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Abstract	Four demonstrators are presented and their use cases in two different scenarios. The requirements of the scenarios and use cases are matched against the available functionalities of the demonstrators and the components to be developed in SP2, respectively. The essential functional primitives are highlighted for each use-case to show the potential extrapolation of the selected use-cases to similar use-cases within the same scenario context.

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1.0	16/01/2015	Final review and submission	TUE

Content

List of Acronyms

WP	Work Package
SP	Sub Project
DoF	Degree of Freedom
I/O	Input/Output
RGB	Red Green Blue
ROS	Robot Operating System
URDF	Unified Robot Description Format
OGRE	Object-Oriented Graphics Rendering Engine

1 Introduction

This report analyses the application scenarios and concrete use cases defined in WP11 that have been selected for implementation within the work package 42. The scenarios are selected to enable an evaluation of the R5-COP technologies with respect to robustness, flexibility, and re-configurability.

The hardware setup of WP42 demonstrator platforms is presented, justifying their appropriateness for the defined use cases. The requirements of the scenarios and use cases are matched against the available functionalities of the demonstrators and the components to be developed in SP2, respectively. The essential functional primitives are highlighted for each use case to show the potential extrapolation of the selected use cases to similar use cases within the same scenario context. The use cases were defined with the target of containing as many functional primitives of the single domains as possible to claim their universality.

The report constitutes the base for the subsequent implementation and integration tasks in work package 42. The extraction of the functional primitives provides the possibility of reusing the different software modules that are already available, or implemented in R5-COP.

1.1 Purpose of document

The document presents the selected application scenarios and specifies the corresponding integration plans and robot platforms to be used, based on the results from task 42.1.

2 Demonstrator platforms

Five demonstrator platforms will be used to implement the two specified use cases, designed for the respective application domains: household and inspection.

2.1 AMIGO

The AMIGO (acronym for: Autonomous Mate for IntelliGent Operations) is a domestic service robot, designed and developed by the Eindhoven University of Technology (see figure 2.1). This human-size robot has a custom-made holonomic base platform, an extensible body, two 7 DoF arms and a 3D vision system.

Figure 2.1: Picture of service robot AMIGO, developed by TUE.

2.1.1 Hardware Components

The frame design of the AMIGO is based on stiffness and can be compared to the Eiffel Tower: four legs are connected to a central box (see figure 2.2). These legs and the central box are made out of aluminum and steel sheets, hence resulting in a construction that is light as well as stiff. Furthermore, using sheet metal reduces the amount of milling required for manufacturing, hence it is both easier and less expensive to manufacture. The legs are used to house the motors and the wheels: four omniwheels are used with the axes along the diagonals of the base platform. The main advantage of this omniwheel platform is that it is holonomic, i.e., it can move instantaneously in any direction, without having to turn first. To maximize the stability and the available space for peripheral equipment, it is chosen to use four omniwheels.

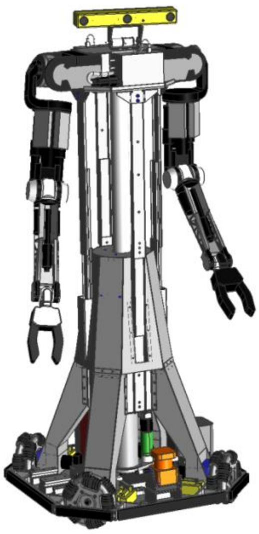

Figure 2.2: Technical drawing of AMIGO

Four mini-PCs with Core i5 processors are placed on the base platform. The PCs are connected to the motors and the encoders using Beckhoff EtherCAT stacks, containing terminals for digital and analog I/O, encoder modules and RS485 modules. Four 24 V, 3.3 Ah Makita power tool batteries are placed on the base platform to provide the necessary power to the robot.

On top of the base platform, the upper body of the AMIGO is mounted using a ball screw spindle mechanism. This way, the robot is able to adjust the height of the upper body: in its lower position, AMIGO is able to pick up objects from the floor. In its upper position, the robot has the size of a child. This way, it is able to operate most features in a domestic environment, while at the same time having a friendly appearance.

For manipulation, two 7- DoF Philips robotic arms are attached to the upper body. Six DoFs are required to position the gripper in any location and orientation, while a seventh, redundant DoF is added to enable the possibility to avoid obstacles. This is similar to human arms. The shoulder, elbow and wrist joint are equipped with a differential drive. This way, a very compact design of the arm is possible. Each arm can lift up to 1.5 kg when fully stretched. With an own (moving) mass of 3.9 kg this leads to a mass-payload ratio of 2.6:1. Furthermore, force sensors are present to measure the force in the joints, so that force control can be applied.

