LIST OF SELECTION CRITERIA
AND SPECIFICATION OF THE SELECTED INDUSTRIAL ROBOT
RÈSUMÈ

Deliverable 3 summarizes how the industrial robots were selected for the robot mediated physiotherapy. Not only the robots but also the manufacturer was selected and linked to the REHAROB project through a subcontract. Selected industrial robots: IRB 140 & IRB 1400. Selected robot manufacturer: ABB Automation – Robotics Systems.
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1 Introduction

This project focuses on developing a system for upper limb motion therapy methodology for patients with neuro-motor impairments. The therapy will be driven by industrial robots utilising intelligent identification of the required physiotherapy motions. This will be achieved by a robotic rehabilitation system called REHAROB.

In order to select adequate robots for the physiotherapy the following requirements have to be considered:
- technological requirements (workspace, speed, payload, control, etc.) for the recommended physiotherapy exercises,
- design requirements like communication with other elements in the cell, and a feasible cell layout,
- safety requirements,
- legal requirements: medical certification,
- economics requirements.

All of the above listed requirements form the scope of subsequent tasks and deliverables like:
- Deliverable 7: Analysis of the upper limb motion, impairments, and motion therapies used and improvements for the impairment rehabilitation,
- Deliverable 9: Technical documentation of the non-commercial part of the 3D motion therapy monitoring system,
- Deliverable 11: Methods and equipment for an improved upper limb motion therapy including the application package for the submission to the Ethics Committee,
- Deliverable 15: Assessment and evaluation of the REHAROB cell for motion therapies,
- Deliverable 11: Specification of the industrial robot adapted to the REHAROB cell.

It was decided on the partner meeting held in Tübingen (D), on 13-14 July 2000 that this deliverable should not give a detailed account on these issues although a significant progress has already been achieved. Instead, it gives proper evidence that all the listed requirements have been considered during the selection of the industrial robots.

For the definition of the requirements the following steps were taken:
1. Collecting users requirements and engineering solutions through interviews, from the literature, and from the World Wide Web
2. Analysis of the relevant robot, safety and medical equipment certification procedures
3. Definition of requirements for REHAROB
4. Market analysis of industrial robots
5. Opening a tender: contacting 18 industrial robot manufacturers
6. Feedback/quotations from 6 robot manufacturers
7. Preselection of robot manufacturers
8. Detailed evaluations of the received quotations
9. Selection of the industrial robot(s)
10. Specification of the industrial robot(s)
2 Definition of the requirements for the industrial robots and the robot manufacturer

2.1 Collecting users requirements and engineering solutions

The main objective of the Reharob project is to develop a robotic system for upper limb motion therapy for patients, who have hemiparesis due to central nervous system damage. In the analysis phase of the project the possible physiotherapy exercises have been collected so as to demonstrate the physiotherapist’s work. The robot (or robots) will be required to execute selected exercises from this catalogue (available on the project Web page: http://reharob.manuf.bme.hu).

2.1.1 Simulation based conceptual design of the REHAROB cell

Due to the high 3D complexity of the physiotherapy exercises it was decided that any decision on the selection of the active therapy devices: industrial robot(s) (See Figure 1!), F/T sensors (See Figure 1!), orthosis(e)s (See Figure 2 and Figure 3!) that connect the patient arm with the robot(s), therapy bed/chair (See Figure 5!) must be verified with simulation.

For the simulation the IGRIP® advanced 3D robot simulation tool of Deneb Robotics Inc. was selected because

- through built in CAD functionality the non-standard elements of the REHAROB cell including the Virtual Reality mannequin can be modelled
- through definition of the upper limb kinematics it is capable for the simulation of the physiotherapy exercises

![Diagram](image-url)
• through reading data of the 3D Motion Analysyer simulation of the physiotherapy exercises can be automated
• all existing industrial robots can be loaded from libraries
• it is capable for detection of constraint violation such as:
  ▪ joint range limits
  ▪ joint velocity limits
  ▪ joint acceleration limits
  ▪ joint force or torque limits
  ▪ detection of the collision of any rigid body with another rigid body

The Virtual Reality mannequin was created on anthropometrical consideration described in Task 1.1 reports which will be parts of Deliverable 7: Analysis of the upper limb motion, impairments, and motion therapies used and improvements for the impairment rehabilitation. (The built in human VR models cannot be used because they satisfy the needs of ergonomic modelling but not the needs of the biomechanical modelling.) The REHAROB mannequin currently consists of simple Euclidean solids which the human kinematics and range of motion (ROM) are associated with. Its current kinematic structure has 5 DOF including only rotational kinematic pairs (See Figure 2!) Later two additional DOF’s will be added to the shoulder to allow the spherical motion of the humerus. Dynamic properties of the biomechanical model will also be added later.

