Best Practice in Robotics (BRICS)

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1. Introduction

This document presents the 9 different hardware platforms that were or are being used in the context of the BRICS project. Each of them is described in detail and the components used to set up the platforms are given. This information shows that BRICS software can be operated on platforms made of a diverse collection of components. The document also mentions how each platform is used within BRICS and what kind of modifications were made.

2. Hardware for Best Practice

2.1. BlueBotics Platform

2.1.1. Description

This vehicle is a custom design for the project chosen as the SME showcase for BRICS. It is made of a customized Kokeisl AGV on which a KUKA arm (KR-60-3) is mounted. The arm is being powered by the vehicle batteries with the help of an inverter to convert DC power to 3 phases AC power.

2.1.1.1. Vehicle functional specification

- Autonomous displacements within the environment.
- Exchange of targets on a support (front end), storage of old targets at dedicated place.

2.1.1.2. Dimensions

Height:	Max 1.14 m.
Width:	Max 1.10 m (without safety sensors).
Length:	Max 3.20 m.

2.1.2. Components

Category	Name (Classification)	Producer	Number	Description
PC	Compact PCI 19 30TI, PowerPC rack system	Inova	1	Rack for navigation
AGV	KPR	Kokeisl	1	Customized for this application.
Arm	KR60-3	KUKA	1	Robotic arm for the manipulation
Laser scanner	S300	SICK	4	Safety sensor for motion and manipulation. Localization sensor.
Inverter	RCTP-6000R	Rip Energy	1	Power converter (24VDC to 3x400V AC)
Operating system	XO/2		1	Real-time deadline driven (EDF) operating system of the Rack
Software	ANT	BlueBotics	1	Navigation software (localization, planning, motion)

2.1.3. Images

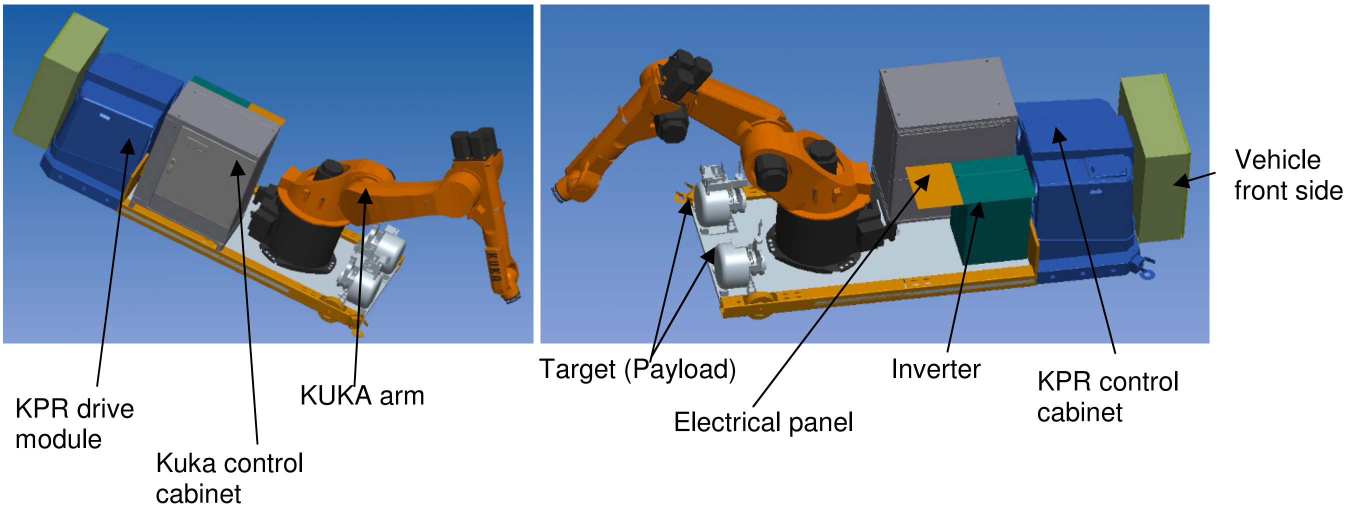


Figure 1: BlueBotics Platform

2.1.4. Use in BRICS

This platform is a custom design for the SME showcase "radioactive target exchange". This showcase is a real project launched by CERN (European Organization for Nuclear Research).

The goal is to exchange targets in a radioactive environment. The vehicle is loaded with a new target at rest position then moves autonomously to the targets support. At the target support, the old target is replaced by the new one with the vehicle's arm. On the way back to the rest position, the old target is stocked to cool down. Finally, the vehicle moves back to the rest position.

2.1.5. Modifications/Enhancements for BRICS

The platform has been specifically designed for the SME showcase. This means that all required features were included in the development process, including the new ANT controller, which uses the EtherCAT technology partially developed within BRICS.

2.2. BRSU Johnny

2.2.1. Description

The robot "Johnny Jackanapes" is based on a modular mobile platform called VolksBot, which has been designed for rapid prototyping of robot applications in education, research and industry by the Fraunhofer Institute for Intelligent Analysis and Information Systems (IAIS). The Johnny robot platform is a customised version, with a Neuronics Katana 6M180 robot arm as an integrated manipulator. It provides five degrees of freedom w.r.t. the gripper's position and orientation in its workspace and has an operation radius of 60 cm. The manipulator has a two-fingered gripper, which is equipped with infrared reflectance as well as force sensors. The arm can handle a maximum payload of 500 g and is mounted in a way to provide good reachability and manoeuvrability. The primary sensor for perceiving the environment is a SICK LMS 200 laser range finder mounted in the robot's centre of rotation. It provides accurate range measurements to surrounding objects intersecting the 2D scan plane in an angular range of 180°. An angular resolution of 1° and a continuous sending mode over RS422 is used. In this setup, the laser range finder delivers 2D scans containing 181 range measurements with a frequency of 75 Hz. The drive unit used for locomotion uses a differential drive with two actively driven wheels, powered by two 150 W motors, and two castor wheels to enhance rotating and stability under load. The robot's maximum velocity is 2 m/s.

