EUROP

The European Robotics Platform

Strategic Research Agenda

May 2006

EUROP EXECUTIVE BOARD COMMITTEE

Sagem Défense Sécurité

Philips

Finmeccanica

KUKA

R U Robots

FOREWORD

This document was prepared by the EUROP executive board and steering board, involving the expertise of over 70 EUROP members.

The Strategic Research Agenda is the concerted action of experts from industry, SME, and academia across the European Union. Special acknowledgements go to the EUROP market segments leaders and co-leaders:

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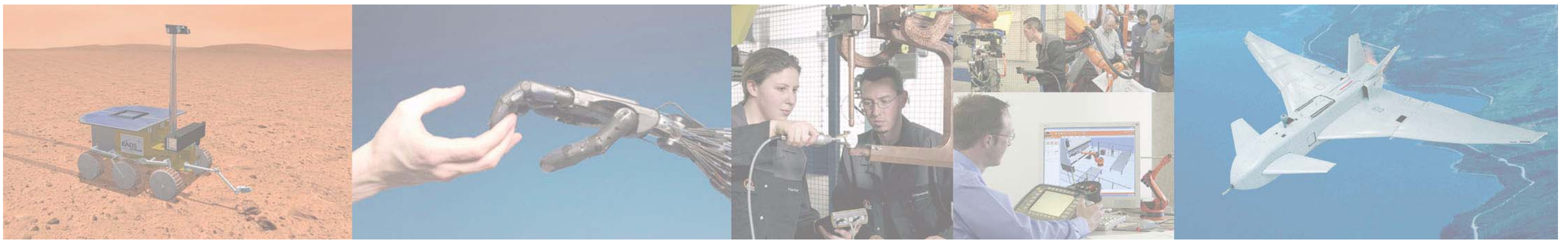


INTRODUCTION

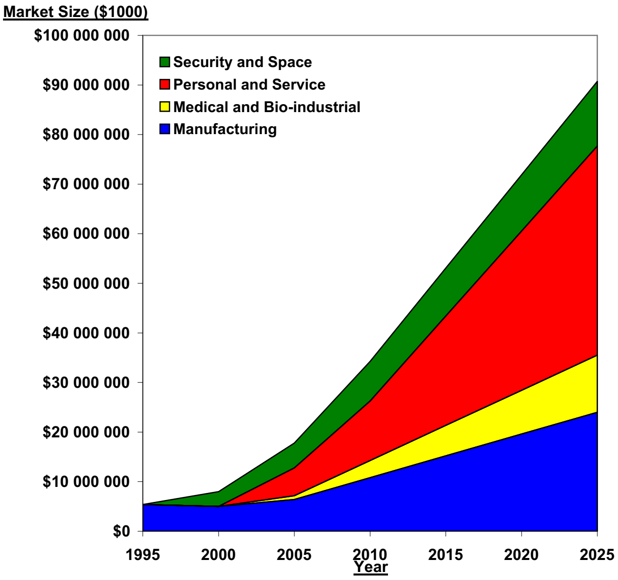
Robotics is a technology at the cusp. Long accepted by industry for improving factory quality, performance and efficiency, robotics has for at least three decades been a key technology in engineering industries for increasing industrial productivity and for competitive manufacturing. Robotics is now at a point where its scope is dramatically expanding. 21st century robot machines will be used in all areas of modern life in the form of surgical devices, machines to explore space and conduct hazardous tasks on earth, robot assistants in the home or work place and the most exciting toys and entertainment devices child-kind has ever seen!

The major challenges for the 21st century are:

- ❑ To develop robotic systems that can sense and interact with the human world in useful ways.
- ❑ To design robotic systems able to perform complex tasks with a high degree of autonomy.

This will result in robot technologies being embedded in literally thousands of future products, each one having huge commercial potential.

Such future robot systems will affect a broad range of social and economic activities. They will transform everyday life as well as industrial processes resulting in a step change of similar impact as internet, mobile phones and laptops technologies have shown at the end of the 20th century. They will enable new kinds of industrial automation; add performance and functionality to future machines; provide a wide range of innovative products, applications and services; and perform complex security and space missions. They will be driven by social aspirations and bring economic benefits, impacting on a wide range of peoples' lives and core issues of our European society. The world-wide market for such future robot systems is forecast by United Nations Economic Commission for Europe (UNECE) and the International Federation of Robotics (IFR) to be in excess of € 55 billion per annum by 2025.

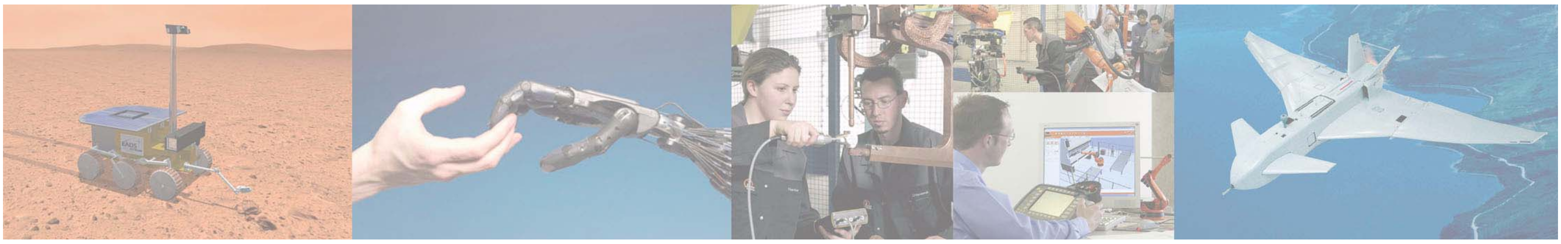


Source: Japanese Robotics Association

R&D initiatives in this field will strongly contribute to the creation of new opportunities towards European employment and growth. These opportunities are even more pronounced when facing socio-economic factors such as the ageing of our society, increasing Europe's competitiveness or the need to develop a knowledge-based society as formulated in the Lisbon Strategy and reinforced by its follow-up review (the "Kok Report"). Robotics can address sustainable perspectives for all of these factors.

In order to reach this vision, a European Technology Platform in Robotics - EUROP (European Robotics Platform) and a Strategic Research Agenda are proposed. The ambition of EUROP is to unite all the main European industrial and academic robotics stakeholders and public authorities around the EUROP Vision, where industrially relevant research goals, priorities and action plans on strategically important issues can be agreed and relevant actions implemented.

Europe has a strong and competitive robotics sector. Moreover, dual use opportunities presented by an improved co-ordination between European civil R&D efforts and similar efforts with defence-related R&D could also pave the way for an accelerated develop-



ment of generic underpinning robotic technologies and integrated robotic systems. So far though, it is outside of Europe that large robotics R&D initiatives have been set up to address similar opportunities and socio-economic challenges. This is particularly true of Korea, Japan and the USA, where efforts are underway to build new robotics industries and to prepare markets for robotic products.

This is further illustrated by Table 1, which compares the level of activity in robotic R&D and the level of key robotic products in USA, Japan, Korea, and Europe. This study emphasises the fact that key industrial organisations in Japan and Korea are highly active in robotics R&D. In the United States, the robotics R&D is very strong in university research labs but not yet taken up widely in industry except in the defence area. By comparison, European R&D activity is fairly homogeneous between the different types of organisation.

Organisations in robotics R&D	Degree or level of activity			
	USA	Japan	Korea	Europe
Basic, University based research	Excellent	Good	Good	Good
Applied, industry-based research (corporate, national labs)	Fair	Excellent	Very good	Very good
National or multi-national research initiatives or programmes	Fair	Excellent	Excellent	Very good
University-industry-government parthnerships; entrepreneurship	Fair	Excellent	Excellent	Very good

Table 1 - Robotics comparison chart

Source: International Assessment of Research and Development in Robotics, WTEC Panel report January 2006

This survey is given as an informative overview. In particular, regarding the industrial robotics in manufacturing, Europe's position is actually much closer to Japan's position. In Japan the emphasis has been on robots that have a structure that is similar to humans - so called "Humanoids". In Korea the 10-year national programme that has been launched to gain leadership in both industrial and service robotics is generously sponsored and it could lead to a significant reliance on Korean technology for service and industrial applications as major companies such as Samsung, LGe, and KIA are backing this effort. It is essential that Europe matches or beats this commitment.