For navigation and object recognition, the AMIGO relies on various sensors. On the base of the robot, a Hokuyo laser range finder is placed. This provides a 2D image of its surroundings at a 40 Hz rate, which is used for localization and obstacle avoidance. Furthermore, a ‘Kinect for Xbox 360’ camera is placed on top of the robot. This is mounted using a pan and tilt mechanism so that it can turn left and right as well as look up and down. The Kinect camera features an RGB camera and a depth-sensor, both operating with 640_480 pixels @30 Hz. The depth-sensor consists of an infrared laser projector combined with a monochrome CMOS sensor. The data from this sensor is pre-processed on board, such that only a point cloud is sent to the computer. The point cloud can be used to obtain a 3D map of the environment and to detect the shape of certain objects. Subsequently, the RGB camera can be used to actually recognize certain objects using 2D techniques. In addition to visual sensors, the Kinect camera also possesses an array of microphones, which can be used for human-robot-interaction.

For transmitting the video image from the AMIGO back to remote locations, a TTS multi-modem real time video system shall be mounted. This technology shall bond multiple modems, networks, and operators so that a virtual broadband link is provided. The digital video feed from any one of the AMIGO cameras shall be encoded in real time and transmitted in high quality while the AMIGO is also moving.

2.1.2 Existing Software Modules

The software on the AMIGO robot is developed within the ROS (Robot Operating System) framework (ROS Wiki), (Quigley et al, 2009). ROS basically has two main features: First of all, it provides a structured communication layer above the host operating systems of a computer cluster. This is based on a graph architecture where processing takes place in nodes that may receive, post and multiplex messages regarding sensors, actuators, planning and control. Secondly, ROS has a large suite of user-contributed packages and stacks for various functions, e.g., planning, navigation, perception and simulation. The AMIGO software is partly based on these packages, which have been extensively modified for this robot.

One of the most basic skills of a service robot is the ability to drive safely to certain target positions. This ability can be divided into six basic skills:

1. Acquiring environment data
2. Localization
3. Mapping
4. Path-planning
5. Obstacle avoidance
6. Control

For all these basic driving skills, dedicated components are being implemented. Most of the primitive actions are currently at the level appropriate for usage. The combination of these primitive actions is something that will need the results from the R5-COP project.

Next to driving around, a robot should also be able to move its manipulators. In order for a service robot to perform tasks involving safe arm movement, such as grasping or object manipulation, collision-aware arm navigation is of vital importance. This ability comprises six main skills:

1. Obstacle detection
2. Constructing a collision map
3. Solving collision free inverse kinematics
4. Planning of a collision free path
5. Control
6. Online collision monitoring and dynamic aborting.

For these basic manipulation skills, dedicated components have been implemented, however all are still in beta state, and require improvement on many aspects.

2.1.3 Simulator

Before implementing software on the actual robot, it is extensively tested in a simulator. To model the robot for the simulator, the Unified Robot Description Format (URDF) is used. This is an XML specification for representing a robot model, assuming that a robot consists of rigid links connected by joints. A link element describes a rigid body with inertia and geometric properties, while a joint element describes the kinematics, such as the joint type, and the dynamic properties, e.g., friction and damping. This model subsequently uses ROS plug-ins to simulate the sensor data from the camera, the laser range finder and the encoders in the base and arms. This simulation model is subsequently used in the Gazebo simulator, a 3D rigid body simulation package which uses Open Dynamics Engine and OGRE. Open Dynamics Engine is a physics engine based on linear complementarity problem constraint formulation, and Object-Oriented Graphics Rendering Engine (OGRE) is a scene graph 3D rendering engine. Various environments, either fictional or measured, can be used within the simulator. The simulation results can be visualized using the rviz package, a 3D visualization environment for robots using ROS that is used for displaying both simulation results as well as actual robot behaviour.

2.2 PR2 and Toad

PR2 and Toad are candidates for solving cooperative tasks combining indoor and outdoor requirements. The ongoing development with PR2 and Toad platforms is focused on tasks to autonomously hand over the objects being conveyed from inside to outside environment (or vice versa).

PR2 is indoor platform designed for research and innovation, developed by Willow Garage and currently maintained by Clearpath Robotics. It is designed as a humanoid, so it has two arms, telescoping torso and head. Instead of legs it has omnidirectional base, which provides more stability.

PR2 is designed to be a personal robot, which means that he is supposed to help and assist people in everyday tasks, like doing dishes, laundry etc. Plenty of sensors are placed on PR2, which helps him work in unstructured environments. It has many safety features to prevent any damage to him or to environment around him.