2.2.2. Components

Category	Name (Classification)	Producer	Number
Mobile Base	Volksbot	Fraunhofer IAIS	1
Manipulator	Katana 400 6M180G	Neuronics	1
Laserscanner	Hokuyo URG-04LX	Hokuyo	1
Laserscanner	Sick LMS 200	Sick	1
Stereo Camera	BumbleBee	Point Grey	1
Camera	QuickCam Pro 9000	Logitech	1
Pan-Tilt Unit	Pan-Tilt Unit model PTU-46-17.5.	Directed Perception	1
Microphone	USB Desktop Microphone	Logitech	1
Motor Controller	VMC Volksbot Motor Controller	IAIS Fraunhofer	1
Computer	MacBook	Apple	2
Computer	X200	IBM	1
Operating System	Windows XP	Microsoft	1
Operating System	LINUX	Debian	1
Operating System	Mac OS X Leopard	Apple	1

2.2.3. Images

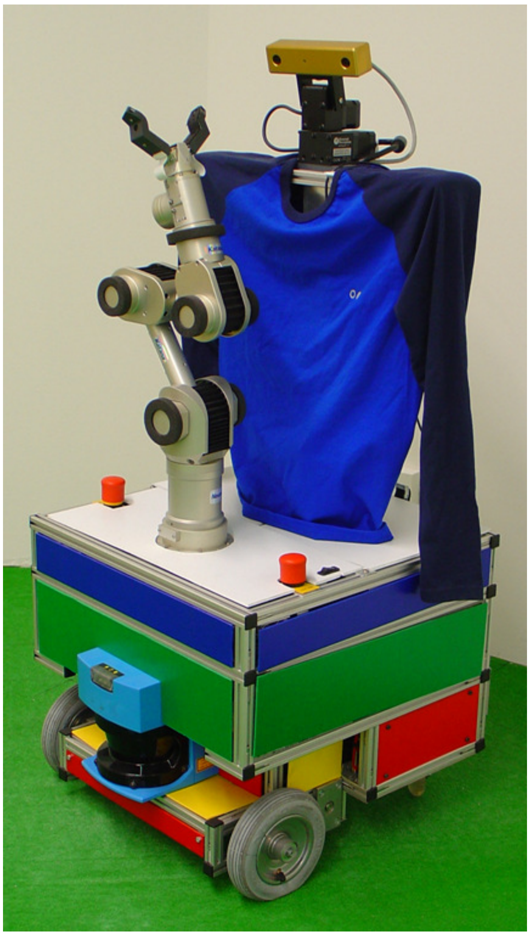


Figure 2: Jonny

2.2.4. Use in BRICS

Work package 2 uses Johnny to test BRICS concepts on real hardware. For instance, concepts and designs for the BRICS OODL have been tested on Johnny. Additionally, different middlewares have been tested on Jonny, which was necessary to develop the BRICS network transparent layer.

2.2.5. Modifications/Enhancements for BRICS

No modifications or enhancements were made to Johnny, because Johnny was to be replaced by a Care-O-bot 3 robot (Jenny).

2.3. IPA Care-O-Bot 3

2.3.1. Description

Care-O-bot® 3 was designed as a product vision of a future robotic household assistant (Reiser et al, 2009). The third generation of the Care-O-bot series by IPA distinguishes itself from other robotic platforms in particular through its elaborate user centred design concept. The appearance and user interaction design were developed based on human interaction studies (Parlitz et al, 2008) in cooperation with a professional design office. Figure 3 displays the two-sided user interaction concept along with a rendering of an early conceptual design.

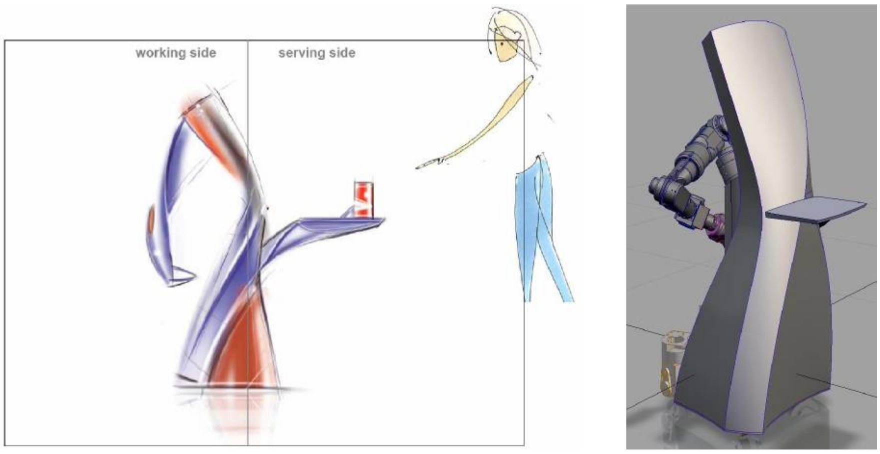


Figure 3: Left: First design sketch, Right: first technical rendering.

The hardware setup of Care-O-bot® 3 can be divided into the following components: mobile base, torso, manipulator, tray and sensor carrier with sensors.

The mobile base consists of four wheels, for each of which orientation and rotational speed can be set individually. This means the robot has an omnidirectional drive enabling advanced movements and simplifying complete kinematic chain control (mobile base - manipulator - gripper). A wheeled drive was preferred to a legged drive because of safety (no risk of falling) and stability during manipulation. The base also includes the battery pack for the robot, laser scanners and one PC for navigation tasks. The size of the base is mainly determined by the required battery space.

The torso sits on the base and supports the sensor carrier, manipulator and tray. It contains most of the electronics and PCs necessary for robot control. The base and torso together have a height of 770 mm.

The manipulator of the first Care-O-bot® 3's is based on the Schunk LWA3, a 7-degrees-of-freedom (-DOF) lightweight arm. It has been extended by 120 mm to increase the work area so that the gripper can reach the floor, but also a kitchen cupboard. It has a 6-DOF force-torque sensor and a slim quick-change system between the manipulator and the 7-DOF Schunk Dexterous-Hand. The force-torque sensor is used for force-controlled movements like opening drawers and doors, but also for teaching the robot new tasks by physical interaction with a human. The quick-change system allows the use of other grippers and robotic hands like a Schunk Anthropomorphic-Hand. In BRICS a Care-O-bot 3 version equipped with a KUKA LWR is used. Please refer to Section 2.3.5 for more details.

The robot hand has tactile sensors in its fingers making advanced gripping possible. Special attention was paid to the mounting of the arm on the robot torso. The result is based on simulations for finding the ideal work space covering the robot's tray, the floor and area directly behind the robot following the 'two sides' concept.

The robot has a sensor carrier equipped with high-resolution stereo vision cameras and 3-D-time-of-flight-cameras, enabling the robot to identify, locate, and track objects and people in 3-D. These sensors are mounted on a 5-DOF positioning unit allowing the robot to direct its sensors onto any area of interest. It is very important in our design concept to avoid creating a face with these sensors, which is actually quite difficult to avoid.