Key robotic products	Degree or level of activity			
	USA	Japan	Korea	Europe
Robotic vehicles; military and civilian	Very good	Fair	Fair	Fair
Space robotics	Good	Fair	Not applicable	Good
Humanoids	Fair	Excellent	Very good	Fair
Industrial robotics; manufacturin	Fair	Excellent	Fair	Very good
Service robotics; non-manufacturing	Good	Good	Very good	Good
Personal robotics: home	Fair	Excellent	Very good	Fair
Biological and biomedical applications	Very good	Fair	Fair	Very good

Table 2 - Robotic products comparison chart

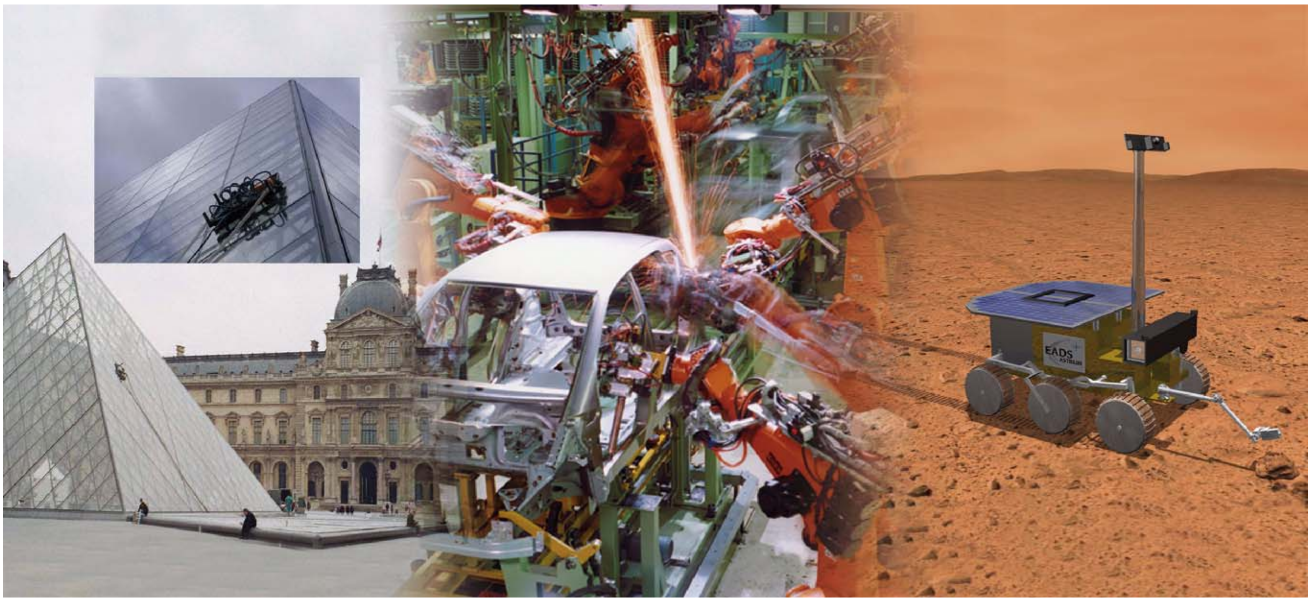
Source: International Assessment of Research and Development in Robotics, WTEC Panel report January 2006

Europe has a very strong base in robotics both from an industrial and research point of view (Table 2). Furthermore, for several years now, many European Member States, ESA and the EU Research Framework Programmes have supported world-class robotics research. On one hand, an improved co-ordination between European civil RTD efforts and, on the other hand, the dual use opportunities presented by an improved co-ordination between European civil RTD efforts and similar efforts with defence-related RTD can also pave the way for an accelerated development of generic underpinning robotic technologies and integrated robotic systems.

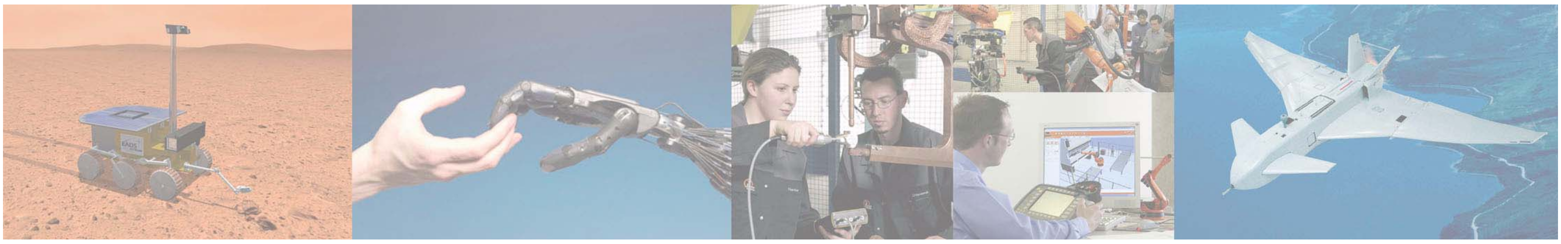
EU research activities on a stronger robotics platform can serve as an ideal means to support the strategies and targets set out at the European Councils of Lisbon 2000, Gothenburg 2001 and Barcelona 2002, in terms of moving towards a knowledge-based economy and society, sustainable development and reaching the 3% target of EU's GDP on R&D.

This ambitious mission, if successful, will see Europe maintaining its leading position in robotics and develop new companies and supply networks to meet the new societal and technology needs while also supporting the Lisbon objectives.

In Europe, there exists today a wide consensus among industrial and academic robotics stakeholders on the future challenges regarding robotics research and on the economic opportunities. This consensus is supported by a solid statistical framework, White Papers and roadmaps. The Strategic Research Agenda provides a clear picture of common core technologies in Advanced Robotics that cross the different market segments. It is of strategic economic importance that Europe exploits its current strengths and builds an effective European robotics industry. The SRA laid out in the following pages synthesises a wide consensus of expertise and provides the basis of a means to achieve this goal.



EXECUTIVE SUMMARY



Vision and challenges

Vision

In the same way as mobile phones and laptops have changed our daily lives, robots are poised to become, sooner or later, a part of everyday life. They will play a role as our appliances, servants and assistants; they will be our helpers and elder-care companions. Robots will assist surgeons in medical operations and will intervene in hazardous or life-critical environments for search and rescue operations as well as cleaning and repairing industrial structures or searching for life elsewhere.

The vision for future robotics systems is therefore that of empowering European citizens and the basis of this empowerment is the provision of robots that work with people rather than away from people; robots that interact with people and with each other and which adapt their behaviour to the requirements of the task they are given and the environment they are in.

The robot systems of the next decades will thus be human assistants, helping people do what they want to do in a natural and intuitive manner. These assistants will include:

❑ ***Robot co-workers in the workplace***

Robots integrated as agents in symbiotic manufacturing systems, empowering the workers, serving them to be more productive. These robot assistants will be at the core of human-centred automation and will allow automation to spread to the majority of manufacturing industry (increasing the 15% currently exploited). This in turn will contribute to less unemployment as more competitive segments of the industry and associated manufacturing capacity will remain in Europe because of the effective reduction in labour cost.

❑ ***Robot assistants for service professionals***

Empowering them to perform a task quicker, safer, with higher quality and more economically. These robot assistants will be in all spheres of the service industries, from surgery to physiotherapy, from construction to demolition, from intelligent transport of people to automatic transport of goods and from subsea inspection and repair to environmental surveillance.

❑ ***Robot companions in the home***

That empower the infirm and the elderly to lead independent lives, providing them with assistance by carrying out everyday tasks such as fetch-and-carry jobs, aiding mobility, rehabilitation and multimedia services.

❑ ***Robot servants and playmates***

That empower individuals by carrying out their domestic chores, thus giving people more time and choice and interactively entertaining and educating them.

❑ ***Robot agents for security and space***

Assisting and empowering people to venture into hostile and dangerous areas and acting on behalf of people in the exploration of unknown environments.

This is a vision of how advanced robots might interact and work symbiotically with us. Technically achieving this vision is still some way off. In the context of the work place, today’s robots are far from being able to understand and reason about their environments, their goals and their own capabilities, or to learn from experience and from what they have been taught.

The evolution of an information society is characterised by a growing spread of ubiquitous computing and communications, and by the development of services that are personalised, location- and context-aware. One facet is the development of artefacts with embedded computing and communication and of ad-hoc networks of sensors forming what has been termed "ambient intelligence". The role played by robots in everyday environments can be enhanced by embedding them into such emerging ICT environments. Through relevant standardisation, they will be able to

call upon a distributed knowledge base, co-ordinate their activities with other ICT devices and systems and become the agents of physical action for delivering (either individually or collectively as a group) novel capabilities, applications and services, resulting in the active home, office and public environment.

These are the factors that have motivated the vision of future European Robotics and the action that will bring it about. Such a vision of a thriving knowledge based industry will only result from proactive joint effort.

Challenges

Considering the extensive investment by Korea and Japan, Europe faces the challenge to stay at the forefront of robotics development, production and use. This calls for a set of co-ordinated actions involving all stakeholder groups, in particular from technology, systems and market developers.

Technological Challenges

Functionalities and performance of robots depend on a vast spectrum of technologies. Today such technologies and components are converging and shared throughout the robotics market segments covering industrial, domestic service, professional service and security and space applications.

Three domains of robotics technology have been defined containing several technology axes. These domains are:

- Robotics system.
- Components and miniaturised robotics.
- Advanced behaviours.

The main technological challenges are described in the rest of this section for each technology axis of the three robotics technology domains.

Robotics System

- ***Manipulation and grasping***

  Very flexible and dextrous arms and end effectors are required with a payload/weight ratios of 1:1 or better.

- ***Sensing and control***

  For everyday situations there is a need to acquire a sufficient understanding of the environment, to be aware of situations, to detect objects and people and to monitor processes with a minimum of instruction and with high-quality and precision. These requirements call for more advanced sensory feedback and use of such information for control.