![Figure 2 Modelling the upper limb in IGRIP®](image)

Biomechanical considerations have led to the decision that two robots have to be used for a correct physiotherapy, i.e. to cope with the problem of axes misalignments between the biomechanical and the therapeutic machine kinematic axes, which so many predecessor researches failed to solve correctly. Robot1 has to move the upper arm and robot 2 has to move the lower arm. Both robots will be connected to the patient’s arm by means of specially designed orthoses. Figure 2 shows simplified models of the lower and upper arm orthoses while Figure 3 shows the conceptual structure of the lower arm orthosis.
To start the conceptual design of the REHAROB cell the upper arm dimensions of the tallest and heaviest patient were defined first (See Figure 4!). The upper limb was scaled up with using a regression tool developed in Task 1.1.

Due to the limitations of time and resources available for the robot selection VR simulations were prepared only for the most workspace and mobility demanding exercises: No29, No37, and No40 (See Figure 5!). Each exercise should be feasible in 8 arrangements: in lying and in sitting positions of the patient, for a left arm patient and for a right arm patient, and with an orthosis with the connector up and with an orthosis with the connector down. Later, for the detailed design of the REHAROB cell this manual simulation technique will be automated: motion measurements recorded in Task 1.2 will be fed into IGRIP® for simulation.

Following the arm movement simulations the robot should be inserted into the simulation environment by connecting it to the orthoses. In the simulation we follow just an opposite strategy to the real therapy: the patient’s arm moves the two robots by applying mechanical constraints at the contacts. The two robots should be inserted into the Virtual Environment (VE) not to collide with any other body in the VE but be able to follow the arm movement throughout the exercise.
This procedure is called layout design in engineering terms. The design requirements for the layout design of the REHAROB cell were:

- consider only 3 elements: robot1, robot2, bed/chair
- fix(screw down) all elements in the VE
- be able to adapt to physiotherapy in lying/sitting positions
- be able to adapt to left arm/right arm physiotherapy
- allow teach-in play back for the physiotherapist
- allow 1 rotational adjustment DOF to the bed
- allow 1 translational adjustment DOF to the bed
- allow 2 translational adjustment DOFs to the bed

![Figure 5 Simulation of selected exercises](image)

It is obvious that with a special multi segment bed/chair the design requirements can be satisfied if left arm patient is allowed to lie/sit just facing to as right arm patient is allowed to sit/lie. For simplicity this case was modelled with 180° turn of the bed.

Another simple case is when two beds/chairs located in right angles to each other are used for the left arm and for the right arm therapy respectively. For simplicity this case was modelled with 90° turn of the bed.

Other cases may require real physical adjustment of the bed/chair so were excluded from the simulation.

Figure 6 shows how teach-in and play back is conceptualised for REHAROB. (The PUMA 560 type industrial robots are used only for illustration.)
If the two robots are based in the same plane then only 3 layouts can be considered as it is shown in Figure 7. All of the shown layouts have been rejected because the selected exercises are impossible to execute without intersection of robot-robot, robot-patient arms during therapy.

The same happens in the case when one robot is installed above the other (See Figure 8!) This figure shows the layout found only successful: two robots are above each other and the upper one is in hanging configuration. The quoted robots were tested for the selected exercises in this layout.
Conclusions drawn from and decisions made on the basis of the literature survey, end user requirements analysis and Virtual Reality simulations:

a) when developing a therapeutic machine for the upper limb the most difficult issue is to cope with the kinematics of the 5DOF shoulder complex. In REHAROB therefore, unlike at other therapeutic machines we will allow 6DOF movement of the upper arm hence not constrain any movement of the shoulder complex. An industrial robot of 6DOF will be necessary to move the upper arm. The robot should be connected to a suitable upper arm orthosis.

b) the lower arm will be moved also by a 6DOF industrial robot. From biomechanical point of view this is not necessary as only 2DOFs: elbow flexion-elbow extension and pronation-supination are added to the DOFs of the upper arm resulting in a 7DOF upper arm model. However, to overcome the design and manufacturing problems of a 2DOF powered orthosis it was decided to use a second 6DOF robot to move the lower arm. The robot should be connected to a suitable lower arm orthosis.

c) physiotherapy of the hand is excluded from the scope of REHAROB due to the numerous DOFs of the hand. During the robot mediated therapy the hand should be kept in an inclined reflex inhibition position that can be adjusted to the patient through the hand support of the lower arm orthosis.

d) literature survey [Valleggi et al, 1996], [Buckley, 1996], [LaSatyo, 1995] and measurements at BUTE have concluded that resultant force and torque at connectors of the upper and lower arm orthoses will not exceed 123N and 65 Ncm during the therapy of hemiparetic patients. Taking into consideration of the allowable 100-1000% overloading of industrial robots when accuracy and high speed is not required 5 kg load capacity industrial robots will be required for the physiotherapy.

e) commercial variable 3D motion physiotherapy machine with the aim of fully and totally replace the physiotherapist in exercise and active physiotherapy of the arm of spastic hemiparetic patients is not known.