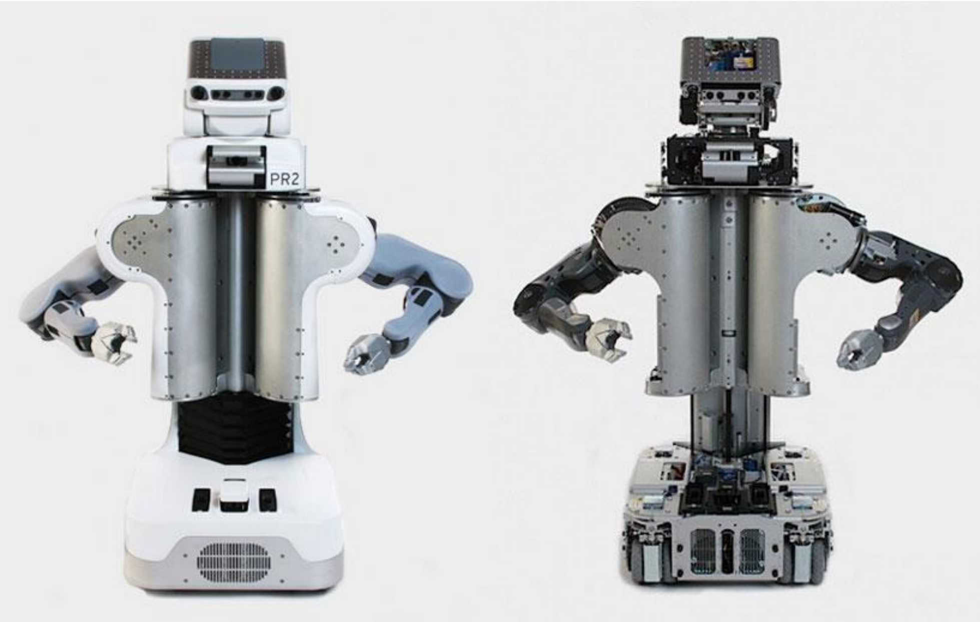

Figure 2.3: PR2 with, resp. without cover.

The Toad is the outdoor mobile platform designed and developed by BUT, Robo@FIT group. The Toad is focused on development of large-scale SLAM, 3D environment model reconstruction, navigation and exploration.

Figure 2.4: Toad design schema and its realization.

2.2.1 Hardware components

PR2 is composed of omnidirectional base with 4 independent caster wheels, telescoping torso, two arms (each with 8 degrees of freedom) and head placed on pan/tilt platform.

Inside the base, two servers control the robot. Each of them contains two Quad-Core i7 Xeon processors and 24GB RAM. The base also contains 1.3 kWh Lion Battery Pack which ensure PR2 approximately 2 hours runtime. The Hokuyo UTM-30LX laser scanner is mounted on the top of the base, which has 270° field of view and 30 meters range. It is used mainly for obstacle detection, localization, mapping of environment and safe navigation.

Between the base and the head is a telescopic spine. When it is fully extended, the height of the robot can be raised from 1330 mm up to 1645 mm (from the floor to top of the head). Two robotic manipulators are attached to the torso. Further, the tilting laser scanner (also Hokuyo UTM-30LX) is placed in the upper part of the torso. Combination of tilting platform and 2D laser scanner allows robot to observe space in front of him as a 3D point cloud. Although this solution is slower than full 3D laser scanner, such solution is of the order cheaper. On the back side of the torso, a big red safety button is placed. Pressing this big-red safety-button directly interrupts current to all robot motors to prevent any damage.

Both manipulators consist of arm with 4DOF, wrist with 3DOF and a gripper with 1DOF. Manipulators are back-drivable and current controlled, so they can manipulate in unstructured environments. Moreover, there is a passive spring counterbalance system so the arms float even when the power is off. The wrist contains colour camera pointed to the gripper. Two of overall 3 joints on wrist are continuous which allows PR2 easily mount screw or manipulate frying pan. Moreover, the right gripper is equipped by a force/torque sensor.

The PR2 head can be rotated around in 350° and tilted forward and backward in 115°. It means that robot can look around his body without rotating himself. He can even look down at his back and check if is safe to drive backward. In front side of the head, two pairs of stereo-camera are placed with narrow and wide field of view. Wide-angle colour stereo camera is usually used for observing environment and narrow angle monochrome stereo camera is meant to be used for observing manipulated objects. Next to them, there is a 5 megapixel camera and the texture projector. An additional depth sensor (MS Kinect) is mounted on the top of the head.