- ***Intelligent, distributed environments***

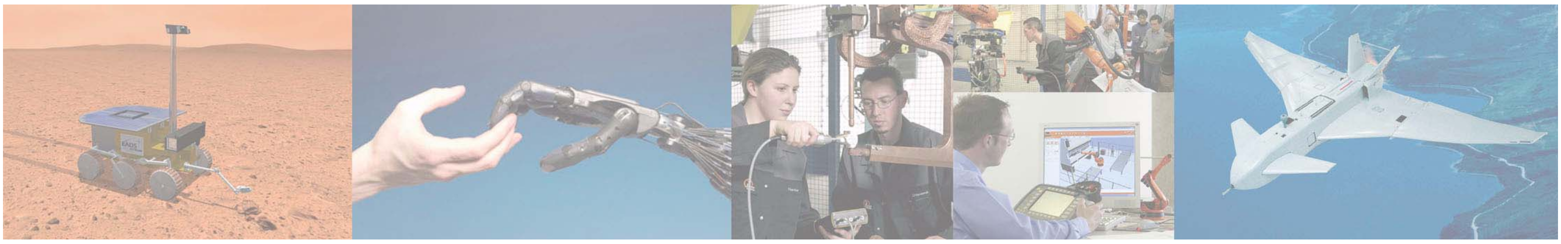
  Whether in manufacturing, public or home environments robots will be embedded into ICT networks in order to become the agents of physical action, for delivering, individually or collectively as a group, new capabilities, applications and services.

- ***Real time control and physical actuation***

  New systems will require forms of control beyond traditional open/closed loop control paradigms.

- **Robotic system engineering**

  These issues span a range of high level design topics from addressing specific aspects such as energy (as for example, energy reduction by reconsidering the overall design, the integration of new types of fuel cells for enabling long-term robot operation…), traction and propulsion systems and communication systems; to design methods and tools for modular autonomous platforms and underlying standardisation issues; to specific system integration issues and to the development of network-centric systems.



For future robots operating in everyday environments, dependability will be a crucial design parameter. This includes robot safety as well as operating robustness, particularly the system's availability, security, reliability, and maintainability in everyday operating scenarios. Design for dependability will be a major challenge affecting any aspect of R&D from architectures to key component functionality and design.

The higher demand for integration of different and more complex systems into complete production/ ambient environment systems will increasingly call for methods to design, model and deploy highly complex systems and for new methods in systems engineering. It will require the design of new software methods both in terms of basic software engineering methodologies, programming & specification methods, and embedded control systems. To achieve maximum effectiveness in the design process, a common *plug* and *play* architecture is required which itself should draw upon standardisation initiatives such as the impending Robot Middleware.

Components and miniaturised robotics

Actuators

The need for intrinsically safe robot arms, fully back-drivable high-torque motor systems and grippers that accommodate variable object geometries calls for novel, highly integrated actuators.

Sensors

A new generation of low-cost sensors is required particularly 3D sensors; tactile sensors and force/ torque sensors, offering better resolution with reduced weight and power consumption.

Processing and communications

The spectacular increase in computing and communications capability will allow engineers to distribute sensing, control and other cognitive functions in the robot more easily and to interface robots with external network-centric systems.

Human-Machine Interfaces

Simultaneous use of several multimodal information channels such as language, gestures, graphics, haptics have to be merged into meaningful and intuitive inputs for future robot systems that purposefully interact with people in an intuitive and natural way. New input devices including sensors for gesture recognition, haptic and tactile devices have to be developed.

Miniaturised Robotics

A range of new, very small and highly distributed micro and nano-robots needs to be developed for a variety of new application areas. Relevant RTD issues include:

- New forms of bio-inspired climbing, walking or flying locomotion.
- Energy related aspects.
- Programmable micro-/nano- assembly & manipulation systems.
- Programming, co-ordination, interaction and control of (a large number of) miniature robots with micro/nano/bio-components.

Advanced Behaviours

Autonomy

Autonomous and safe behaviour for robots acting in everyday environments and coping with a wide set of tasks in all operational modes constitutes a fundamental requirement for tomorrow's robotic machines. These systems should detect unforeseen situation and recover into a controlled state.

Cognitive skills

There is a need to endow the systems with higher cognitive functions that allows recognition of context, reasoning about actions and a higher degree of error diagnostics and failure recovery. Such flexibility can only be achieved through use of advanced cognitive skills and requires elements of perception, decision making, machine learning and other intelligent systems.

Cognitive skills are also highly relevant to effectively and safely use robot systems and thus increase user acceptance. Appearance and interaction of future robot systems may include expressive motions, mimics, emotions, affective computing…

Collective behaviours

The collective action of multiple robots with a single mission will involve co-operative and collaborative actions, and sharing of goals and resources. Arising in network centric systems, collective behaviours will emerge due to progress in ICT technologies. Systems of systems and systems of robots are generalising these concepts.

Rich sensory-motor skills

In new applications, there is a need for a significant change in system design to rely on less accurate and cheaper mechanical structures that are complemented with a rich set of sensory feedback to provide a performance that is beyond that of present technology. This requires adoption of new control methods and significantly more flexible sensory systems.

Data fusion/algorithm

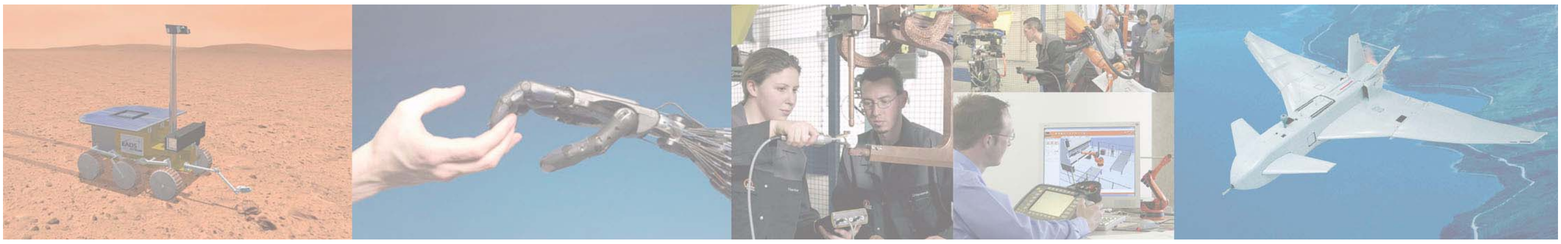
With the increasing amount of information and data from sources internal or external to the robot; the challenge will lie in performing real-time fusion of the information and the design of effective and efficient algorithms for information processing.

Intuitive and flexible interfacing

To equip robots with more intuitive and flexible user interfaces in order to allow people to use them with no or minimum training. In fact, the quality of user-interfaces will, to a large extent, determine the market success of a new generation of robots.

Intuitive human machine interaction

The transfer of information and instructions regarding tasks, skills, objects or environments between human and robot should be as intuitive and efficient as the communication between two people. Robots should be equipped with user-friendly interfaces that require minimal training and that render the robots socially acceptable. Intuitive and efficient instruction schemes are also critical for co-operating industrial robots.



Education and Skills

Robotics is seen as "exciting" for students and is attracting them at a moment when many countries are experiencing a decline in admission to engineering education, due to lack of interest. By definition robotics knowledge must consider the full scope of engineering skills from basic mechanical design to control and intelligence so as to provide an acceptable solution. The combination of systems engineering and "excitement" can be utilised as a catalyst to demonstrate how robotics is a confluence of many different disciplines. In education it can be used to generate interest and at the same time provide a basis for the education of a new generation of engineers. Cross-disciplinary research ought to be a component at all levels of education to ensure European leadership across many different sectors.

Today though, robotics skills are often taught in a sectarian fashion, i.e. with a focus in mechanical-, electrical-, computer-, or systems engineering. Skills are required in not only one of the areas of robotics, but across all. For this, one needs to have a solid interdisciplinary background with additional knowledge in design and in specific applications. It is thus essential to develop a new generation of engineers and systems designers that have a sufficient broad perspective to undertake the development of the system platform and its integration into applications. The scope of such education must however not be at the expense of depth, as the problems to be addressed are fundamental and difficult. Teamwork will also be a requirement for the integration of systems. Europe faces the challenge to stay at the forefront of robotics development, production and use. This calls for a co-ordinated action involving all stakeholder groups, in particular from technology, systems and market developers and educators.

Societal and Structural Challenges

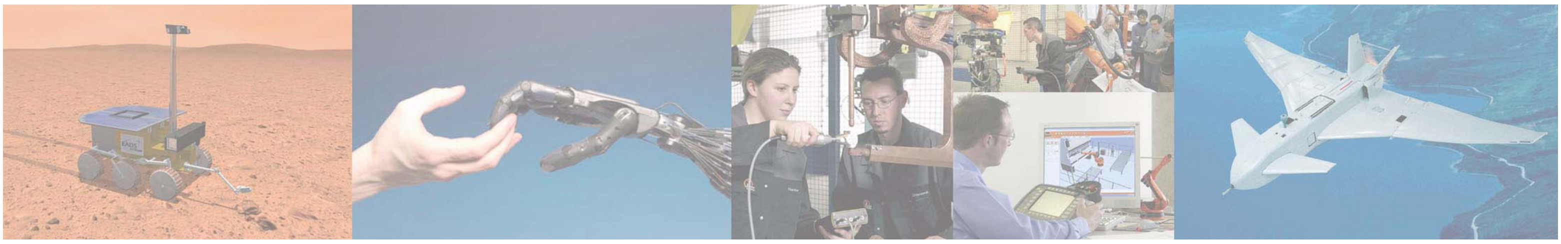
The Lisbon Strategy, committed the EU to establish itself as the most dynamic and competitive knowledge-based economy in the world, a strategy that was critically assessed and reinforced by the Kok Commission in 2004. This Commission identified major societal challenges: the greying Europe, the EU enlargement, economic growth, productivity and employment. In addition, the ability to take appropriate precautions against security threats has become a major topic of concern for the European citizen.