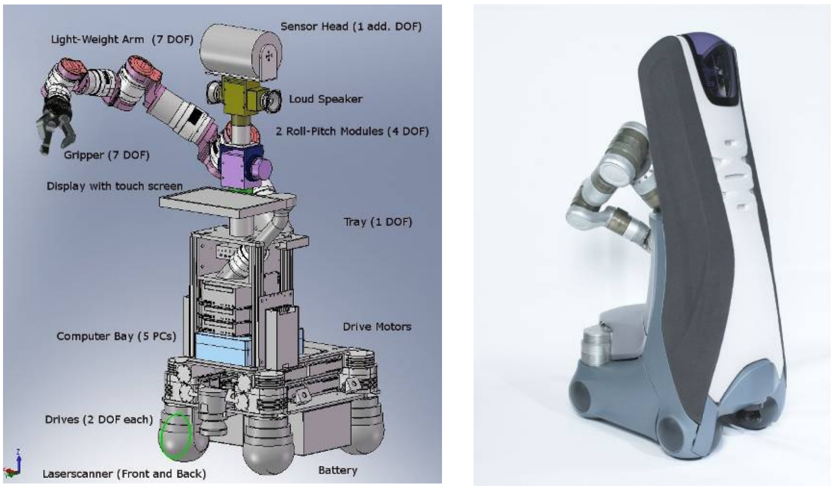


Figure 4: Left: Hardware set-up of Care-O-bot® 3, Right: Care-O-bot® 3 with flexible casing.

Figure 4 shows the complete hardware setup of the robot. The convergence of the original design idea and the underlying technology can be seen in on the right-hand side, showing the robots final appearance.

2.3.2. Components

Category	Name (Classification)	Producer	Number	Description
Camera	Prosilica 1380 GC	AVT	2	
3D-Sensor	CSEM SR-3000	Mesa Imaging	1	
Controller	Encoder HEDL-5540 A14	Nanotec	1	
Motor	Motor DB42M	Nanotec	1	camera axis
Motor	Schunk PW 90 Drive	Schunk	1	for torso
Speakers	Visation Frs8 303661-24	Conrad	2	
Motor	Schunk PW 70 Antriebseinheit	Schunk	1	for torso
Manipulator	Lightweight Robot LBR IV	KUKA	1	
Manipulator	Schunk LWA 3 Manipulator	Schunk	1	
Gripper	SDH	Schunk	1	
Controller	FWS	Schunk	1	
Motor	PRL 100	Schunk	1	for tablet
LCD	G104X1-L01	Data Modul	1	
Touch Screen	ATP-104	Data Modul	1	

Controller	LCD Platine eMotion P1:1	Data Modul	1	
Controller	TSC10/USB-pi	Data Modul	1	
Controller	Relay board	Neobotix	1	
Controller	CAN-USB Dongle Peak	PEAK System	5	
PC	CPCI Rack (3CPUs)	EKF	1	
WLAN Adapter	D-Link Wireless108G	Alternate	1	
Controller	Whistle WHI-10/60, WHI 7195002	Neobotix	4	
Motor	APM SB03AAK3-9	Metronics	8	for mobile platform
Laser scanner	S300	Sick	2	
Laser scanner	URG-04LX	Hokuyu	1	

2.3.3. Images

Figure 5: Top Left: Care-O-bot 3 in a serving scenario, top right: Care-O-bot performing at Robocup@Home German Open 2011 in Magdeburg, Bottom: Care-O-bot at the BRICS Mobile Manipulation Research Camp in October 2010.

2.3.4. Use in BRICS

The Care-O-bot 3 is generally used within BRICS as demonstrator for the showcase research. It was provided prior to the first BRICS Research Camp in October 2010 for the implementation of mobile manipulation tasks (see Figure 5). Furthermore, the Care-O-bot participated in the RoboCup@Home Challenge in Magdeburg 2011, prepared by the b-it-bots team of BRSU and supported by IPA. This allowed the project to gather information about competitive and distributed robot development on complex hardware and about scenarios for later analysis of the development processes involved. BRICS partners of WP3 and WP6 additionally use Care-O-bot 3 as data source and testing platform for their developments in their work packages.

2.3.5. Modifications/Enhancements for BRICS

The Care-O-bot 3 hardware was enhanced with manipulator hardware interfaces allowing the robot to be flexibly used with either the Schunk LWA3 manipulator or the KUKA LWR manipulator with minimal effort. Demonstrating this is an important goal of BRICS. For the mechanical integration, a new flange was constructed to incorporate the arm such that it could reach the tray, while having still enough dextrous workspace available for the grasping in the back of the robot. At the same time the integration had to comply with the overall design of the robot.

The electrical integration encompassed the provision of the required motor and supply voltages as well as the integration of the LWR into the emergency stop circuit. Furthermore a new industrial PC had to be inserted for the KUKA control unit. Due attention was paid to ensure that the LWR can be attached to a standard KRC without significant additional effort in case of repair or servicing.

An additional Care-O-bot 3 (called Jenny) was built up to be used by the partner BRSU as a replacement for the Jonny robot. This robot is identical to the IPA Care-O-bot 3 robot.

The hardware configurations of the Care-O-bot 3 before and after the adaptations made in BRICS are shown in Figure 6.

Figure 6: Care-O-bot 3 setup with SCHUNK LWA3 (left) and KUKA LWR (right).

2.4. The DESIRE Technology Platform

2.4.1. Description

The DESIRE technology platform (TP) was created by the DESIRE project (2005-2009), which was funded by the German Ministry for Education and Research, for use as project demonstrator for household scenarios. Requirements from 14 partners had to be integrated into a single, common platform, such that the platform is now very well suited for research on mobile manipulation.

2.4.2. Components

Category	Name (Classification)	Producer	Number	Description
Camera	Pike F-145C	AVT	2	
3D-Sensor	CSEM SR-3000	Mesa Imaging	1	
Speakers	Visation Frs8 303661-24	Conrad	2	
Motor	Schunk PW 70 Drive	Schunk	1	Sensor head
Manipulator	Lightweight Robot LWR3	KUKA	2	
Gripper	SDH	Schunk	1	
Controller	FWS	Schunk	1	
Controller	Relay board	Neobotix	1	
Controller	CAN-USB Dongle Peak	PEAK System	2	
PC	CPCI-Rack (6 CPU slots)	Kontron	1	
WLAN Adapter	D-Link Wireless108G	Alternate	1	
Controller	Whistle WHI-10/60, WHI 7195002	Neobotix	4	
Controller	KRC2lr	KUKA	2	for Arms
Motor	APM SB03AAK3-9	Metronics	8	for mobile platform
Laser scanner	S300	Sick	2	
Laser scanner	URG-04LX	Hokuyu	1	

2.4.3. Images

Figure 7: Mechatronic view (left) and final appearance (bottom).