f) there are several commercially available therapeutic machines (Kintrex, Artromot, EX N’ Flex, Biodex, Cybex, Kinetec, Danniflex, etc.) for the Continuous Passive Movement
(CPM) or fixed trajectory exercise ([Dixon, 1985], Constant Rate Velocity Change Motion Controller) therapy of hemiparetic patients

g) there are some custom made commercially available [Engen & Spencer, 1969], [Snelson et al, 1961], [Leonard et al, 1989], [Hokken et al, 1993] or post-research phase [Sauter et al, 1989], [Romilly et al, 1994], [Dixon, 1985] powered and passive orthoses to assist the motion of the patient’s arm. These are not considered as therapeutic machines.

h) there are prototype physiotherapy machines with the aim of fully and totally replace the physiotherapist in the exercise and active physiotherapy of the arm of spastic hemiparetic patients. These are: powered orthosis [Johnson et al, 1998], custom made SCARA robot [Hogan et al, 1992], [Hogan et al, 1995], [Krebs et al, 1999] combination of passive arm support and industrial robot [Lum et al, 1999].

i) industrial robots are technologically capable for force control. Vast majority of the industrial robots are position controlled, there are however some applications (painting, machining, assembly) in which industrial robots are controlled by force sensory input. REHAROB can benefit from these applications but will need additional developments from the robot manufacturer. Theoretical foundations for the various force control approaches exist and already implemented in non-industrial robots: space robots, research robots, tele-robotics, haptic devices.

2.2 Analysis of the relevant robot, safety and medical equipment certification procedures

The following robot, safety, and medical equipment certification related standards and norms have been reviewed:

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<td>EN ISO 8373:1994  Manipulating industrial robots -- Vocabulary</td>
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<td>EN 418 Safety of machinery, emergency stop equipment</td>
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<td>EN 563 Safety of machinery, temperature of surfaces</td>
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<td>EN 614-1 Safety of machinery, ergonomic design principles</td>
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<td>EN 60204 Electrical equipment for industrial machines</td>
</tr>
<tr>
<td>prEN 574 Safety of machinery, two-hand control device</td>
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<td>prEN 953 Safety of machinery, fixed / movable guards</td>
</tr>
<tr>
<td>prEN 954-1 Safety of machinery, safety related parts of the control system</td>
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<tr>
<td>EN 50081-2 EMC, Generic emission standard</td>
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<tr>
<td>EN 55011 Class A</td>
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<tr>
<td>EN 61000-4-2 Electrostatic discharge immunity test</td>
</tr>
<tr>
<td>EN 61000-4-3 Radiated, radio-frequency. Electromagnetic field immunity test</td>
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<tr>
<td>ENV 50204 Radiated electromagnetic field forming. Radio telefones immunity test</td>
</tr>
<tr>
<td>EN 61000-4-4 Electrical fast transient / burst immunity test</td>
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</table>
Conclusions drawn from the analysis:

a) there is an approach difference between the listed robot or safety standards and the medical device standards. Robot and safety standards are low-level technical standards while medical device standards are high level generic standards.

b) industrial robots fulfil all robot and safety standards for industrial applications, which was the major reason to select industrial robots for the robot mediated physiotherapy.

c) industrial robots on the other hand need to be certified as medical devices. This is always a specific application dedicated procedure when a certified body issues the CE mark for the medical device. The REHAROB cell will definitely belong to the device Class 2b as physical contact between the therapeutic machine and the patient occurs. At the moment it cannot be precisely forecasted what mechanical, electric and control safety measures and devices will be required for the REHAROB cell, so the robot manufacturer will be required to collaborate with the REHAROB project throughout its full duration and provide the REHAROB cell with product support after termination of the project.

d) according to Council Directive 93/42/EEC the manufacturer of the medical device has to apply for the certification. In case of the REHAROB project all project wide developments have to be admitted and approved by the robot manufacturer who as legal entity shall apply for the certification.

e) members of the REHAROB project believe that service robotics including medical robotics applications could benefit from the mass of standards referring to industrial robots. In order to formulate a technical standard on service (including medical) robotics BUTE as coordinator of the REHAROB project has made an official enquiry to the Hungarian Standardization Body. The enquiry was about to initiate the change/creation of the legal, standard and safety basis for the use of industrial robots in human rehabilitation. It is thought that EN 775 ISO 10218:1992 Manipulating Industrial Robots-Safety standard should be harmonized with EN/ISO standards referring to medical equipment applications (93/42/EEC). BUTE was informed that to initiate negotiations about a New Work Item Proposal needs at least 5 supporting votes of National Bodies. The robot manufacturer will be required to lobby for the votes of National Bodies of the EU and associated states.
3 Requirements for the industrial robots

The analysis briefly outlined in Section 2 has resulted in the following list of requirements for the industrial robots:


• arm type: jointed, or polar, or cylindrical
• load capacity: max. 6-7 kg
• number of axes: min 6
• speed: expected to be low – not crucial factor for REHAROB
• repeatability: expected to be medium – not crucial factor for REHAROB
• accuracy: expected to be medium – not crucial factor for REHAROB
• acceleration: expected to be medium or high – subject to detailed simulation with the quoted robots
• workspace: robot 1: reach of max 1 m, robot 2: reach of max 2 m
• weight: as less as possible
• vibration: low – it is recommended not be sensitive to external excitation
• drive system: electric