As already shown in this report, robotics can address sustainable perspectives for all these challenges. Industrial Robotics will be an important enabler to achieve increased industrial efficiency. The new branch of service robotics will be crucial for the elderly and for an increased "quality of life" for everyone. Advanced robots can also help in achieving effective crisis management (such as floods, earthquakes, and forest fires), through search and rescue missions. In addition, monitoring illegal and clandestine activities, border surveillance and everyday security concerns can benefit from robot systems.

However, the introduction of robotics into new domains poses significant challenge. The successful application of robotics in e.g., the car industry has required a long-term strategic alliance between the car manufacturers and the robotics industry. To enter into new markets and build new product lines, there is a need for integration across traditional industrial

boundaries. Here systems integrators will play a very important role.

At the same time it remains to be seen if the service robotics segments will become a natural extension of the present white-goods industry or if the result will be an entirely new industrial sector. It also remains to be seen if the civil security robotics industry will emerge from the migration into civil applications of many large companies that are today purely defence-oriented or if the result will be an entirely new industrial segment. Either way, the potential for economic growth will be very significant.



EUROP benefits Europe

European society stands to benefit greatly from a successful EUROP strategy. The EUROP strategy will help to develop a vibrant and dynamic Advanced Robotics supply chain that will improve competitiveness, boost knowledge-based employment and help in meeting the key Lisbon objectives. Without a successful European robotics industry, European citizens and industry will be competitively disadvantaged and will be dependent upon foreign imports in a strategically vital technology.

A strong European Advanced Robotics supply network will grow to be a strong economic sector with the potential for strong international earnings. Such a supply network will also allow Europe to be at the leading edge in providing manufacturing and service industry with high productivity tools and systems, keeping these industries competitive in a world market and preserving long term job prospects. A European based Advanced Robotics industry will also be a key component in converting low-skilled manual jobs to knowledge-based employment.

EUROP will also bring key advantage to existing European industries by providing them with the pool of skills, techniques and components to incorporate robotic and cognitive science technologies into their products, keeping them relevant and competitive for the approaching age of robotics and ubiquitous computing. Without the strong supply network that EUROP envisages, these companies will be dependent upon technology primarily being developed to increase the viability of their international competitors.

A strong and active European Advanced Robotics supply network will provide politicians and officials with more freedom to design policies to meet the key European social challenges without being reliant on technology and standards developed to meet non-European priorities.

The social challenges include the key areas of a greying population, the need for competitive and knowledge based manufacturing and service industries, the creation and retention of high quality employment, greater opportunities for social inclusion (and particularly the gender gap within manufacturing) and dealing with economic and competitive disparity arising from current and future EU enlargement.

Finally, a strong Advanced Robotics sector will also help Europe meet its essential security needs by providing flexible response mechanisms for dealing with the wide range of civilian security issues faced by Europe and thereby providing a greater perception of security for the European citizen. In this area EUROP can be a key catalyst in the effective application of dual-use technologies in civil applications and can make an effective contribution to European-wide security initiatives such as PASR (Preparatory Action in the field of Security Research).

EUROP's activities will take advantage of the significant existing robotics assets in Europe from an industrial and research point of view. Furthermore, EUROP will take advantage of outcomes from the world-class robotics research supported by many European Member States, ESA and the EU Research Framework Programmes by, on one hand, developing improved co-ordination between European civil RTD efforts and, on the one hand, promoting the dual use opportunities presented by an improved co-ordination between European civil RTD efforts and similar efforts with defence-related RTD.

EUROP SRA METHODOLOGY

The major expectation from industry is to develop innovative robotics products in the different market segments by 2020. Inherently, these products will present multiple technological challenges that need to be solved, and thus will need breakthroughs in several technological axes.

One of the first objectives of the EUROP platform is to identify the technological axis where cross-fertilisation will benefit and provide technological solutions to robotic products in the defined market segments. Indeed, the objective was to highlight the technological axis where common research efforts should be focused.

Through a series of three workshops with 70 EUROP members, this first objective was achieved with the following method:

The first step consisted of defining reference **product scenarios** ready for market by 2020 in the five defined market segments. Each scenario includes end-user needs, product requirements, key features, design concepts, business model and a development roadmap.

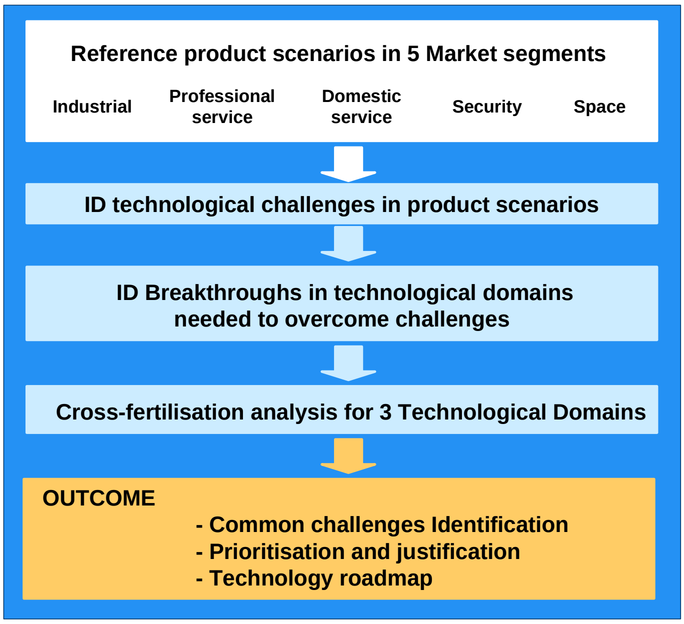
The goal of the second step was to characterise major technological breakthroughs and their relevance to the products. During a second workshop, the main technological challenges were identified for each product, through the consideration of their key features and development roadmaps. As a result, the platform managed to consider more than 120 challenges.

These challenges were then crosschecked with the technological axis defined previously in the document. The goal was to determine, for a given challenge, where technological breakthroughs are needed to answer the challenge.

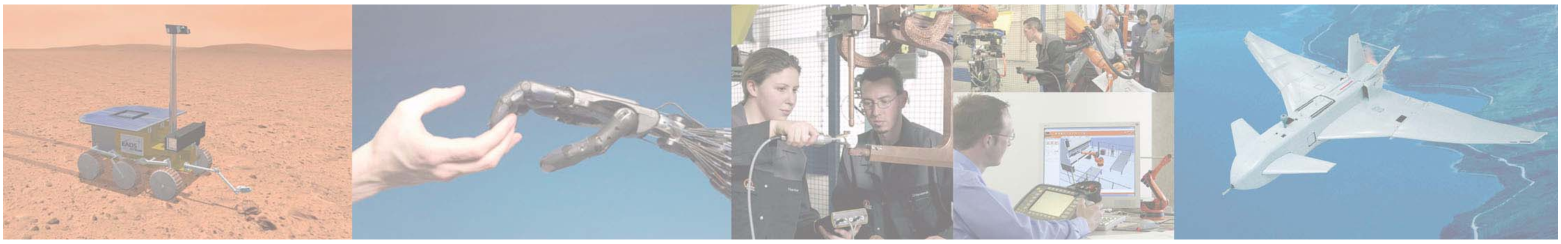
The outcome of this step is a mapping of **breakthrough requirements** in the different technology axes and domains to each of the reference product scenarios.

Lastly, the final step consisted of reaching a consensus on the technological breakthroughs by fusing, analysing, and **cross-fertilising** the outcome of step two. As a result a **common technology** requirement **roadmap** across the market segments has been elaborated.

In the next sections, the product scenarios, breakthrough requirements, cross-fertilisation and common technology roadmap will be presented at a detailed level.



APPLICATIONS DRIVING RESEARCH



Product scenarios

A set of visionary reference products was selected by the platform. This set is the result of an iterative process which evaluated more than 100 proposals of future product scenarios submitted by EUROP members. The following table summarises the number of scenarios selected per market segment, which were filtered based on innovation, competitiveness and market relevance criteria during the first platform workshop.

	Selected
Industrial	5
Professional Services	6
Domestic Services	5
Security	3
Space	3
Number of product scenarios	**22**

In the following five market segment subsections, the market segments and their selected product scenarios will be described. For each market segment, one product scenario will be described in detail and a general description will be given for the others.