2.4.4. Use in BRICS

The DESIRE technology platform is mainly used for the showcase research. A long-term evaluation is carried out to study development processes in the research community. The study involves partners from BRICS and other projects as well as external research institutes.

2.4.5. Modifications/Enhancements for BRICS

For the use in BRICS the technology platform was refurbished, including new cabling, removal of components not required (e.g. the RFID reader) and reduction of external cable connections. The arm controllers were replaced by a new type of controller from KUKA. These new controllers have several advantages, including a much smaller build size and 48V power supply option. It is the same controller as the one used in the Care-O-bot 3, thereby allowing the consortium to experiment with and demonstrate the transferability of software from one platform to the next.

2.5. IPA rob@work 2

2.5.1. Description

The rob@work 2 system was created by PiSA, an Integrated Project of the Sixth Framework Program of the EU, with the objective to assist human workers at the workplace and to combine the advantages of human skills and a machine. The system integrates a robot and an operating box on the same footing that makes it possible to install the robot in industrial environments where it is needed or to attach it to a mobile platform. The system adapts a sophisticated industrial NC to perform Cartesian position control of the robot. One prototypic system setup is pictured in Figure 9.

The hardware setup of rob@work 2 can be divided into the following components: footing, an operating box with an industrial PC and a touch-screen serving as human machine interface, manipulator, a controller, and a sensor system for high performance tasks in industrial environments. Additionally, the footing can be attached onto a mobile platform in particular the MP-L655 of Neobotix.

The laboratory setup consists of a modular 7 degree-of-freedom light-weight manipulator provided by Schunk (LWA3). The diameter of the robot's workspace is 783 mm. The payload of the robot is about 5 kg. The NC controller was adapted to the special needs of rob@work 2. The standard GUI of the robot shows the current mode of operation of the NC-kernel. The GUI elements are based on the Windows GUI, i.e. it consists of buttons, edits, and graphical windows. Soft buttons offer different functionalities related to the current context. These buttons can easily be operated through the touch-screen. In manual mode the execution of motion can be controlled by peripheral devices e.g. through a jog wheel or buttons. In automatic mode it is possible to execute a full NC program. Finally, in MDI mode, single commands can be sent to the controller. Figure 8 shows the internal architecture of the controller system.

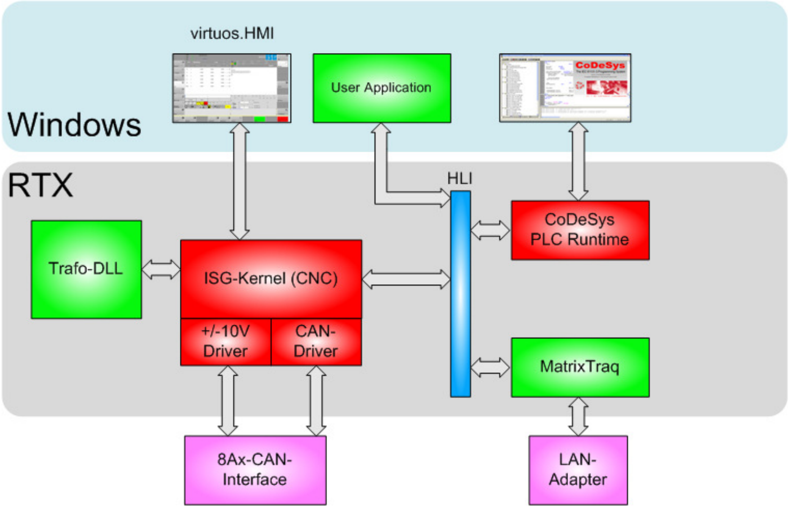


Figure 8: Internal Architecture of the rob@work 2 Controller

2.5.2. Components

Category	**Name (Classification)**	**Producer**	**Number**	**Description**
Sensor	EoSens ® GE GigE Vision	Mikrotron	2	MatrixTraq sensor involving two Gigabit cameras for Cartesian position measuring
Operating System	Microsoft XP Professional	Microsoft	1	Operating System
Real-Time Extension	RTX	Ardence	1	Windows Real-Time Extension
Controller	CoDeSys 2.3.7.1	3S-Smart Software Solutions GmbH	1	Software for PLC programming
Network Interface Card	Intel Pro 1000/PT	Intel	1	PCIe Gigabit Network Interface Card in the Box PC for connection with the Gigabit camera
Driver	Intel Pro Set Driver	Intel	1	Driver of the Gigabit Network Interface Card in the Box PC
Manipulator	LWA 3	Schunk	1	Standard assembly of PRL Modules and standard links to an 7-axes-structure (2x PRL 120, 2x PRL 100,2x PRL 80, 2x PRL 60)
Hardware	CAN/USB Interface	esd electonics Inc.	1	Physical Interface for direct addressing of the drives via PowerCube Software
Software	PowerCube	Schunk	1	Software for direct addressing of the drives
Sensor	Electric Safety Cut-Out ESX10-T	E-T-A Elektrotechnische Apparate GmbH	1	Overload protection for the LWA 3, Limitation of short-time occurring peak currents
Controller	010829-3 Marshaling Panel I/O	ISG - Industrielle Steuerungstechnik GmbH	1	Digital/analogue in- and outputs incl. CAN axes connection (8-axis-card): Physical interface for addressing of the drives via ISG-Software
Controller	010828 PCI Basic Card	ISG - Industrielle Steuerungstechnik GmbH	1	PCI card in the Box PC: Interface between Box PC and Marshalling Panel
Controller	ISG NC - SBV	ISG - Industrielle Steuerungstechnik GmbH	1	NC - Control Software

2.5.3. Images

Figure 9: Application example involving the rob@work 2

2.5.4. Use in BRICS

rob@work 2 is used as a demonstrator of a state-of-the-art integration of proprietary robot control approaches in the context of the industrial showcase. In addition, it is available as a test bed for the integration of offline programming tools and development processes with standard industrial programming languages.

2.5.5. Modifications/Enhancements for BRICS

The system architecture was enhanced with an additional real time library. The so called “Trafo-Dll” exports three functions, in particular initialisation, forward transformation, and reverse transformation function calls. During each cycle one can access the (old) values of the physical just as the programmed axis. Algorithms for the transformations need to be implemented in ANSI C.