CONTROL/PROGRAMMING CHARACTERISTICS:

• the robot will be integrated with a PC which will be used also for programming and monitoring of the robots, this PC should be able to communicate with the robot controller
• spline interpolation
• 6 DOF F/T measurement at the end effector or at the joints: very important
• force-position (compliance) control: very important, what bandwidth is available?
• on-line and off-line programming
• is teach-in play-back programming technology available?
• path correction facilities,
• on-line program correction
• high-level structured object-oriented programming language

SAFETY SYSTEMS
In addition to the safety systems required by the EN 775 ISO 10218:1992 the selected industrial robot will be certified during the project by

• Medical Devices Directive 93/42/EEC
• EN IEC 60601-1 Safety of medical electrical equipment, Part 1: General requirements for safety

Very strong preference will be given to an industrial robot that has already obtained the CE mark according to 93/42/EEC Class 2b and EN IEC 60601-1, i.e. it can contact humans.

CAXx and SIMULATION SUPPORT:

• support of CAD model, postprocessor for programming in simulation environment, sensor modelling, kinematics and dynamics modelling
• is there a standalone 3D simulation environment for the robot offered available?
• is the robot offered available in or attachable to commercial simulation packages like RobCAD®, IGRIP®, RobSim®, Workspace®, etc?
PLEASE LIST THE MOST RELEVANT INDUSTRIAL OR SERVICE APPLICATIONS FOR THE INDUSTRIAL ROBOTS YOU OFFER US:

- .............
- .............
- .............

OTHER CHARACTERISTICS:
- clean room application
- easy cleaning
- is optional covering possible?
4 Requirements for the Robot Manufacturer

The analysis briefly outlined in Section 2 has resulted in the following list of requirements for the robot manufacturer:

REQUIREMENTS FOR THE ROBOT MANUFACTURER

- the robot and the controller should be a serial product of annual volume not less than 100 pieces,
- sell or lease the two robots and the controller to the REHAROB consortium in a discount price,
- join the REHAROB consortium as a subcontractor: contribution to the project for 100000 EUR can be subcontracted to the robot manufacturer
- willingness to lobby for the modification of safety standards to allow contact between humans and the robot,
  (Most problematic clause of EN 775 ISO 10218:1992 can be found in Section 4.1 on p.3: “the absence of persons in the safeguarded space during automatic operation.” In the case of robotized rehabilitation of patients this cannot be kept.)
- willingness to proceed with/support a certification procedure enforced by 93/42/EEC Class 2b and EN IEC 60601-1
- experience in force-position control for industrial tasks
- reference to service robot applications
- reference to medical robot applications
5 List of contacted robot manufacturers

The list contains all the industrial robot manufacturers identified by the REHAROB project. Cells of the robot manufacturers contacted by the REHAROB project are shaded.

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<td>KUKA</td>
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| MITSUBISHI  | http://www.meau.com/      | MITSUBISHI                                   | 200 Cottontail Lane
Somerset, NJ 08873
USA
Tel (732) 560-4500
Fax (732) 560-4535
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| MOTOMAN     | http://www.motoman.com/   | Motoman, Inc.                                | 805 Liberty Lane
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(937) 847-3300
info@motoman.com
farkasat@westel900.net |
| NACHI       | http://www.nachirobotics.com/ | Nachi Robotic Systems Europe GmbH (NRSE)        | Stuifenstrasse 50
D-74385, Pleidelsheim
Germany
Tel: 49.7144.80350
Fax: 49.7144.803520
FORM |
| NORMADIC    | http://www.robots.com/    |                                             |                                                        |
| OTC-DAIHEN  | http://www.otc-daihen.com/ | OTC-DAIHEN                                   | Dynamic Robotics Division
761 Crossroads Ct.
Vandalia, OH 45377
USA
Tel: (937)454-9660
Fax: (937)454-9661
DRD@otc-daihen.com |
| OXIM        | http://www.oxim.co.uk/    | Oxford Intelligent Machines Ltd              | 12 Kings Meadow, Ferry Hinksey Road
Oxford OX2 0DP
United Kingdom
Tel: (44) 1865 204881
Fax: (44) 1865 204882
"Tim Jones" tim@wynford.fsbusiness.co.uk |
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Winsbergring 15  
D - 22525 Hamburg  
Germany  
Phone: 040 - 85 38 62 75  
Fax: 040 - 85 38 62 18  
FORM: [http://www.pfae.com/contact/contact.php3](http://www.pfae.com/contact/contact.php3) |
| PEUGEOT      |                                  |                                                                                               |
| REIS         | [http://www.reisrobotics.com](http://www.reisrobotics.com) | Reis Robotics  
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Fax +49-6022-503-110  
websales@reisrobotics.de  
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Seestrasse 240  
CH - 8810 Horgen  
SWITZERLAND  
Tel: +41.1.728.61.11  
Fax: +41.1.728.66.34  
E-mail: info@staeubli-ag.ch |
| YAMAHA       | [http://www.yamaharobotics.com](http://www.yamaharobotics.com) |                                                                                               |
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<td>ESHED, FANUC, KAWASAKI, OXIM</td>
<td>KUKA</td>
<td>COMAU, CRS, HITACHI, ISE, MITSUBISHI, NACHI, OTC-DAIHEN, PANASONIC, SEF ROBOTER</td>
</tr>
<tr>
<td>MOTOMAN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REIS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STÄUBLI</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

