirements and specifications and the safety requirements, a preliminary version of the demonstrator has been designed, accordingly, at LMS premises. This pilot has been used as a starting point to integrate the ROBO-PARTNER technologies and modules developed within the project and, successively, it has been finalized, tested and validated at LMS machine shop, replicating a working environment quite close to the industrial one. In this demonstrator, which represents a working station of refrigerator assembly lines, novel communication and interaction mechanisms have been implemented and integrated using the service oriented ROBO-PARTNER Integration and Communication platform. Augmented Reality applications, interfacing with wearable devices (AR glasses, tablets, smartwatches etc.) have been also integrated to increase the human safety feeling while including the operator in the execution loop. Human-robot direct interaction techniques, such as the manual guidance, have been also included in the cell in order to reduce the operator's fatigue and physical strain. Moreover, in order to ensure the safe human robot collaboration, while producing a certifiable solution in relation to European standards, a safety architecture has been implemented based on the outcome of the first version of Risk Assessment for the white goods pilot. In addition to this, further safety sensors, such as the robot

Safety skin, were introduced in order to ensure the safe close collaboration between human operators and industrial robots. The cell for this case is illustrated in Figure 4.

Figure 4: Demonstrator close up of the robots and the simulated tooling

Potential impact and main dissemination activities and exploitation results

In the proposal phase of the project it was estimated that “As a direct consequence, system integrators, expect to increase market share, especially in new developing high-potential sectors, to achieve a market share up to 6-7% or more in Europe, with an additional increased penetration in non-European markets”.

Considering the project achievements this objective can be considered as fully achieved especially due to the generic nature of the technologies that are applicable in multiple production stages and very diversified sectors. According to the latest reports the four industry groups that are expected to be on the front of investment for robotics are: computers and electronic products; electrical equipment, appliances, and components; transportation equipment; and machinery. **At least 85% of the production tasks in these industries are automatable** involving assembly and the tending of machines which are highly repetitive[1].

Especially for the automotive sector and their suppliers the market for collaborative robots is very large:

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[1] H. L. Sirkin, M. Zinser, and J. Rose, 2015, Industries and Economies Leading the Robotics Revolution, link.

FCA only operates more than 15 assembly lines in Europe and Estimates around **20 – 30 applications in each line** where the THOMAS results are applicable. Thus around **450 applications come only from one automotive OEM**. Considering that there are at least 8 more major firms in EU (PSA, Daimler, Citroen, BMW, Audi, Renault, Opel, Ford, Volkswagen) the number becomes **3600**. The identified applications are assembly, refuelling, assembly and screwing, kits insertion/removal from the line etc.

In a similar way, TIER 1 suppliers may also be considered for application of the ROBO-PARTNER solutions and are a potential customer base with direct business potential after the end of the project:

Company name	Plants/ Countries	Estimated number of applications
VALEO	136/ 29	More than 350, at least 2 or 3 per factory.
GRUPO ANTOLÍN	161/ 26	More than 400 applications.
FAURECIA	330/ 34	More than 500
GESTAMP	100 /20	More than 75

Table 1: Automotive tier 1 suppliers

Similar projections can be made for the white goods and large parts measuring industries. More detailed analysis can be found in the WP8 deliverables.

The projections on the impact that robotics will have on competitiveness are more than convincing on the direction to be followed: **assuming that robots will perform at least one-quarter of the manufacturing tasks** that can be automated, (current global average is 11%) the **average savings in total manufacturing labour costs until 2025 could be 16%** lower, in the world's 25 largest goods-exporting economies than they would be otherwise. By installing advanced robots, and depending on the location, **output per worker in manufacturing industries will be 10 to 30% higher** in 2025 than it is today. This is well above the productivity gains that can be expected from other measures, such as lean production practices and better supply-chain management. Robotics systems currently cost around $10 to $20 per hour, on average, to own and operate in the U.S.—**already below the cost of human labour**—and will decline further over the next decade. The following list summarizes the expected percentages of robotized production tasks by 2025 for the leading economies:

a. Aggressive adopters (South Korea, Taiwan, Thailand): **40-50%**
b. Fast adopters (Canada, China, Japan, Russia, UK, U.S): **30-45%**
c. Moderate adopters (Australia, the Czech Republic, Germany, Mexico, Poland): **30-35%**

d. Slow adopters (Austria, Belgium, Brazil, France, India, Italy, Netherlands, Sweden, Spain, Switzerland): **15%**

By addressing all this potential market, the original objective of achieving 6-7% additional market share is considered feasible when considering the tangible project outcomes.

When considering the white goods sector the impact refers to:

- Increased flexibility and productivity in sealing process. The joint operability of the human-robot team and the cooperative control of the correctness of the process might assure high level of quality and repetitiveness
- A better-quality performance of a reproducible process (sealing) without requiring too relevant investment. The preliminary calculation of ROI has demonstrated that the potential investments are in line with the Electrolux criteria
- Opportunity for employees to skip repetitive work that could not previously be automated. In the demonstrator, the OCRA analysis is still under evaluation. In other applicable cases, the application of HRC technologies might eliminate some ergonomically unfavorable manual tasks in favor to others considered simpler. .
- A good technological base to reduce risks of injuries. The safety package developed for the pilot cell (technologies for robot as impedance control, force limitation, safety skin) and the auxiliary devices to support the human operability and the process control (such as AR glasses, robot-connectable objectives etc.) are a good starting point to ensure operator's safety.