2.6. KUKA Lightweight Robot (LWR)

2.6.1. Description

The characteristics of the LWR are based on concepts which are generally regarded as important for the next generation of robots that are to be capable of working together with humans. The weight was reduced to the limits of what is technically possible, which decisively improves the robot's dynamic performance. The LWR is designed for a rated payload of 7 kg, and itself has a mass of 15 kg. Its low mass helps reduce the power consumption and additionally allows a hitherto unknown degree of mobility for robot arms. In the first place, the robot can be carried by hand to its place of use, and secondly, battery-powered operation is possible in mobile robot systems, for example.

With its seven axes, the robot has one redundant degree of freedom, which gives the programmer more flexibility in cluttered workspaces. The seven axes also help to avoid typical singularities of 6-axes kinematic systems. The rounded design, which rules out any risk of clamping between structural components, contributes to the overall safety.

Torque sensors in each of the seven joints, a detailed dynamic model of the robot, state control and a high servo control cycle rate (3 kHz locally in the joints, 1 kHz overall), combined with powerful drives and the lightweight construction, enable active damping of vibrations to achieve excellent motion performance (path accuracy, repeatability). Furthermore, this also makes it possible to achieve a programmable compliance, both axis-specific and Cartesian. This allows the robot to act like a spring-damper system in which the parameters can be set within wide limits. This compliance control enables the robot to be manually guided, thereby opening up a totally new experience in human-robot interaction. A programmer or user can thus move the robot intuitively and quickly to the desired position. A further advantage is the possibility to program assembly procedures that could previously be implemented only with great difficulty. Moreover, it is no longer necessary to use compliant grippers or other equipment, as the arm already provides the required compliance.

Control parameters can be switched over within one control cycle (1 ms). In this way, it is possible to switch extremely quickly between, for example, a stiff, position-controlled mode and a compliant behaviour. The high sensitivity of the lightweight arm and the detailed knowledge of the model allow detection of collisions. This sensitivity, coupled with advanced servo control, enables faster joining of components since it is possible to move on the programmed path right up to a planned collision with the component, and then search for an edge or hole in compliant mode. In this way, the time taken to execute an assembly task can be significantly reduced. Table 1 summarises the differences between classical industrial robots and the LWR.

"Classical" industrial robot	**Future production assistant**
fixed installation	flexibly relocatable (manually or on mobile robots)
periodic, repeatable tasks; seldom changes	frequent task changes; tasks seldom repeated
programmed online / offline by a robot specialist	instructed online by a process expert supported by offline methods
infrequent interaction with the worker only during programming	frequent interaction with the worker, even force / precision assistance
worker and robot separated by fences	workspace sharing with the worker
profitable only with medium to large lot sizes	profitable even with small lot sizes

Table 1: Comparing classical industrial robots with future production assistants

2.6.2. Components

This table lists the major components (both hardware and software) used in the LWR.

Category	Name (Classification)	Producer	Number	Description
PC	Industrial PC running VxWorks	confidential	1	PC to control the robot
Operating	VxWorks with KUKA			

System	robot control software			
Interface	Connection box	KUKA	1	Control interface for robot via Ethernet, power input for robot (48V), emergency stop interface
Drives	Motors, gears and power converters	confidential	7	controlled via Sercos using connection box
Gripper	MEG 50 EC	Schunk	1	peripheral currently used by KUKA

2.6.3. Images

Figure 10: The KUKA lightweight robot with KRC2 lr controller

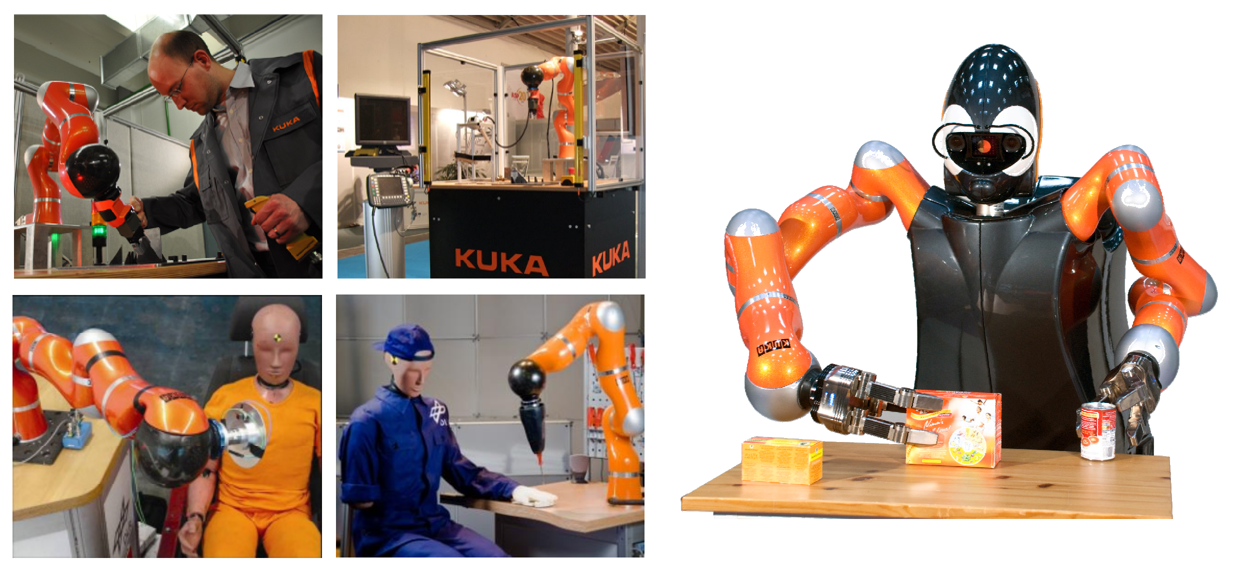


Figure 11: Application examples involving the LWR

2.6.4. Use in BRICS

The LWR is used in several ways within BRICS. In one case it was mounted on a Care-O-bot. Here a prototypical controller was used in order to make the platform more mobile (the KRC2 controller is too big and requires 230V). The setup is described in more detail in Section 2.2.

Figure 12: LWR on the Care-O-bot

In a second case a demonstrator involving two LWRs collaborating with a human was set up. Here the two KRC2 controllers were connected to an OROCOS PC using the FRI interface. This PC was running the application. Figure 13 shows one version of the demonstrator which was shown at AUTOMATICA 2010. Here a human could move one of the robots next to the box. By tapping the other robot, the operator could give the command to pick up the box. This meant the second robot calculated the location and orientation of the box from the position of the first robot and, knowing the dimensions of the box, positioned the other robot accordingly. Now the human could move the box or either of the robots to put the box in the desired location. Finally, the robots would let go of the box again.