None of the four quotations met fully the stated requirements so BUTE entered into further personal negotiations with ABB, MOTOMAN and STÄUBLI. Only REIS was excluded from the negotiations as no commitment to collaboration arrived with the quotation.
6 Comparison of the quotations of the pre-selected robot manufacturers

During personal multi round negotiations all quotations and commitments of the preselected robot manufacturers were finalized. Evaluation of the quotations was made with using a score system. If a requirement is fulfilled then it is indicated with a tick and the score associated with the requirement item at the upper left index is added to the total of the robot manufacturer. If the quotation does not meet the requirement than a cross is shown at the manufacturer’s column and no scores are added to the manufacturer.

The table below compares the quotations of the three pre-selected industrial robot manufacturers:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Stäubli</th>
<th>ABB</th>
<th>Motoman</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>robot 1: reach&lt;1m:</td>
<td>RX 60LB</td>
<td>IRB-140</td>
<td>UP6</td>
</tr>
<tr>
<td>arm type, DOF</td>
<td>jointed, 6 DOF</td>
<td>jointed, 6 DOF</td>
<td>jointed, 6 DOF</td>
</tr>
<tr>
<td>load capacity</td>
<td>2.5 kg</td>
<td>5 kg</td>
<td>6 kg</td>
</tr>
<tr>
<td>max reach$^2$</td>
<td>865 mm</td>
<td>810 mm</td>
<td>1373 mm</td>
</tr>
<tr>
<td>robot 2: reach&lt;2m:</td>
<td>RX 90BL</td>
<td>IRB-1400</td>
<td>UP6</td>
</tr>
<tr>
<td>arm type, DOF</td>
<td>jointed, 6 DOF</td>
<td>jointed, 6 DOF</td>
<td>jointed, 6 DOF</td>
</tr>
<tr>
<td>load capacity</td>
<td>3.5 kg</td>
<td>5 kg</td>
<td>6 kg</td>
</tr>
<tr>
<td>max reach$^2$</td>
<td>1185 mm</td>
<td>1440 mm</td>
<td>1373 mm</td>
</tr>
<tr>
<td>total$^3$ list price:$^4$</td>
<td>EUR 108,700</td>
<td>EUR 83469</td>
<td>EUR 67260</td>
</tr>
<tr>
<td>REHAROB price:$^5$</td>
<td>EUR 72,000</td>
<td>EUR 71000</td>
<td>EUR 67260</td>
</tr>
<tr>
<td>appearance</td>
<td>nice looking</td>
<td>too industrial</td>
<td>nice looking</td>
</tr>
</tbody>
</table>

$^1$ Based on the information of the manufacturer the robot can be loaded up to 20-24 kg if nominal accuracy and nominal speed are not required

$^2$ Point is given if simulation proves the easiness of the application.

$^3$ Including the two robot, controllers and basic software.

$^4$ Point is given if it is equal to the REHAROB price. If point can’t be given then the manufacturer offering lower price should be preferred.

$^5$ Treshold is EUR 72000 which was communicated to the pre-selected manufacturers.

$^6$ ABB offered to cover the IRB 1400 robot to fit medical applications.
<table>
<thead>
<tr>
<th>Control:</th>
<th>YES</th>
<th>YES</th>
<th>YES</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration with PC</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Type of control</td>
<td>position</td>
<td>position</td>
<td>position</td>
<td>position</td>
</tr>
<tr>
<td>Access to control gains</td>
<td>YES</td>
<td>✔</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Safety:</td>
<td>YES</td>
<td>✔</td>
<td>YES</td>
<td>✔</td>
</tr>
<tr>
<td>EN ISO 10218:1992</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>93/42/EEC for RX90 (Ortomaquet)</td>
<td>NO</td>
<td>✔</td>
<td>NO</td>
<td>✔</td>
</tr>
<tr>
<td>Simulation support</td>
<td>YES</td>
<td>✔</td>
<td>YES</td>
<td>✔</td>
</tr>
</tbody>
</table>

Subtotal: 12 12 11

Eligibility: YES YES NO

(The recently launched RX60LB and IRB 140 robots are not available in IGRIP yet. A similar robot: A465 of CRS was used in the simulations.)