The idea proposed by ROBO-PARTNER is perceived as a strong innovation compared to the current state of technology, because the industrial grade robots are more robust and flexible in operations when a higher payload is required. The industrial collaborative robot, even more with the most recent models now available in the market, can also offer optimized performances in terms of precision, strength and applicability, beside the possibilities to install a higher variety of end effectors for the scope of the application. Moreover, their functionalities are well-known among shop-floor personnel and also in terms of maintenance, the impression is that the lightweight robots will require more activities and costs than industrial ones for the same applications.

The knowledge gained by the Electrolux team in ROBO-PARTNER project might be fast transferred, also partially, into the assembly lines in various manufacturing areas and systems. Initially it will be applied into the selected scenario area and successively in other potential cases, described below. The feeling that the extensive application of HRC technologies, capable of mixing the human intelligence and the robot efficiency, can drastically improve the productivity within the factories is considered a priority challenge in Electrolux manufacturing innovation

Other important figures proving the high impact of the project are as follows:

- Number of exploitable results: 10
- Number of patents submitted: 1
- Share of participating SMEs: 35.7%
- Training & Events: 40
- System integrators market share potential: 6-7%
- Full scale demonstrators: 3
- Type of new jobs created: 4
- Scientific publications
    - More than 15 peer reviewed publications
- Dissemination Activities – Participation in fairs
    - 26 Presentations
        - European Robotics Forum 2014
        - EU FoF Impact Workshop 2014
        - Robotic Technology Exhibition 2014 (RTEX 2014) Pre-Launch
        - IEEE International Conference on Industrial Informatics (INDIN 2014)
        - Leading Enabling Technologies for Societal Challenges (LETS 2014)
        - European Robotics Forum 2015 (ERF 2015) - Hybrid Production Systems
        - EU Impact of the Factories of the Future PPP 2015 – Human-centred Manufacturing: Human Robot Interaction
        - CIRP Conference on Manufacturing Systems (CMS) 2015 - Augmented Reality applications for supporting human robot interactive cooperation, and Performance assessment for production systems with mobile robots

- CIRP Global Web Conference 2015 (CIRPe 2015) - Design considerations for safe human robot collaborative workplaces
- Robotic Technology Exhibition 2015 (RTEX 2015)
- National Congress of Mechanical and Industrial Engineering 2015 (CONEMI 2015) and State Seminar of Mechanical and Industrial Engineering 2015 (SEEMI 2015)
- International Symposium on Mechatronics and its Applications 2015 (ISMA 2015) - A Health and Usage Monitoring System for ROS-based Service Robots
- Robot Forum Assembly 2016 (RFA 2016) - ROBO-PARTNER: Safe human-robot collaboration for assembly: case studies and challenges
- European Robotics Forum 2016 (ERF 2016) - ROBO-PARTNER - Human robot interactive cooperation in hybrid assembly systems, Human – Robot Partnership in assembly operations, Planning of mobile assistant units in assembly lines for performing material supply operations, and Task Planning in Flexible Manufacturing
- Impact of the Factories of the Future PPP
- CIRP Conference on Assembly Technologies and Systems 2016 (CIRP CATS 2016) - A Decision Making Framework for Human Robot Collaborative Workplace Generation, and Short – term planning for part supply in assembly lines using mobile robots
- RoboBusiness Europe 2016
- Industrial Technologies 2016
- International Conference on Machine Design and Production 2016 (UMTIK 2016) - Industry 4.0 and Deployment Of Internet Of Things Technology In Production
- European Factories of the Future Research Association (EFFRA) Factories of the Future Conference 2016 - Materialising Factories 4.0

        - European Factories of the Future Research Association (EFFRA) Factories of the Future Conference 2016 - Materialising Factories 4.0 - Making Innovation Happen
        - Turkey in Horizon 2020 Cities of the Future 2016
        - IEEE International Conference on Systems, Man, and Cybernetics 2016 (IEEE SMC 2016) - Context-aware Switching between localization methods for robust robot localization, and On the design of the ROBO-PARTNER Intra-Factory Logistics Autonomous Robot
        - Next-Generation Robotics & Automation Technologies 2016 - Automotive Manufacturing 2016
        - ERF 2017 - http://www.erf2017.eu, Organization of workshop in Hybrid production Systems - Live demo of AR and smartwatch technologies
        - Turkey's 3rd National Robotics Conference (TORK 2016) - Human robot interaction in hybrid assembly systems using medium payload robots
    - 6 Joint presentations with other projects
    - 6 Booth/Posters/Leaflets
    - 7 Exhibitions/Demos
- Other - High visibility in all major European events
    - Automatica 2016
    - CIRP Conferences (CATS, CMS etc.)
    - IROS 2015
    - European Robotics Forum (2014/2015/2016/2017)
    - FoF Impact Workshops

Address of project public website and relevant contact details

- **Coordinator:** Onder Tokcalar, onder.tokcalar@tofas.com.tr
- **Project Manager:** Dr. George Michalos, michalos@lms.mech.upatras.gr
- **Project website address:** http://www.robo-partner.eu/

  On the web portal, the following data are available for the public:

    - Technical Objectives
    - Demonstrators
    - Project Newsletters (6 issues)
    - Public papers
    - Public conference presentations
    - Consortium information
    - Contact and Social media information
- **Facebook address:** https://www.facebook.com/robopartner.euproject
- **Twitter address:** https://twitter.com/ROBOPARTNER
- **YouTube channel address:** https://www.youtube.com/user/ROBOPARTNER
- **Google+ address:** https://plus.google.com/106758057480234180817