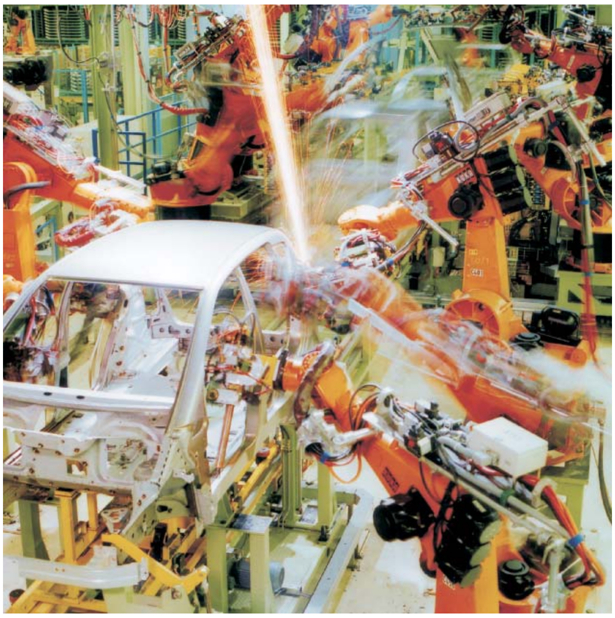
Industrial segment

It is recognized that future manufacturing scenarios throughout all industrial branches will have to combine highest productivity and flexibility with minimal manufacturing equipment life-cyclecost. This paradigm is particularly valid for today's small and medium sized productions as these are particularly prone to relocation due to high labor costs. Facing these challenges paradigms of knowledge-base manufacturing have been formulated, which concentrate on high-added value products, skilled work force and superior manufacturing technology to respond to changing customer demands. This holds particularly for the situation in the New Member States where a sustainable alternative to typical low-wage manufacturing has to be offered.

Up until now robot automation technologies have been specifically developed for capital-intensive large-volume manufacturing, resulting in relatively costly and complex systems, which often cannot be used in small and medium sized manufacturing. Furthermore new branches of robot automation such as food, logistics, recycling etc. require radically new designs of robot systems. Thus, future robot systems will not be a simple extrapolation of today's technology but rather follow new design principles required by a wide range of possible applications (application pull). Novel technologies, particularly from the IT world and mass markets will have an increasing impact on the design, performance and cost of industrial robot automation (technology push). From the current trends it is evident that the operation of robots will increasingly depend on information generated by sensors, worker instructions or CAD product data. Thus it can be expected that manufacturing competence will be further concentrated on robot systems as a key component in the digital factory of the future.

The discussions about the future of manufacturing automation culminated in five product scenarios that help to formulate requirements towards future robotics solutions, to identify challenges and obstacles to progress and to deduce research challenges. These five product scenarios are:

- Large structure manufacturing robots.
- Robot systems with integrated process control.
- Flexible manufacturing concepts based on robot-robot co-operation.
- Robot Assistants in industrial environments.
- Clusters of robots with coordinated movement (closer look).



Large structure manufacturing robots

For large work production such as in aerospace, shipbuilding, and civil engineering, dedicated manufacturing robots would be of great benefit to ensure high absolute accuracy over the full workspace. Reliability in terms of resistance to dirty and heavy processes, self-calibration and recalibration will increase the overall efficiency and quality of the manufacturing and thus the productivity. To a greater extent than standard production robots, this system will be composed of multi-use and multi-purpose robot demanding a high level of interaction, as well as advanced sensing and control.

Robot Systems with Integrated Process Control

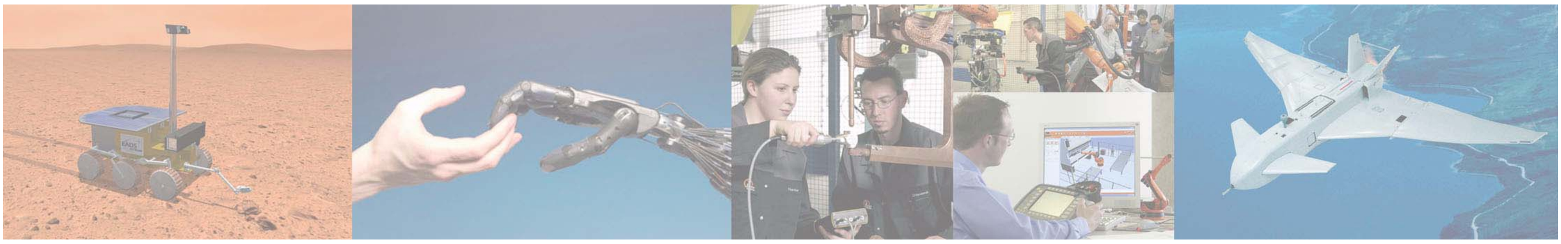
This scenario is concerned with robot systems that integrate both robot and process control to yield highest system performance characteristics and product quality. Examples for processes to be highly integrated in future robot systems are welding, soldering, gluing, cutting, milling and grinding. Especially demanding are highly integrated laser systems with high laser power, reduced weight and also new laser concepts, such as fibre lasers. The applications covered by these systems are within general manufacturing, especially the cutting of thick metal, but the also include the cutting of plastic and compound material. Remote laser welding is a further laser technology to be addressed.

Flexible manufacturing concepts based on robot-robot co-operation

As unit prices drop at increasing rates, the cost of typical robot peripherals (conveyors, feeders, positioning devices, fixtures…) can be drastically reduced and at the same time provide more flexibility. The result would be a network of interlinked robots which co-operatively transport, machine, handle and assemble work-pieces. A typical, simple scenario is a robot presenting a work-piece and positioning it so that a second robot can work on that piece, before it is handed over to a third one. A big challenge in such a scenario is to install, calibrate and automatically programme all robots by simply providing a task description that only relates to work pieces and/or processes. Other RTD tasks in this context comprise scalable/distributed architectures for multiple robots, so that synchronisation, sensor data processing, programming, task allocation, decision making and diagnosis can be organised and managed in a distributed system. Plug and play of heterogeneous multi-robot systems, the automatic distribution of workload between co-operating robots according to the current situation and automatic collision avoidance between robots in complex work cells.

Robot Assistants in industrial environments

This scenario gives attention to a robot assistant, which is used as a versatile tool by the worker at a manual workplace. The applications could be manifold: arc welding, machining, woodworking… The robot system works in close cooperation with humans. The robot provides power and repeatability. The human provides accuracy and flexibility. The safety features of the robot (e.g. improved sensor systems for man machine interaction) enable operations in shared workspaces without separating safety fences.



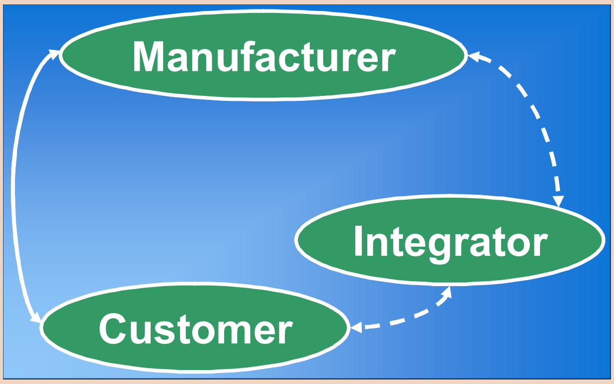
A closer look: Clusters of robots with coordinated movement

Clusters of robots individually sharing a specific work-scope in a common area will become a key-technology to increase productivity in mass-production industries such as automotive, electronics and white goods. As robots continuously increase their performances, speeds and abilities there will be a need to increase their working range by moving them along the process lines.

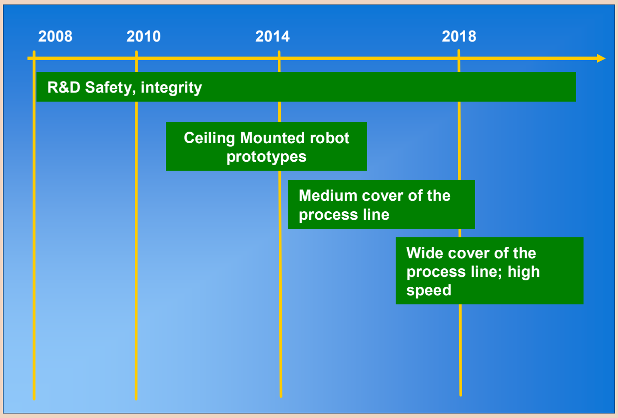
Loop-arrangements (continuous flow) of processes in comparison to line arrangements are advantageous from a point of view of working space, material-flow, worker accessibility as well as availability of line. There is a strong trend towards suspended (ceiling mounted) robots in order to have free access for workers or/and to keep space free for machines, process and material flow.

The technology challenges for this system lie in the three following categories:

- ***Ceiling mounted robot track structures***
  - Self-supporting robot track structures.
  - Line, curve or loop arrangements of robot track. High torsional.
  - Bending stiffness.
  - Switching stations for maintenance- or service-tracks
- ***Communication to & between robots***
  - Advanced HMI technologies.
  - Radio controlled real-time communication.
  - Easy to handle multi-robot programming.
  - Radio performed safety features (E-stop, enabling switch).
- ***Robot technologies***
  - Lightweight robots to reduce moving mass.
  - On-board controller.
  - Compliance with latest safety regulations.
  - Advanced sensing and calibration technologies.