---

7 Point is given if a kind of force control is offered.
8 Conclusive requirement: quotation is eligible if point is received.
Comparison of the robot manufacturers:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Stäubli</th>
<th>ABB</th>
<th>Motoman</th>
</tr>
</thead>
<tbody>
<tr>
<td>1manufacturer</td>
<td>Stäubli Robotics World Headquarters (F)</td>
<td>ABB Flexible Automation and Robotics AB (SE)</td>
<td>Motoman Robotics Europe AB (SE)</td>
</tr>
<tr>
<td>1serial product</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>1product support</td>
<td>many EU countries, not in associated countries</td>
<td>all EU countries, all associated countries</td>
<td>all EU countries, many associated countries</td>
</tr>
<tr>
<td>1mission</td>
<td>focus on niche market</td>
<td>focus on industry</td>
<td>focus on industry</td>
</tr>
<tr>
<td>1support to standardisation</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>1subcontractor</td>
<td>FD-Engineering GmbH (A)</td>
<td>ABB AG Flexible Automation Austria (A)</td>
<td>REHM Welding Technology Ltd (HU)</td>
</tr>
<tr>
<td>1R&amp;D potential</td>
<td>limited support</td>
<td>required support</td>
<td>no support</td>
</tr>
<tr>
<td>1willingness in the re-negotiations and for the later cooperation with REHAROB</td>
<td>- no written commitment for med. certification - no benefit from the med. CE of RX90, - no written commitment for standardisation - rigid payment conditions - no written commitment statement, - delays in communication, - draft offer for services to be subcontracted</td>
<td>- written commitment for standardisation and med. certification, - 10% discount from list price to any REHAROB follow-up sale - deferred payment conditions, - written commitment statement, - good communication and quick reactions, - detailed services to be subcontracted</td>
<td>no re-negotiations happened due to</td>
</tr>
</tbody>
</table>

Subtotal: 5 7 5
Eligibility: EC has approved EC has approved EC has approved
Total: 17 19 16

Based on the evaluation quotation and collaboration offer of ABB was accepted.
7 Specification of the selected ABB robots

## Technical data

### IRB 140 industrial robot

**SPECIFICATION**

<table>
<thead>
<tr>
<th>Robot version</th>
<th>Handling capacity</th>
<th>Reach of</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRB 140</td>
<td>5 kg</td>
<td>810 mm</td>
<td></td>
</tr>
<tr>
<td>IRB 140F</td>
<td>5 kg</td>
<td>810 mm</td>
<td>Extra protection</td>
</tr>
<tr>
<td>IRB 140CR</td>
<td>5 kg</td>
<td>810 mm</td>
<td>Clean Room</td>
</tr>
</tbody>
</table>

- **Supplementary load (on upper arm, wrist)**
  - on upper arm: 1 kg
  - on wrist: 0.5 kg

- **Number of axes**
  - Robot manipulator: 6
  - External devices: 6

- **Integrated signal supply**
  - 12 signals on upper arm
- **Integrated air supply**
  - Max. 8 bar on upper arm

### PERFORMANCE

- **Position repeatability**
  - ±0.03 mm

- **Axis movements**
  - 1. C Rotation
  - 2. B Arm
  - 3. A Arm
  - 4. D Wrist
  - 5. E Bend
  - 6. R Turn

- **Movement on ISO test plane, all axes in movement**
  - Max. TCP velocity: 2.5 m/s
  - Max. TCP acceleration: 20 m/s²
  - Acceleration time 0-1 m/s: 0.15 sec.

### ELECTRICAL CONNECTIONS

- **Supply voltage**
  - 200–600 V, 50/60 Hz
- **Rated power**
  - Transformer rating: 4.5 kVA

### PHYSICAL

- **Robot mounting**
  - Floor, wall and suspended

### Dimensions

- **Robot base**
  - 400 x 400 mm
- **Robot controller H x W x D**
  - 950 x 800 x 620 mm

- **Weight**
  - Robot manipulator: 96 kg
  - Robot controller: 250 kg

### ENVIRONMENT

- **Ambient temperature**
  - Robot manipulator: 5 – 45°C
  - Robot controller: 5 – 52°C
- **Relative humidity**
  - Max. 95%

- **Degree of protection, Manipulator**
  - Standard: IP54
  - Foundry/Clean Room: IP67
  - Clean Room: Class 10
- **Controller**
  - Enclosed air-over
  - Sealed computer, air-over
  - Totally enclosed
- **Noise level**
  - Max. 70 dB [A]

### Safety

- **Double circuits with supervision, emergency stops and safety functions, 3-position enable device**

### Emmission

- **EMC/EMI-shielded**

### MAN-MACHINE-INTERFACES

- **Operators’ panel**
  - In cabinet or external
- **Teach pendant**
  - Portable with joystick and keypad. Display 16 lines x 40 characters. Window style communication. 3 position enabling device, back lighting. 5 user definable keys, emergency stop.
- **Languages**
  - Choice of 11 national languages
- **PC, off-line**
  - “The S4C plus software on your PC”
  - Quick Teach training on PC
  - RobotStudio™, ProgramMaker™
  - VirtualRobot simulation
  - Monitor and control of robots, FactoryWare™
- **PC, on-line**
  - Monitor and control of robots, FactoryWare™
- **RRS Simulation**
  - From simulation companies