Figure 13: Two LWRs cooperating and collaborating at the same time

2.6.5. Modifications/Enhancements for BRICS

The KUKA KRC2lr controller has for a long time offered ways to control the robots using external devices. The interface matching the academic requirements most closely is the Remote Sensor Integration (RSI) interface. As can be seen in Figure 14, this interface allows the user to feed commands into the Motion Kernel at a rate of 12 msec. The interface was originally designed to connect sensors to allow for applications such as visual servoing in the context of a predefined task. The interface is not powerful enough, however, to allow the robot to be controlled using an external interpolator.

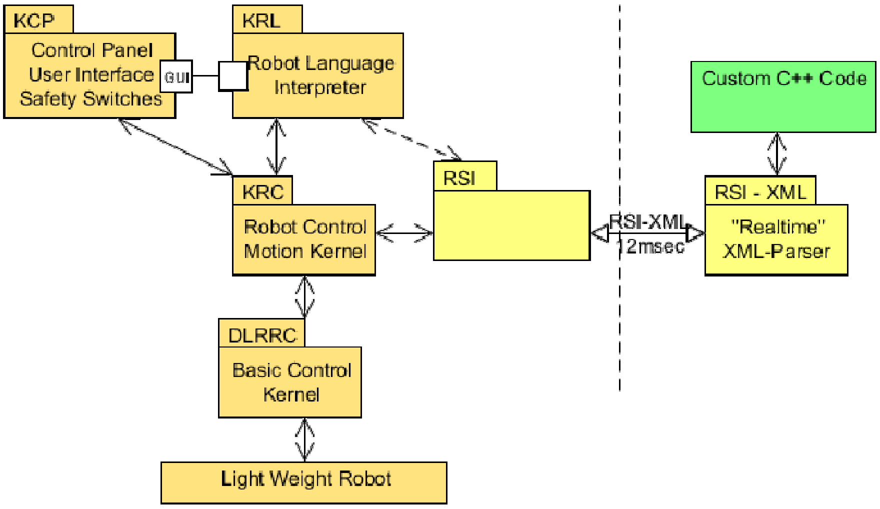


Figure 14: The KUKA Remote Sensor Integration (RSI) Interface

During the first year of BRICS KUKA analysed the needs of academia to determine what an advanced interface should look like. Based on this analysis, KUKA developed the FRI interface. This interface allows communication rates between 1 and 100 ms. It also allows the external PC to switch between the different control modes of the robot to utilise the special features of the LWR (e.g., the impedance mode). This is realised by entering the controller at a lower level as shown in Figure 15.

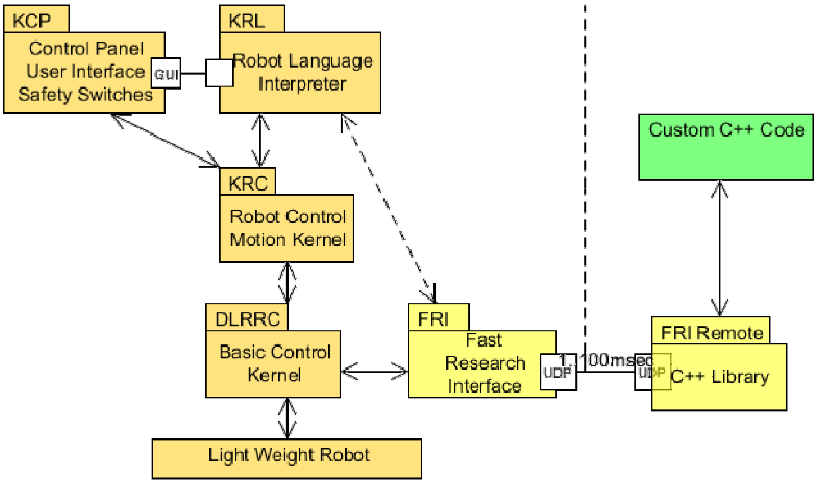


Figure 15: The Fast Research Interface (FRI) interface

2.7. KUKA omniMove

2.7.1. Description

The omniMove is currently sold by KUKA as a mobile platform which is operated by a human and can transport goods in a manufacturing environment. It is based on Mecanum wheels and can therefore move omnidirectionally. Depending on the size of the platform it will have 4 or more wheels. Most platforms can raise themselves to pick up a load which is positioned above them. The platforms are either driven using hydraulics or electric motors. There is a second version called TripleLift, which carries a platform for human workers that can be raised several meters. The platforms currently on sales are manually controlled using a joystick. In some cases several platforms are coupled into a single system. Laser scanners are installed at several locations to ensure the system does not collide with obstacles or people.

2.7.2. Images

Figure 16: examples of omniMove platforms

2.7.3. Use in BRICS

Within BRICS KUKA has conducted some experiments to add collision avoidance and autonomy to the platform. The movement commands were to come from controller software rather than a human operated joystick. In this context the laser scanners, which were formerly only used as a safety precaution, were now used to detect obstacles, to build maps and to localise within these maps. The main interest here was to determine how well state-of-the-art navigation, SLAM and collision avoidance software performs on such significantly larger platforms.

2.7.4. Modifications/Enhancements for BRICS

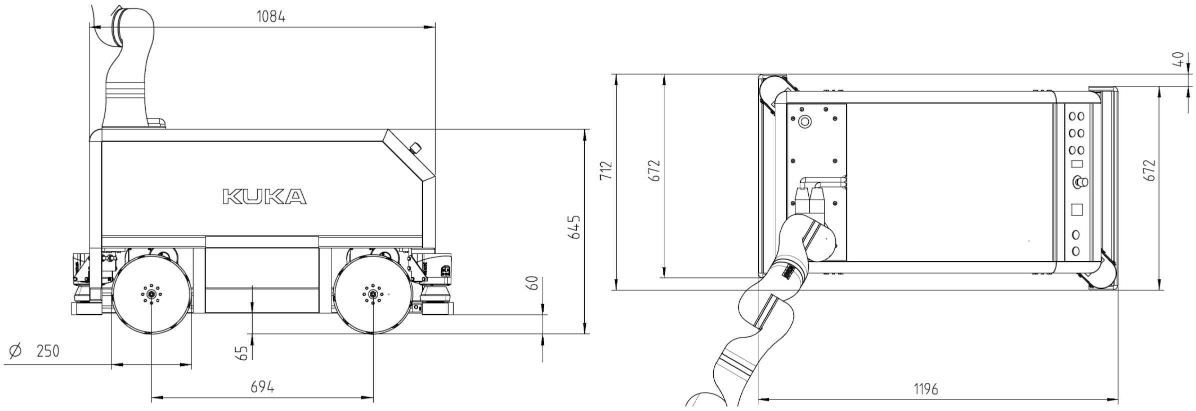
The controller running the collision avoidance and navigation software had to be integrated into the system. The interfaces for this integration had to be developed. Some additional modifications were necessary to the safety system of the omniMove platforms. Some hardware modifications (e.g. the type and location of sensors) were also necessary.