Toad platform is based on Pioneer 3-AT solution of MobileRobots and is equipped with various depth and vision sensors for research and experimental tasks. The 3D lidar, Velodyne

HD Lidar HDL-32E, lasers are aligned from +10° to -30° to provide an unmatched vertical field of view, and its patent pending rotating head design delivers a 360° horizontal field of view natively. The HDL-32E generates a point cloud of 700,000 points per second with a range of 70 meters and typical accuracy of +/- 2cm. Then standard 2D Lidar, Hokuyo UTM-30LX, and low-cost structured-light dept sensor (MS Kinect) are also included. Further, high-performance, miniature GPS-Aided Inertial Navigation System (GPS/INS), IMU+GPS 3DM-GX3-45-USB-SK1, is used as one source of localization data. For vision purposes, the couple of UniBrain cameras is mounted on the platform and used for computation of stereo-dissimilarity map and/or terrain analysis and obstacle detection and object classification.

2.2.2 Existing Software Modules

Like Amigo, PR2 is built on the top of the ROS, which provides communication layer between all parts of robot (PCs, sensors, actuators etc.). ROS consist of several tools, libraries and conventions which simplify creating complex and robust robotic applications. It contains packages for basic functionality like acquiring environment data, localization and mapping, obstacle detection, collision free path-planning etc. These modules are developed and tested by many users across the whole world.

We use MoveIt! to navigate and control robotic arms on PR2 and other platforms. It is state-of-the-art software for mobile manipulation with latest advances in motion planning, kinematics, 3D perception, navigation, control etc. Since it is originally developed by the Willow Garage, it is already implemented on PR2.

Over these basic modules, some advanced modules are currently in development either by us and other researchers. These include modules for object detection and pose estimation, localization and mapping in dynamic environment, interaction with the user and interaction between multiple robots.

Besides fundamental modules already developed in ROS and utilized by PR2 for the following tasks:

PR2	Toad
• Acquiring environment data • Localization and Mapping • Path-planning and control • Obstacle detection	• Acquiring environment data • Localization and Mapping (GPS, terrain cost map) • Path-planning and control

• Collision free Path-planning and Control	

Other, more advanced modules improving the autonomy and functionality of service robots like PR2, that are under development and/or experimental stage are:

PR2	Toad
• Object detection and pose estimation • Localization and Mapping in dynamic environment • Interaction with the user (visualization, gestures) • Interaction between robots (data sharing, control).	• Collision avoidance • Interaction between robots (data sharing, control)

2.2.3 Additional equipment

Toad and PR2 may carry 3rd party equipment to assist in, as well as broaden the scope of and/or benefit from, their assignments.

In one example and in one of the integration scenarios listed below, TTS video processing and/or transmission over multiple links shall be integrated. With that, high quality video may be transmitted to remote monitoring and control from outdoor, without deploying new networks bur when relaying on existing cellular and WiFi networks, wherever assignment takes place. This is especially relevant for the search and rescue scenario, the examination of suspicious objects and other security related scenario. The TTS system shall be carried by the robots, use either the robot own cameras or dedicated cameras, and transmit using it's internally integrated modules.

2.2.4 Simulation

To simplify and speed up our research and development on PR2, Toad and other robotic platforms, we use the Gazebo simulator. Gazebo offers the ability to accurately and efficiently simulate populations of robots in complex indoor and outdoor environments. It can simulate any type of robot based on the Unified Robot Description Format (URDF). Model inside the simulator can provide data from various sensors like laser range finders, 2D/3D cameras, Kinect style sensors, contact sensors, force-torque, and more. To achieve realistic rendering of environments including lightning shows and textures, the OGRE library is used.

Model describing PR2 is already included in gazebo simulator and it is ready to use. For Toad, we had to create the model by ourselves (see figure 2.5).


Figure 2.5: Toad model in Gazebo simulation tool.

2.3 DrRobot Jaguar

The research group Mechatronics at Saxion has a Jaguar 4x4 Wheel platform from DrRobot (www.drrobot.com) to be used as a carrier in several research projects.
The main electronics is similar to that of the smaller two wheel drive DrRobot X80SV, also owned by the group. So software that is developed for e.g. navigation can be shared.


Figure 2.6: DrRobot Jaguar (left), DrRobot X80SV, modified (right)

2.3.1 Hardware Components

The Jaguar is fit for outdoor use, has 4 80W motors, and can carry up to 20 kg payload. The standard platform is equipped with the following major components:

- GPS and 9-DOF IMU
- Integrated fixed camera with audio
- Integrated wireless router (for communication with base laptop and transfer of video)
- Logitech gamepad controller for manual operation

As an option a Hukoyo 04 Laser Range Finder (not on picture) is fitted.