### MACHINE INTERFACES

- **Inputs/outputs**
  - Up to 2 x 1024 signals,
  - Digital
  - 24 V DC.
  - 120 V AC or relay outputs
  - ±10 V and 4-20 mA
- **Serial channels**
  - Two RS 232 and one RS 422
- **Networks**
  - 2 x Ethernet
  - Allen Bradley PLC
  - 2 x CAN/Device Net
  - Interbus-S
  - Profibus DP
- **Process interfaces**
  - Media and signals on upper arm

### EXAMPLE OF ARC WELDING EQUIPMENT AND FUNCTIONALITY

- **Process equipment**
  - Weld power sources
  - Wire feed systems
  - Welding torches
  - Workpiece manipulators
- **Example of process signal interface**
  - Status of arc, voltage, current,
  - water, gas, wire feed (digital input)
  - On/off of power, gas, wire feed, error information (digital output)
  - Value of wire feed velocity, voltage, current (analog output)
- **Example of ArcWare™ functions**
  - General power source interface
  - Process tuning of welding parameters during program execution (hot edit)
  - Weld-retro including “go-to-service” routine
  - Weld error report and logging
  - Arc start/stop
  - Material pre-heating/cooling
  - Scraps start/stop
  - Groove filling
  - Wire burnback
  - Weaving pattern definition
  - Monitoring of arc data, seam coordinates, wire, water, voltage, current, gas

### Diskette drive

- **3.5” MS-DOS**

### Robot vision

- **Interface for vision**

**Data and dimensions may be changed without notice.**
Working range and Load diagram

- **Roo mounted**
- **Wall mounted**
- **Suspended**

Working range to center of axis S. All measurements in mm.
Working Range and load diagram

Examples of ISO test results at rated load and speed

<table>
<thead>
<tr>
<th>ROBOT TYPE</th>
<th>IRB 1400</th>
<th>IRB 1400H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated load</td>
<td>5 kg</td>
<td>5 kg</td>
</tr>
<tr>
<td>Rated speed</td>
<td>1 m/s</td>
<td>0.5 m/s</td>
</tr>
<tr>
<td>Max. velocity</td>
<td>2.1 m/s</td>
<td>1.3 m/s</td>
</tr>
<tr>
<td>Repeatability RP</td>
<td>0.04 mm</td>
<td>0.04 mm</td>
</tr>
<tr>
<td>Linear path accuracy AT</td>
<td>1 mm</td>
<td>0.84 mm</td>
</tr>
<tr>
<td>Linear path repeatability RT</td>
<td>0.16 mm</td>
<td>0.21 mm</td>
</tr>
<tr>
<td>Circular path repeatability RT</td>
<td>0.33 mm</td>
<td>0.21 mm</td>
</tr>
<tr>
<td>Minimum positioning time to 0.2 mm on 36 mm linear path</td>
<td>0.2 sec</td>
<td>0.3 sec</td>
</tr>
<tr>
<td>on 350 mm linear path</td>
<td>0.55 sec</td>
<td>0.6 sec</td>
</tr>
<tr>
<td>Average power consumed on ISO test paths</td>
<td>130W</td>
<td>150W</td>
</tr>
</tbody>
</table>

*"Rated speed" designates test speed, according to the ISO standards.*
# Technical data

## S4C Industrial Robot Controller

<table>
<thead>
<tr>
<th>PERFORMANCE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller axes</td>
<td>12</td>
</tr>
<tr>
<td>Control principles</td>
<td>Dynamic model</td>
</tr>
<tr>
<td></td>
<td>Self optimising</td>
</tr>
<tr>
<td></td>
<td>Completely coordinated</td>
</tr>
<tr>
<td></td>
<td>12 axes interpolation</td>
</tr>
<tr>
<td></td>
<td>7-frame coordinate chain</td>
</tr>
<tr>
<td>Corner path concept</td>
<td>Automatic singularity handling</td>
</tr>
<tr>
<td>Control hardware</td>
<td>Multi-processor system</td>
</tr>
<tr>
<td></td>
<td>32 bit with floating point</td>
</tr>
<tr>
<td></td>
<td>Up to 24 Mb RAM memory</td>
</tr>
<tr>
<td></td>
<td>RAM disk</td>
</tr>
<tr>
<td></td>
<td>Up to 35,000 instructions</td>
</tr>
<tr>
<td>Control software</td>
<td>Object-oriented design</td>
</tr>
<tr>
<td></td>
<td>High-level RAPID robot language</td>
</tr>
<tr>
<td></td>
<td>Portable, open, expandable</td>
</tr>
<tr>
<td></td>
<td>PC-DOS file format</td>
</tr>
<tr>
<td></td>
<td>RobotWare software products</td>
</tr>
</tbody>
</table>