Business Model



Product roadmap

Professional service segment

In the professional market, a number of robots are already successfully operating in field areas such as forestry, agriculture, cleaning, surgery and rehabilitation, mining, autonomous transport of people, goods, demolition, nuclear power plants… Future potential applications range from transportation (smart cab) to prosthetics and (remote) medical interventions to hostesses and smart attendants. Robot diffusion in all these areas is gradually happening and Europe has a number of dominant suppliers. However non-European companies are rapidly entering the market. Through the creation of joint initiatives, it will be possible for Europe to maintain its leadership in a domain that is expected to have a value of at least € 2B over the next 4 years.

The six product scenarios presented are the following:

- Service robots for aerospace maintenance.
- Autonomous handling.
- Fabricator: "the robot apprentice".
- Mapping inspection robot.
- Surgery haptics for tele-diagnostic, training and intervention.
- Autonomous transport (closer look).

Service robots for aerospace maintenance

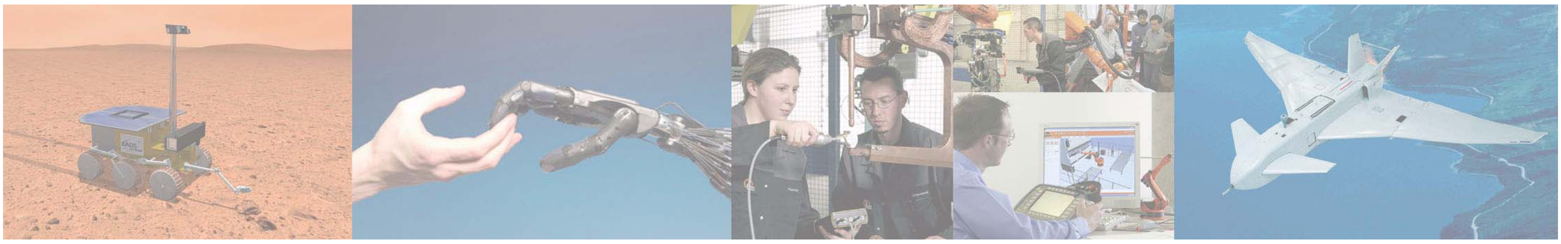
In order to have safer airplanes, preventive maintenance is an important issue. Companies want to have better maintenance but shorter maintenance time to increase their profitability. The use of robots is a way to make maintenance faster and safer. This scenario requires different kinds of robots; long range robots can inspect external structures of the plane (wings, fuselage) and smaller mobile robots can be used for inspection of internal parts. The co-operation of several robots can make inspection more systematic and safer than human inspection. Aerospace companies can create a market for such robots.

Autonomous handling

On harbours, in forestry domains and in mines, heavy payloads have to be handled by huge machines driven by humans. For the human driver, the working conditions are rather unpleasant. It appears that the majority of the tasks accomplished by such machines can be performed autonomously. The rest of the tasks can be performed in a teleoperated or supervised way. The driver could therefore be taken away from difficult environment. This will ensure fail-safe operations and longer uptime running.

Fabricator: "the robot apprentice"

A fundamental new way in robotics application are assistive robots which cooperate with the worker to interactively carry out manufacturing tasks. For this to happen, the metal helpers must be completely redeveloped. This new robots must understand easy-to-learn, "intuitive" commands. It must meet all safety-relevant requirements for sharing the workplace with human colleagues. And it must be capable of being installed and put into operation within three days. Its modular design will ensure a wide scope of applications, be it for processing wood, metal or ceramics, or for drilling, sawing or lifting. Ideally, it will not be more than a third of the amount that a conventional system would cost.



Mapping inspection robot

In civil engineering, offshore or in energy supply, there is a regular need for inspection in hazardous or restricted areas (limited access, radiation, high temperature, under water, high pressure). The risk these environments pose for a human beings justifies the use of inspection robots. Considering the various situation where they have to intervene, inspection robots can be wheeled, flying, swimming, crawling, walking, climbing… They need to carry suitable sensors for the inspection task but they also have to perform localisation and mapping to accurately indicate the position of an eventual repair to be undertaken.

Surgery haptics for tele-diagnostic, training and intervention

Haptic devices are able to give force feedback to the hand of the operator. They can be coupled to real tools to improve remote control of these tools through processing and filtering of the forces. They can also be coupled as well to virtual environments to allow the physical exploration of a virtual space.

The use of haptic devices in minimally-invasive surgery can provide the surgeon with a much better feeling of what he his surgical instruments and as a result can make the surgery much more efficient. Coupled to a virtual patient, haptic devices can help to prepare surgical intervention in a more realistic way avoiding risk to the patient or the need for animal studies.

Furthermore, minimally-invasive surgery will become more and more frequent. It necessitates small size of openings and allows a reduction of post-operative trauma while also reducing the cost and duration of the hospital stay.

Today, minimally-invasive tools are more or less grippers and scissors. They require a high dexterity of the surgeon and some interventions are impossible with such rudimentary tools. There is a need for high dexterity tools: a miniature 6 degree of freedom robot that could be inserted inside the patient’s body and reproduce all the motions the surgeon would make with his hands surgeon while providing accurate force feedback.

A closer look: Autonomous transport

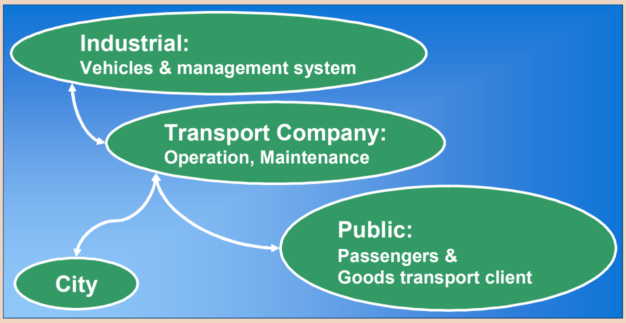
The mission of the autonomous transport is to convey people (cybercars, horizontal elevator concept), or goods (proximity delivery for shops or customers). Autonomous transports could also be operated using a central fleet management system to collect passenger's requests, manage the fleet of vehicles, dynamically assign routes and missions to them, manage conflicts and incidents, and schedule preventive maintenance.

These robots would be deployed in urban, populated zones, such as pedestrian areas and inner city centres. They will need to be partially autonomous; that is to follow an assigned route while ensuring security and safety of passengers and surrounding pedestrians through obstacle detection and avoidance.

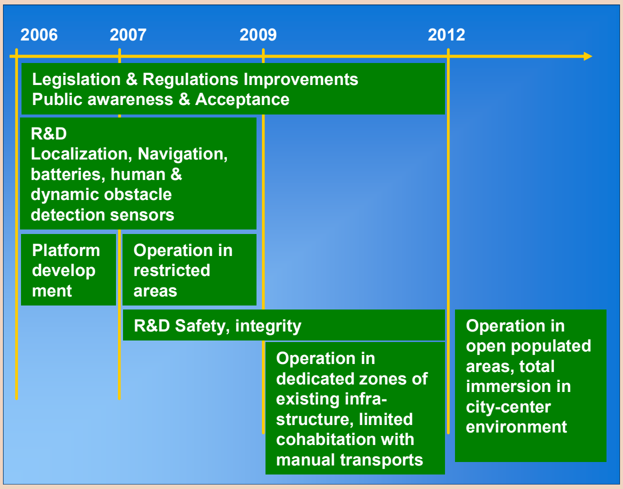
The passengers could assign destinations, preferred routes, and be provided with online tourist information and web services. The fleet management system would calculate routes and the optimisation of traffic, trip duration, and sightseeing assignment.

The technology challenges for this system lie in the following four categories:

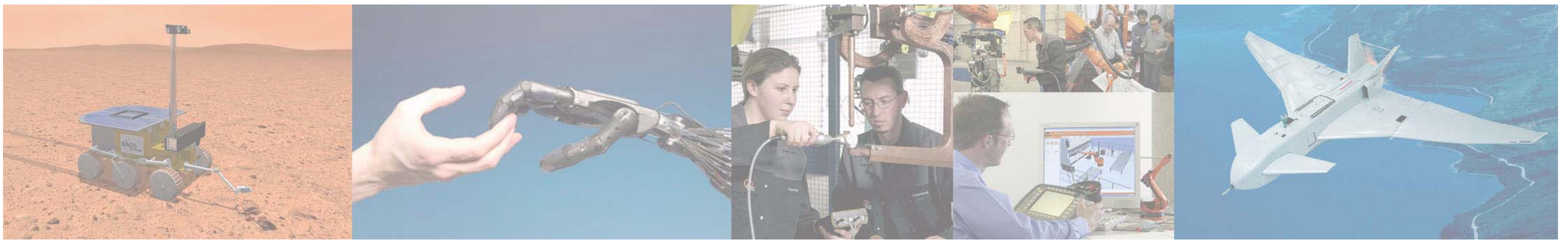
- *Components*
  - Actuation, batteries.
  - Robust dynamic obstacle detection sensors.
  - Absolute localisation sensors.
  - Secured wireless communications.
  - Intuitive HMI.
- *Systems Engineering*
  - Safety, integrity, dependability.
  - Real-time, robustness.
  - Flexibility, Modularity.
- *Advanced Behaviours*
  - Safe navigation in populated and unstructured areas.
  - Robust navigation using very limited infrastructure.
  - Dynamic optimisation of routes & missions.
  - Automatic planning and scheduling.
  - Fast and easy deployment in new areas.
- ***Robotic technologies***
  - Robust dynamic control.
  - Precise localisation.
  - Navigation.
  - Fleet management/co-ordination.