The next half year a student group project will focus on hardware integration with:

- A breadboard payload platform on top, above the Hukoyo level
- A small Scara robot arm with Dynamixel motors, plus gripper, now being built
- A (steerable) network-camera (Vivotek)

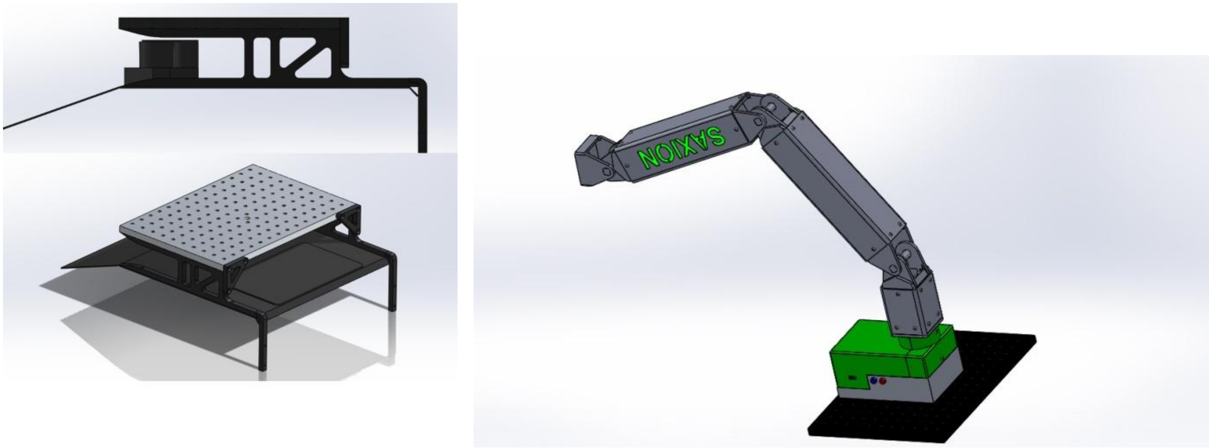

Figure 2.7: Breadboard top platform, Scara robot arm

2.3.2 Existing Software Modules

The Jaguar platform comes with basic ready-to-use control and navigation software, plus a software development kit. But this does not include ROS. Packages for the Jaguar are available on wiki.ros.org, but these have not been implemented or tested yet by Saxion.

Two students have performed their bachelor thesis on local and global navigation, with additional work by staff. These student projects at Saxion have until now all been done on the mentioned smaller X80SV, using mainly the cheap Neato LRF for mapping and obstacle avoidance. For software testing the X80SV has been fitted with a small Asus laptop with Ubuntu. Because the electronics of both robots is similar the software can probably be transferred.

The software that has been developed is available from the Github repository of Saxion.

2.3.3 Ongoing developments

During the first half year of 2015 the following activities are scheduled:

- Hardware (group project): the integration described above, including its software.
- Navigation software (bachelor thesis): further refinements, integration, higher efficiency, convert to embedded.
- Still uncertain, in cooperation with UTwente: vision based mapping and navigation.

2.4 PIAP Scout

PIAP Scout® is a reconnaissance robot with a small frame suitable for operating in places that are not easily accessible for other, larger robots. It has excellent manoeuvrability and relatively high speed (7 km/h). With a modular structure, SCOUT supports various scenarios such as reconnaissance in narrow rooms or vehicle chassis inspection. When the manipulator is mounted on the mobile base, the robot lifts objects up to 5 kg.

Equipped with its specific drives, the robot efficiently travels across uneven terrain and obstacles with the inclination as high as 45°. The robot wheels are easily removed in case of the need to further reduce the robot's overall dimensions. Small weight and compact size enable convenient transportation, possibly in a backpack.

In the default configuration, the robot is equipped with 4 cameras with IR LED or white LED light, and as such it is able to carry out operations in various visibility conditions. Optional use of a fibre optic transmission enables the robot to operate at significant distances, even in an environment with a high electromagnetic noise level.

2.4.1 Hardware Components

Physical properties

The robot has the following dimensions (L x W x H) in a stowed position:

- with wheels, manipulator and camera: 67x54x57 cm.
- with manipulator and camera, but without wheels: 66x40x56 cm.

PIAP Scout® weights 27.5 kg (includes manipulator, main camera and battery, doesn't include additional accessories).

The robot can overcome vertical obstacles of up to 20 cm, climb stairs up to 30° or slopes up to 45°. It has a clearance of 6 cm (5 cm without wheels) and acceptable lateral tilt of up to 35°. Maximum speed is 7 km/h in normal mode and 1.8 km/h in operating mode.