## ELECTRICAL CONNECTIONS

- Supply voltage: 200-600 V, 50-60 Hz
- Transformer included

## PHYSICAL

- Cabinet size (H x W x D): 950 x 800 x 540 mm (same size for complete robot range)
- Weight: 240 kg
- Cabinet variants: For process hardware
- Lifting eyes: Can be removed
- Wheels: Can be mounted

## ENVIRONMENT

- Ambient temperature: 5-52°C
- Relative humidity: max 95%
- Form of protection: IP 54
- EMC: Immune and emission-free

## USER INTERFACES

- Control panel: On cabinet or external
- Control pendant: Portable and light
- Joystick and keypad
- 5 user-designated keys
- Display 16 lines x 40 characters
- Windows-style communication
- Emergency stop
- All programming functions available

## PC

- Connection for PC
- Monitoring and control
- "S4 software on a PC"
- Deskware™ software for PC
- Off-line ProgramMaker™
- Virtual robot on PC
- RFS from simulation companies
- QuickTeach™ training on PC

## Languages

- Choice between 10 national languages for MMC and Manuals
- Possibility to add user dialogues and references

## Maintenance

- LEDs and test points for electronic boards
- Diagnostic software
- Recovery procedures
- Logging with clock

## SAFETY

- Safety and emergency stops
- Software functions
- Passwords
- 2-channel safety circuits with supervision
- 3-position enable device

## MACHINE INTERFACES

- Digital inputs/outputs: up to 512 signals, 24V DC
- 120V AC or relay outputs
- Analogue inputs/outputs: up to 120 signals x 10V x 20 mA
- Serial channels: RS-232 and RS-485
- Network: Ethernet (10 Mbits per second)
- Fieldbuses: Allen Bradley PLC, CAN, Interbus-S, Profibus
- Process interfaces: Media and signals for upper arm
- Space in controller for equipment
- Robot vision: OptiMaster integrated
- Diskette drive: For 3.5" MS-DOS

## SENSORS

- Search stop with automatic program shift
- Vision system
- Servo tracking
- Contour tracking
- Conveyor following

## USER DEFINED FUNCTIONALITY

- Program instructions
- Operator dialogues
- Names for all objects and data
- I/O and instruction pick lists
- Predetermined data
- Robot configuration
- Start-up sequences
- Corner paths
- Process monitoring
- Event logging
- Diagnostics, error messages
- Error handling

## PROGRAM FEATURES

- Pull-down menus, dialogues and joystick for robot motion, function keys and windows
- Cut-and-paste, copy, delete, search, change functions, undo
- Manager functions for different user needs
- File handling
- RAPID = powerful and open robot language
- ProcessWare, application software packages
- Motion to a position or fly-by at a defined distance
- Linear, joint and circular interpolation
- Mirror function
- Soft servo function
- Unlimited rotating axes 4 and 6
- Restart on path
- Forward/backward/simulated wait and input testing
- Multi-tasking functions
- Concurrent I/O function
- Independant motion of external axes
- Position fixed I/O function
- Master-slave functions
- Real-time clock function
- Hot-edit functions
- Unlimited number of data

Data and dimensions may be changed without notice.
REFERENCES

EN 292-1 EN 292-1 Safety of machinery, basic terminology
EN 292-2 EN 292-2 Safety of machinery, technical principals / specifications, emergency stop
EN 418 EN 418 Safety of machinery, emergency stop equipment
EN 50081-2 EN 50081-2 EMC, Generic emission standard
EN 50082-2 EN 50082-2 EMC, Generic immunity standard
EN 55011 EN 55011 Class A
EN 563 EN 563 Safety of machinery, temperature of surfaces
EN 60204 EN 60204 Electrical equipment for industrial machines
EN 61000-4-2 EN 61000-4-2 Electrostatic discharge immunity test
EN 61000-4-3 EN 61000-4-3 Radiated, radio-frequency. Electromagnetic field immunity test
EN 61000-4-4 EN 61000-4-4 Electrical fast transient / burst immunity test
EN 614-1 EN 614-1 Safety of machinery, ergonomic design principles
EN 775 ISO EN 775 ISO 10218:1992 Manipulating industrial robots -- Safety 10218:1992 (Ed. 1; 10 p; E)
EN IEC 60601-1 EN IEC 60601-1 Safety of medical electrical equipment, Part I: General requirements for safety
EN ISO EN ISO 9946:1999 Manipulating industrial robots -- Presentation of 9946:1999 characteristics
ENV 50141 ENV 50141 Conducted disturbances inducted by radio-frequency fields, immunity test
ENV 50204 Radiated electromagnetic field forming. Radio telephones immunity test


IEC 204-1 IEC 204-1 Electrical equipment of industrial machines

IEC 529 IEC 529 Degrees of protection provided by enclosures


prEN 574 prEN 574 Safety of machinery, two-hand control device

prEN 953 prEN 953 Safety of machinery, fixed / movable guards

prEN 954-1 prEN 954-1 Safety of machinery, safety related parts of the control system