Business model



Product roadmap



Domestic service

The introduction of Domestic robots will provide many tangible and intangible benefits to consumers both in terms of useful function and through social change. However the section of society that is most likely to benefit are the elderly and infirm. With the rising cost of care and the difficulty of maintaining care standards in an ageing population the application of advanced robots to this segment has many compelling benefits. The potential to reduce welfare and support costs arising from enabling infirm and older people to lead independent lives, living for longer in their own homes, is significant, as is the potential to improve the monitoring, quality and consistency of service. Robot companions which can perform basic everyday tasks and monitor the well being of the elderly have the potential to improve life quality and reduce the associated support costs while providing improved services.

In the domestic service domain the five selected product scenarios are:

☐ Cleaning robots.

☐ Personal care assistants.

☐ Companions.

☐ Sports & Rehabilitation robots.

☐ Fetch & Tidy robots (closer look).

Cleaning robots

The mission of this class of robots is to autonomously clean floors in an open-boundary, unstructured domestic environment, freeing the user from the chore of having to clean floors on a regular basis. The ability of the machine to map and navigate around a home will ultimately allow the user to ask the machine to carry out sequences of cleaning tasks without further user interaction.

Personal care assistants

The main purpose of the personal care assistant is to ease the daily task of the person thereby increasing their quality of life. Examples of these tasks are assistance in the mobility of the person, fetching, and carrying objects, either because they are heavy or because the user has misplaced them. Such systems also bring a degree of safety by monitoring the well-being of the person through remote biometric sensing. Being intuitive and safe in use will be a critical part of the machine design, as will the design of an intuitive interaction between the user and machine.

Companions

Midway between a toy and personal assistant, the companion robot will bring a presence and a personality into the home much like a family pet. It can also perform simple tasks such as supervision. Again, the interaction between the companion and the members of the home would be very adaptive. The robot will be able to evaluate and respond to facial and body expression as well as understand natural language.

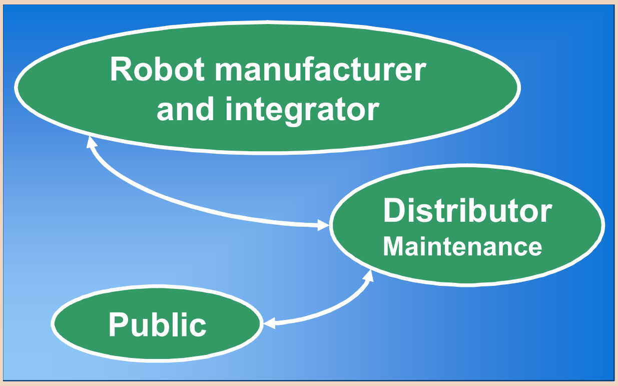
Sports & Rehabilitation robots

This robot will assist the user at home in rehabilitation or for sport exercise. This robot can come in different forms: from an exoskeleton with passive constraints to a neural control exoskeleton ultimately able to replace limb function. As the technology progresses it will be possible to develop sports companions able to interact and teach or critique the player at their level of achievement.

A closer look: Fetch & Tidy robots

The role of the Fetch & Tidy robot is to be able to recognise and class everyday household objects, evaluate how to grasp and manipulate them and, within a limited context, understand their semantics (for example a self-loading dishwasher). These simple attributes would allow the robot to fetch and tidy objects to their correct storage places. The safe manipulator technology necessary for these robots will also find outlets in other domestic tasks such as emptying and loading dishwashers. As these types of robot develop they will become able to adapt to a home and its occupants and learn new objects.

- ***Components***
  - Safe actuation and manipulation, batteries.
  - Absolute localisation sensors, inertial sensing.
  - 3D sensing.
- ***Systems Engineering***
  - Safety, integrity, dependability.
  - Real-time, robustness.
  - Flexibility, Modularity.
- ***Advanced Behaviours***
  - Safe indoor navigation.
  - Dynamic obstacle avoidance.
  - Centimetre accurate space localisation.
  - Millimetre accurate self localisation.
  - Context aware cognitive behaviours.
- ***Robotic technologies***
  - Robust dynamic control.
  - Advanced grasping.
  - Manipulation.
  - Intuitive user interfacing.

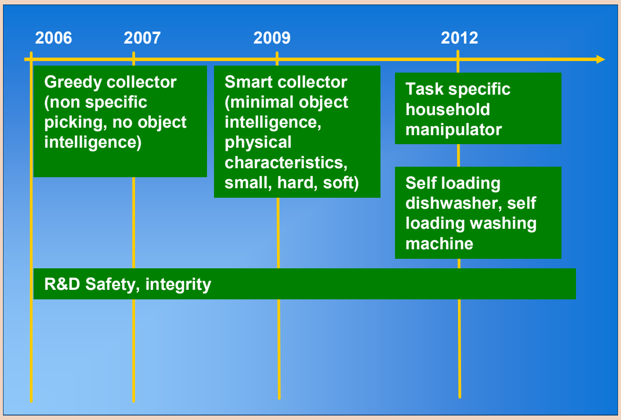


Robot manufacturer and integrator

Distributor
Maintenance

Public

Business model



2006 | 2007 | 2009 | 2012

Greedy collector (non specific picking, no object intelligence)

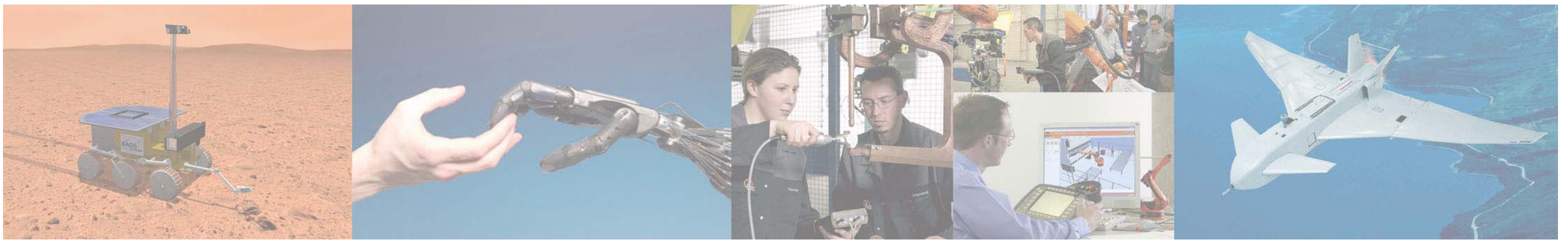
Smart collector (minimal object intelligence, physical characteristics, small, hard, soft)

Task specific household manipulator

Self loading dishwasher, self loading washing machine

R&D Safety, integrity

Product roadmap



Security segment

Robots in security applications will need to operate in hostile, tedious, or hard-to-access environments that are partially or completely unknown, complex or poorly structured. High dependability properties will be essential in the preparation and execution phases of a mission. Usability and flexibility will also be required to adapt the robot to its mission and the context of operations. Complex security missions will increasingly require the deployment and co-operation of many robotic systems that are inter-operable, inter-communicate, and closely collaborate and interact.

The three selected product scenarios are:

- Distributed border surveillance.
- Site protection robots.
- Disaster response robots (closer look).

Distributed border surveillance

The border surveillance scenario involves multi-level distributed actions. The actors are: different range capacity UAVs and UGVs, fixed infrastructures and command station operators. Robotic border patrolling requires a high level of autonomy in mission management together with advanced cognitive capabilities. The robotic team will operate and evolve in dynamically changing, partially unknown, complex and sometime hostile or hazardous environment and this will require modular, autonomous and mission-reconfigurable platforms.

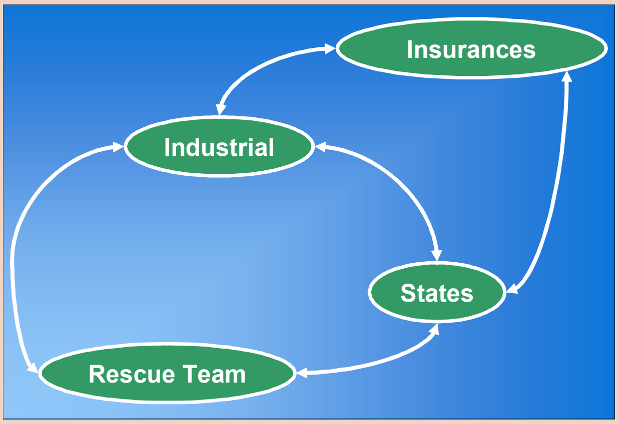
Site protection robots

Compared to border surveillance, the site protection robots operate on a more local level, indoors as well as outdoors on sites ranging from industrial sites to public sites. These robots will be integrated in the overall surveillance team, which includes security patrols and a command station, to fulfil tasks such as: surveillance, threat and illegal activities detection, dissuasive action, entrance control… The environment of operation is one of high dynamic changes and potentially of high human presence. Multiple robots, mini to micro UAVs, UGV, "human-friendly" robots are envisioned, for such a scenario.