Manipulator

Property	Additional information	Value
Maximum lift capacity	Close-in at the front	5 kg
	Fully extended at the front	2.5 kg
Maximum reach	Vertical (from the ground)	1.5 m
	Horizontal (from the rotation axis)	1.17 m
Clamp opening		20 cm

Sensors

PIAP Scout® has a set of cameras:

- Main: a mobile PTZ camera, 22 x optical zoom, with IR LED illuminators or white LED light, with variable focal length, 350 degrees of vertical and 150 degrees of horizontal motion range.
- Gripper: IR LED / white LED, with integrated heater, easily removable or adjustable.
- Front: IR LED / white LED, heater.

- Rear: IR LED / white LED, heater.

Additionally, the robot can be equipped with a microphone and a speaker, both waterproof.

IMU

The robot is equipped with an Inertial Measurement Unit.

Computing platform

For the R5-COP project, PIAP Scout® will be equipped with a Ventana 5300 computer with a 4-core ARM processor and a GPS.

Communication

The standards for communication are Ethernet and Wi-Fi.

2.4.2 Existing Software Modules

Currently, PIAP Scout® is running native software responsible for controls, which is built around CAN, and native real-time communication protocol implementation.

The plans for integration include moving to ROS 1 or ROS 2 (in available implementation version). The robot will then use appropriate ROS packages to handle its capabilities and provide feedback to the operator's console.

2.4.3 Simulation

Adjustments will be made in order to support Unified Robot Description Format (URDF). PIAP Scout® model defined in this format will be tested in a simulation environment that supports URDF, such as the one provided by Gazebo simulator.

3 Application Scenarios

In the following section 2 different scenarios will be presented that differ with respect to environmental conditions, related objects and users. For each scenario, it is indicated which of the respective hardware platforms from section 2 are used. Within each scenario, an exemplar use case is specified that can be extrapolated to similar use cases within each scenario context.

3.1 Cooperating cleaning robots

TUE, SAX, BUT, TTS

In this scenario, a use-case is demonstrated where multiple robots cooperate to clean an indoor environment.

Cleaning of households and more professional environments is an important task for future robotic applications. At first, many cleaning tasks have to be performed in a care situation, as elderly are not capable of doing many of them, as they typically involve deep bending, accurate movements, heavy lifting, and good memory. Furthermore, cleaning is a task which many people don’t like to do, and would favour a robot taking care of it. Also in young families, where people want to spend time with kids and at work, rather than cleaning the house.

Looking at the scenario from a technical viewpoint, it is a perfect demonstration in which many different skills of the robot are needed. In other words, when we are capable of executing such use-case, many other use-cases are also feasible.

Most effective robots nowadays, are not very general purpose, even in academia. Therefore, to effectively execute complete cleaning tasks, cooperation with humans and other robots is necessary.

The scenario is also a very challenging one, not only because of the cooperative aspects of it. Also as the environments where the robots need to operate in are very unpredictable and dynamically changing. They typically contain many ‘unknowns’ which the robots need to adapt to.

The scenario shall also demonstrate the ability to share the video that the robot sees with remote operators, people and/or systems in real time and in high quality.

The robots used are: AMIGO, PR2, Toad, DrRobot Jaguar

3.1.1 Use Case: Cleaning of a lunch area

In this use-case, a human operator commands the robot AMIGO to clean the lunch area of a restaurant from loose litter, after which AMIGO starts searching for objects on the table and on the floor. When a known object is located, AMIGO picks it up and moves the object to the designated spot. When the robot is confronted with an unknown object, though classified as trash (i.e. no furniture or infrastructure) the robot signals the human operator that teaches the robot how to handle (or ignore) this new object.
When AMIGO detects a known object at a location it cannot access (e.g. underneath a table or chair), AMIGO autonomously asks Jaguar to carry out this task, that will execute this task accordingly.
To prove modularity of the used software components, two other robot platforms, the PR2 and Toad, are available at a different location to carry out (parts of) the same demonstration use-case.

3.1.2 Functional Primitives

The described use case can be assembled from the following list of functional primitives:

- Human-robot communication
- Robot-robot communication
- Object detection
- Object recognition
- Localization
- Learning by operator demonstration
- Reasoning
- Object grasping
- Object moving
- Object placing
- Obstacle avoidance
- Path planning
- Exploration

3.1.3 Technology Requirements

The requirements of the use cases, corresponding to necessary functional primitives as defined above, are related to other R5-COP work packages in the following way:

- WP22: The use-case heavily relies on the environment sensors from this work package, as the scenario is very unstructured and dynamically changing.
- WP23: Also (autonomous) manipulation is an important part of this use-case, which is addressed in WP23. From WP23, this use-case will especially make use of the whole-body motion planning, as focussed on in Task 23.4, as autonomously navigating robots with this many degrees of freedom is very hard to plan, and would better be controlled. Furthermore, the use-case is also specifically setup to test the results of Task 23.6, focussing on Programming by demonstration, in the part where the robot is taught by the operator to handle an unknown object.
- WP26: Planning and reasoning, as also a key functional primitive in this use-case, is addressed here.