2.8. KUKA omniRob

2.8.1. Description

The KUKA omniRob robot was developed at KUKA Predevelopment as a technology platform to integrate and evaluate technologies required for mobile manipulation tasks, such as navigation, manipulation and perception. A first version of the KUKA omniRob was demonstrated at AUTOMATICA 2008, the robot's industry most acknowledged exhibition, as part of a common service robotics booth. In 2010, a second version of the omniRob system was developed and presented at the KUKA booth of AUTOMATICA 2010.

The KUKA omniRob is a mobile manipulator consisting of an omnidirectional undercarriage, a 7-DOF robot arm and a two finger gripper (Figure 18). All required energy supply, computing power and sensor are mounted and integrated to enable autonomous operation for extended periods of time.



The most important technical details are:

Unloaded weight	Approx. 270 kg
Maximum load	150 kg
Maximum total weight	800 kg
Maximum speed	1.4 m/s
Maximum incline/decline	0.5%
Battery capacity	84 Ah
Length/width/height	120/71/65 cm

The KUKA omniRob has a rectangular undercarriage. Its dimensions are suitable for indoor navigation including the safe passage of standard sized doors. The load area on top of the platform (680 mm x 515 mm) can be easily reached by the LWR mounted in the front left corner.

The robot is driven by four independently powered omniWheels, which compose an omnidirectional drive system that allows for arbitrary combinations of translational and rotational motions. This yields high manoeuvrability and high-precision motions even under heavy payloads. Front and rear bumpers protect the two laser scanners mounted in opposite corners of the undercarriage.

The manipulator used on top of the KUKA omniRob system is the KUKA Lightweight Robot (LWR) described in Section 2.6. It is possible to connect a huge variety of end effectors, such as grippers and cameras, at the flange.

The mobile platform is equipped with two Sick safety laser scanners S300 CMS professional (Figure 17). Each scanner has four switchable fields for warning and emergency stop fields. The scanning plane is at a height of 139 mm above the ground. This height was chosen to conform to safety norms and to be able to safely recognize Euro palettes on the floor.

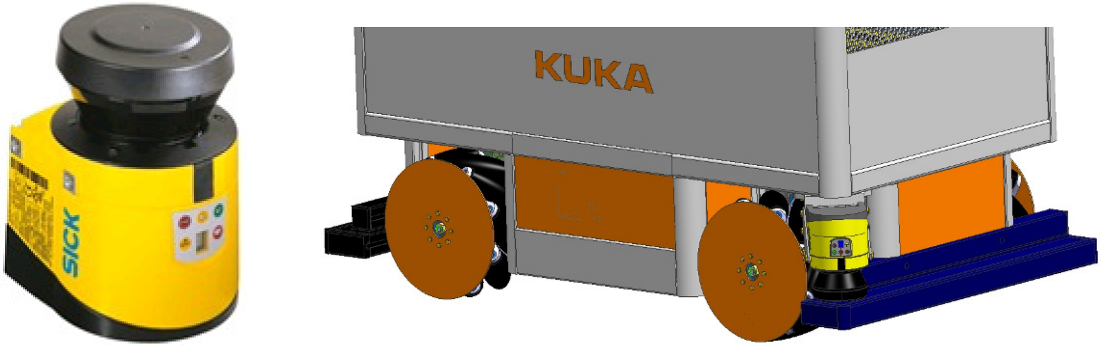


Figure 17: Sick Laser Scanner S300 and mounting position at omniRob.

At the back of the KUKA omniRob undercarriage is a bevelled control panel, which is used for basic user-robot interaction, such as switching the platform on and off, releasing the brakes or enabling various control modes. USB and Ethernet ports exist to connect peripheral devices such as joysticks and external PC hardware (e.g., laptops), which can be used for tasking the robot system.

The omniRob system is controlled through a new controller framework that allows synchronous control of all joints (mobile platform and manipulator) in real time. The controller runs on an industrial embedded PC with VxWorks as real-time operating system. The controller communicates with the drives of the mobile base through EtherCAT and with the drives of the LWR through the Sercos field bus. The platform navigation and user interaction tasks run on a second embedded PC, which is connected by standard Ethernet to the controlling PC. Commands can be given over a wireless LAN connection from a remote device. The robot is programmed through the Robotics API which is a high-level object-oriented interface. This way the omniRob can be controlled to perform a sequence of tasks or skills. The Robotics API is currently under development.

One of the main hindering issues for integrating mobile manipulator systems in real work environments is safety. The current version of the LWR can be considered safer than normal industrial robots (due to its light weight and advanced control performance including compliant motions and collision detection capabilities), but when considering the ISO 10218 safety requirements for industrial robot arms even the LWR should only be operated behind a fence. The following risks and safety measures are in place with the current demonstrator:

- intended use for research and (pre-)development purposes only
- navigation system with collision avoidance that checks the current desired velocities against potential collision with the environment and slows down the robot up to a complete halt if necessary
- certified emergency stop (at the back and front of the robot's undercarriage) to cut the power to the omniRob and LWR drives
- certified remote emergency stop in series to the fixed emergency stop
- front and rear bumpers (without sensing elements) to protect safety scanners from direct collision with the environment
- button to release the brakes while an emergency stop is active, to move the robot's undercarriage by hand. For example to clear the area where the robot was stopped or to free an object/person from a trapped situation.

2.8.2. Components

Category	Name (Classification)	Producer	Number	Description
Structure	Frame and covers	confidential	Various parts	
PC	Industrial PC running VxWorks	confidential	1	PC to control the robot
Operating System	VxWorks with KUKA robot control software			
PC	Industrial PC running Linux	confidential	1	PC for navigation (CARMEN framework)
Operating System	Suse Linux with CARMEN framework	confidential	1	
Interface	Ethernet Switch	confidential	1	
Interface	Wireless Access Point	confidential	1	
Safety system	Safety bus terminals and switches	Beckhoff		Safety system to stop platform and arm in emergency situations
Safety system	Laser scanners S300 Professional	SICK	2	for navigation and safety
Jogging device	Joystick “Rumble pad II”	Logitec	1	to move robot manually
Drives	Motors, gears and power converters	confidential	4	controlled via EtherCat
Structure	Wheels	confidential	4	Mecanum wheels
Power	rechargeable batteries	confidential	4 * 12V	gel batteries
Manipulator	LWR	KUKA	1	
Gripper	MEG 50 EC	Schunk	1	peripheral currently used by KUKA

2.8.3. Images

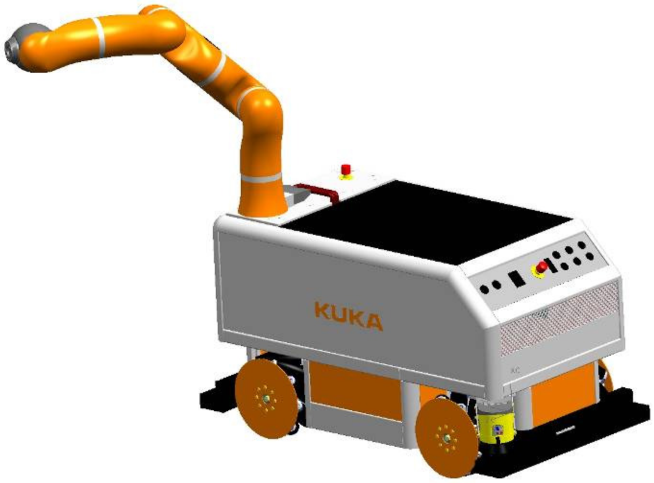


Figure 18: Left: Concept drawing of KUKA omniRob (version 2).

Figure 19: KUKA omniRob at the Automatica 2010 fair where basic navigation and manipulation capabilities were demonstrated.

2.8.4. Use in BRICS

The omniRob is used for several purposes within BRICS. Firstly it is the platform on which the new version of the FRI interface for mobile manipulation is being developed. It will also be used to evaluate how well mobile manipulation solutions developed for example for the youBot or Care-O-bot can be transferred to other platforms. Finally, it is planned to be used in the industrial showcase.

2.8.5. Modifications/Enhancements for BRICS

The design of the omniRob was greatly advanced partly based on input from BRICS requirement analyses. The most obvious difference to previous designs is the robot's shape – the robot can now traverse doors more easily. However, a lot of changes were also made internally, thereby leaving more room for devices and sensors.

BRICS demands for the integration of various hardware and software modules. KUKA's new controller framework enables such interfacing in an easy manner. Some of the required interfaces are being built with the help of BRICS and based on requirements determined through the project. They will on the one hand allow for receiving data from all the sensors and actuators mounted on the mobile manipulator, and on the other hand, allow for sending motion commands to the mobile manipulator. They should allow for position, velocity, and torque control in close feedback loops.

2.9. KUKA youBot

2.9.1. Description

The youBot is a desktop mobile manipulator for education and research. Its standard configuration consists of a mobile platform and a 5-axes-robot. The platform and the arm can also be operated independently. It is further possible to attach a second arm to the platform. The key features of the youBot are:

- omnidirectional mobile platform
- 5-DOF manipulator
- two-finger gripper
- real-time EtherCAT communication
- open interfaces
- arm and platform can be used independently

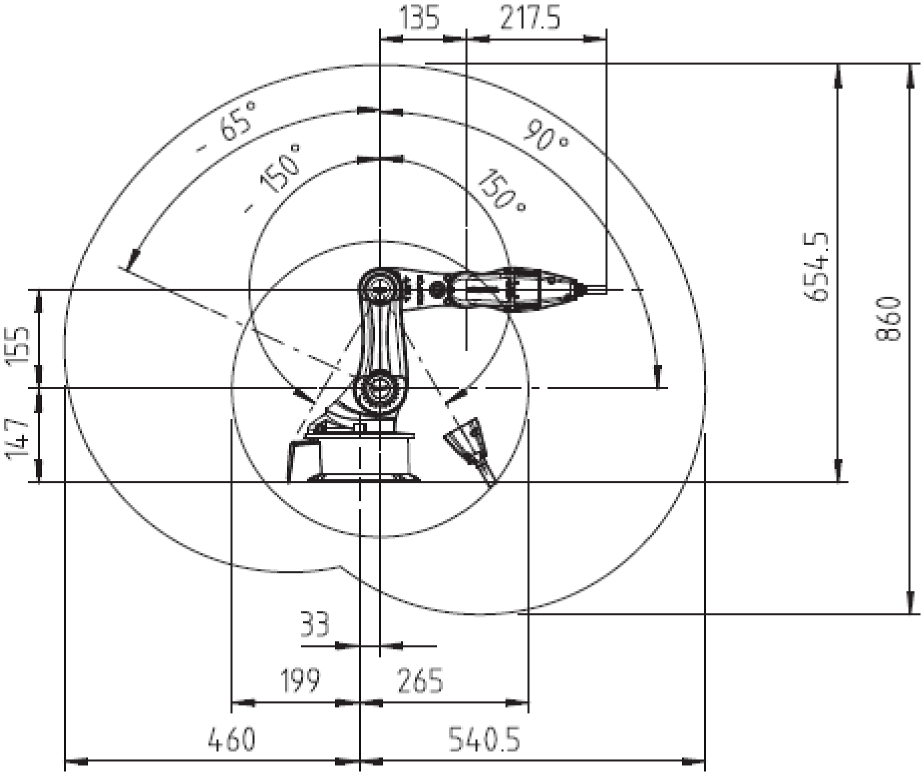


Figure 20: Operating envelope of the youBot arm

2.9.2. Images

Figure 21: The youBot in a one- and a two arm configuration

2.9.3. Use in BRICS

The youBot is the integration platform used within BRICS as this is the only platform that can be distributed to all partners. This means that a lot of the software within BRICS is being developed and/or tested on this platform. The youBot is further used at the research camps to allow the students to run experiments and to compare their results.

2.9.4. Modifications/Enhancements for BRICS

The youBot was modified several times to take into account feedback gathered through BRICS. This feedback was given either through direct consultation (e.g. the BRICS questionnaires) or at the research camps. This information, together with experiences made by KUKA and the project partners led to the redesign of several hardware and software features including firmware revisions. BRICS software connects directly to the robots open interfaces, which were realised to meet requirements stated in BRICS questionnaires.

3. Conclusions

The hardware platforms used within BRICS have been presented. Each of them was described some detail. Their use within BRICS was explained and the most significant modifications made in the context of BRICS were explained.

It could be seen that platforms of different sizes (centimetres to meters), with different setups (0 – 2 arms), using different types of controllers, different sensors and different drive systems (differential, omnidirectional…) are used. This is done on purpose to ensure that BRICS software is transferable between different setups.

4. References

(Parlitz et al, 2008)

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