3.1.4 Integration plan

The identified primitives as developed within R5-COP that will be integrated, are planned according to the schedule as given in the table below. The maturity level is defined as follows

- A – Development in progress. Component not integrated and tested on the robot hardware, yet.
- B - Basic functionality of component has successfully been integrated and tested on the robot hardware
- C – Extended functionality of component has successfully been integrated and tested on the robot hardware
- D – Complete functionality of component has successfully been integrated and tested on the robot hardware

Component	Maturity level	Brief description / component supplier	Integration completed at (MXY)
Interaction			
Human-robot communication	B	Implementation of basic skills such as TTS and STT are implemented. Understanding of signals to teach the robot has to be developed.	M30
Robot-robot communication	A	Communication through an online database is implemented, but for the presented use-case a more direct means of communication will be exploited.	M24
Cognition			
Object detection	C	Mostly relying on existing implementation which is	M20

		appropriate for the required functioning.	
Object recognition	B	New implementations are being developed for more robust behaviour.	M24
Localization	C	Mostly relying on existing implementation which is appropriate for the required functioning.	M20
Learning by operator demonstration	A	First results currently being tested on an industrial robot arm in WP41. These results will be ported to this domestic application when ready.	M32
Reasoning	B	A first working implementation is implemented, but this being one of the most complex functional parts, this requires much effort still.	M30
Manipulation			
Object grasping	B	Basic implementation finished and tested. Now focussing on whole-body motion planning implementation.	M30
Object moving	B	Basic implementation finished and tested. Now focussing on whole-body motion planning implementation.	M30
Object placing	B	Basic implementation finished and tested. Now focussing on whole-body motion planning implementation.	M30
Locomotion			
Obstacle avoidance	D	Currently implementation satisfactory for this use-case.	M14
Path planning	D	Currently implementation satisfactory for this use-case.	M14
Exploration	B	Basic simple implementation finished and tested. Now focussing on more intelligent implementation making use of reasoning.	M26

3.2 Outdoor tele-robotic security

In this scenario the PIAP Scout robot is remotely operated in order to recover a weakly specified object (some package, a case in a car's trunk, etc.).

The operator is allowed to make multiple runs, optionally reconfiguring the robot between them. The robot is capable of hosting multiple payloads and the operator uses a reconfigurable control and awareness system that helps with the identification of dangerous objects, movement planning and manipulation.

The scenario is performed in an outdoor environment, either industrial or rural.

The robot used is: PIAP Scout.

3.2.1 Use Case: Measuring robot and operator performance in a search and retrieval scenario.

The idea behind this use case is to not only to demonstrate the search and retrieval capability of the robot, but also to compare the current state-of-the-art tele-robotic security system (PIAP Scout robot and current OCU) with the improved platform and new HMI that will be results of R5-COP projects. Additionally, the way to comparatively test a group of operators that this scenario introduces can be viewed as a demonstration of an operator training framework.

Tests will be based on a chosen subset of scenarios described by NIST (National Institute of Standards And Technology, U.S. Department of Commerce) [1]. These tests are used to measure both the robot's capabilities and operator proficiency. Major factors that influence the performance are:

- HMI control system efficiency.
- Operator situation awareness (enhanced by various types of HMI visual display peripherals).
- Autonomous functions (quality and range of operations, operator's cognitive load reduction).

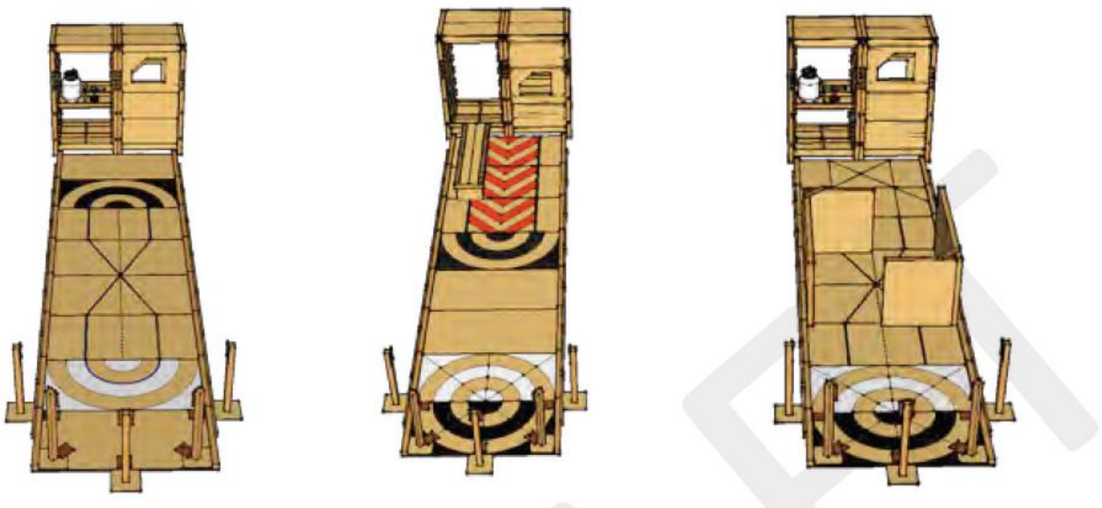

Fig. 1: Test stand configuration [2]

This use-case is generalized and a large subset of specific use-cases can be created with ease for particular demonstration, following the described generic pattern.

In the first run, the operator will perform a tele-operated object search and identification. An object will be placed on the stand, and the operator will navigate through the test environment and explore the area using a robot equipped with an array of sensors. Tasks to be performed by the operator, which can be tested for performance, include:

- Control the camera to look around (Pan/Tilt/Zoom tasks).
- Manoeuvring (line following, decreasing slalom, maze navigation).

In the second run, a manipulator will be attached and object retrieval will be tested. Performance can be tested with objects varying in shape, size, weight, and surface characteristics. Some might be easily compressible (i.e. an empty soda can) in order to test the control over gripping strength. In some scenarios, obstacles such as additional walls or other (i.e. breakable) objects might be placed in order to test for manipulation dexterity.

At the end of each test scenario, a general performance score will be presented as well as more detailed measurements of particular phases and subtasks. Some of the presented data will be visualized in form of graphs, plots and tables.

[1] http://www.nist.gov/el/isd/ks/upload/DHS_NIST_ASTM_Robot_Test_Methods-2.pdf
[2] Apparatus Assembly Guide for Operator Training and Proficiency Evaluation, NIST 2014

3.2.2 Functional Primitives

The described use case can be assembled from the following list of functional primitives:

- Human-robot communication
- Localization
- Non-autonomous (but potentially autonomous): object detection, recognition and grasping, exploration and obstacle avoidance.

3.2.3 Technology Requirements

The requirements of the use cases (corresponding to unavailable functional primitives) are related to other R5-COP work packages in the following way:

- Human-robot communication can be done with native PIAP protocols, but for further demonstrations with the use of the versatile console, a middleware described in WP42 should be used.
- Sensors from WP22 are to be used in the demonstration.

3.2.4 Integration plan

The identified primitives as developed within R5-COP that will be integrated, are planned according to the schedule as given in the table below. The maturity level is defined as follows

- **A** – Development in progress. Component not integrated and tested on the robot hardware, yet.
- **B** - Basic functionality of component has successfully been integrated and tested on the robot hardware
- **C** – Extended functionality of component has successfully been integrated and tested on the robot hardware
- **D** – Complete functionality of component has successfully been integrated and tested on the robot hardware

Component	Maturity level	Brief description / component supplier	Integration completed at (MXY)
Interaction			
Human-robot communication	A	Interface for communication is yet to be designed. Native PIAP protocol is implemented, but effort is required to port communication to ROS standards. Hardware components are already available.	M18
Cognition (autonomous)			
Object detection	A	Autonomous cognition is not yet implemented.	M30
Object recognition	A	Autonomous cognition is not yet implemented.	M30
Localization			
Area mapping	A	Creating and updating local map, marking objects of interest. Map interface for human operator.	M24
Positioning	A	Basic GPS and local map positioning, displayed on OCU map interface.	M18
Autonomous locomotion and manipulation			
Obstacle avoidance	A	Autonomous locomotion is not yet implemented.	M30
Path planning	A	Autonomous locomotion is not yet implemented.	M30
Exploration	A	Autonomous locomotion is not yet implemented.	M30
Object grasping	A	Autonomous object grasping is not yet implemented.	M30

4 Summary

For all four used demonstrators, the hardware has been presented, justifying their appropriateness for the defined use cases.

The requirements of the scenarios and use cases are matched against the available functionalities of the demonstrators and the components to be developed in SP2, respectively.

The essential functional primitives are highlighted for each use-case to show the potential extrapolation of the selected use-cases to similar use-cases within the same scenario context. The use-cases were defined with the target of containing as many functional primitives of the single domains as possible to claim their universality.