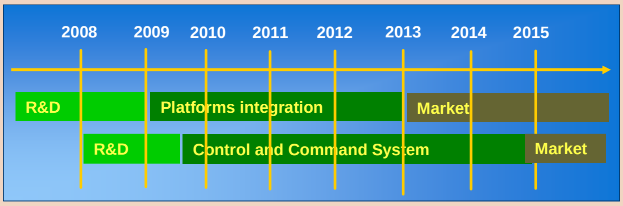
A closer look: Disaster response robotics

These robots are to be deployed for disaster assessment and search & rescue operations. This requires multi-level action and a variable number and mixture of active actors both human and robot (UAVs and UGVs, Command station operators/rescue team/scientists). The missions include inspection, detection of activity (survivors), information gathering, evacuation of people…

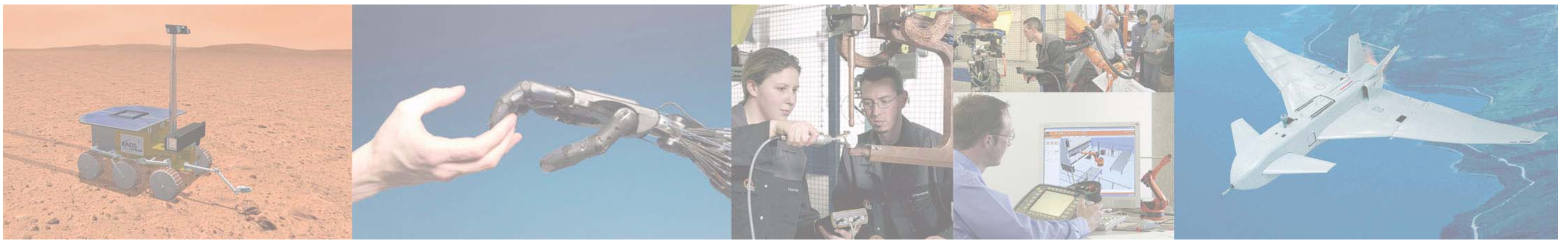
- ***Components***
  - UGVs.
  - UAVs.
  - Localisation, observation, and chemical sensors.
  - Communications.
- ***Systems Engineering***
  - Safety, dependability.
  - Modularity.
  - Distributive action.
  - Fleet management.
  - Multi-level communication.
- ***Advanced Behaviours***
  - Automatic re-planning.
  - Resource management.
  - Priority action management.
  - Real-time on board data analysis (fusion, sorting).
- ***Robotic technologies***
  - Mobility in unstructured area.
  - Power autonomy.
  - Grasping.



Business model



Product roadmap



Space segment

"… And when the Americans send astronauts to Mars, then an European robot should open the door for them…", this statement of the former German minister of science and technology, Mrs Bulmahn, expresses precisely the political vision for European robotics in space. It also describes the major tasks for space robotics to perform services and to support humans in remote hostile environments.

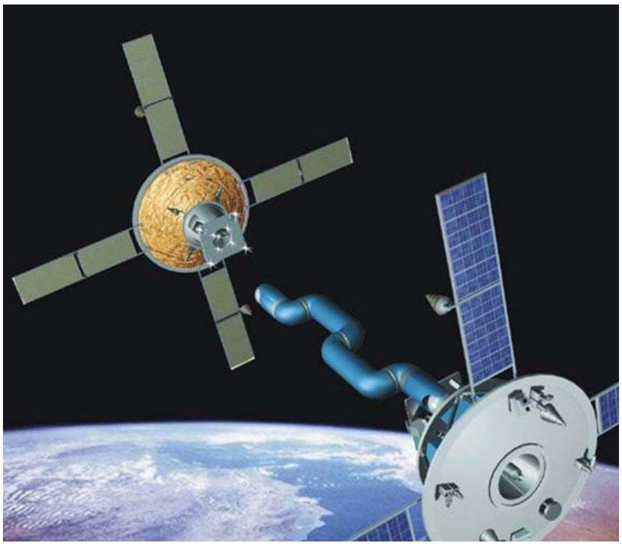
The application of ***robotics in space*** is unique in that it forces the robot to operate without direct human assistance (autonomously and remote controlled) and to act as a platform for the projection of human capabilities to remote and hostile environments, but also requires working in combination with astronauts sharing the same workspace. Robotic applications in space fall into two categories: assembly/repair in space and planetary exploration, both relaying on reconfigurable modules and agents in space:

Assembly & Repair in Space

In the past five years, the incidence of on-orbit satellite failures has reached epidemic proportions. Space-based robotic manipulators provide the basis for on-orbit servicing of satellites, through the replacement of equipment modules. The recent emergence of highly dextrous space robots could help relieve cosmonauts of many routine inspection and maintenance chores and enable previously impossible complex in-orbit repairs to be undertaken. In the longer term robots will become humankind's agents and partners in space, constructing and servicing orbital and surface facilities with millions of components.

Planetary Exploration Robotics

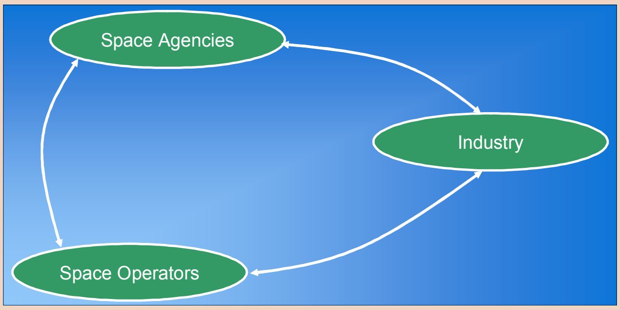
ESA's and NASA's visions for space exploration now include teams that combine the information-gathering and problem-solving skills of astronauts with the survivability and physical capabilities of robots. In such future space missions, robots will become the personal assistants of astronauts. They will operate on distant planets, using high level directives, responding to and interacting with humans. They will be our agents of planetary surface and deep space exploration, handling the repetitive and time-consuming tasks of data collection and data reduction. Teams of robots will survey vast regions, and will classify geological features and formations and search for evidence of life.



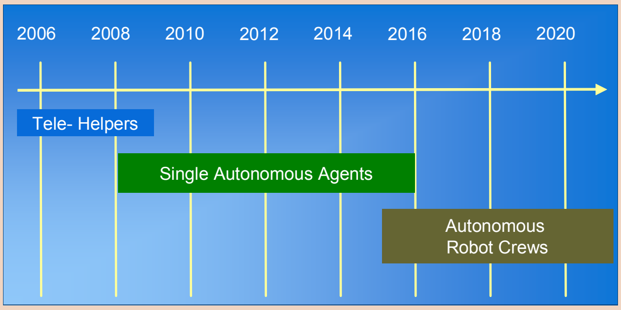
A closer look: Reconfigurable Agents in Space

These elements comprise components for manipulators and locomotion subsystems as well as complex manipulators and platforms as components of entire infrastructures. The components include mechanical items combined with a large variety of general or mission specific sensing elements as well as modules and segments for the reconfigurable control of the various robots. The command stations are, in general, remotely located, implicitly requiring a high autonomy of systems, equipment and control. The mission profiles include a large variety of support and servicing functions such as inspection, sample handling, assembly, maintenance, repair, self-reconfiguration…

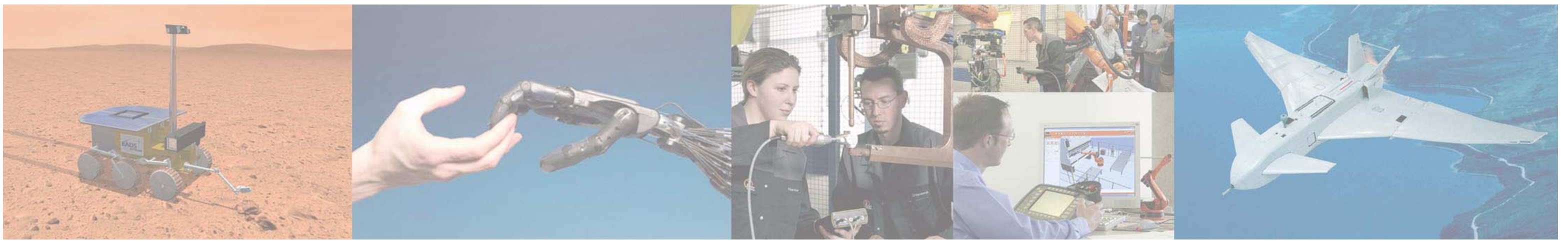
- ***Components***
    - Actuators with embedded control.
    - Sensors with integrated processing.
    - Self reconfigurating H/W and S/W systems.
- ***Systems Engineering***
    - Reliability, graceful degradation.
    - Modularity, reconfigurability.
    - Workspace sharing, co-operation with astronauts.
    - Local autonomy.
    - Multi-level communication.
- ***Advanced Behaviours***
    - Automatic re-planning.
    - Resource management.
    - Priority action management.
    - Real-time on board data analysis (fusion, sorting).
    - Autonomous reconfiguration.
- ***Robotic technologies***
    - Mobility in unstructured area.
    - Autonomous Navigation in unknown terrain.
    - Power autonomy.
    - Grasping.



Business model



Product roadmap

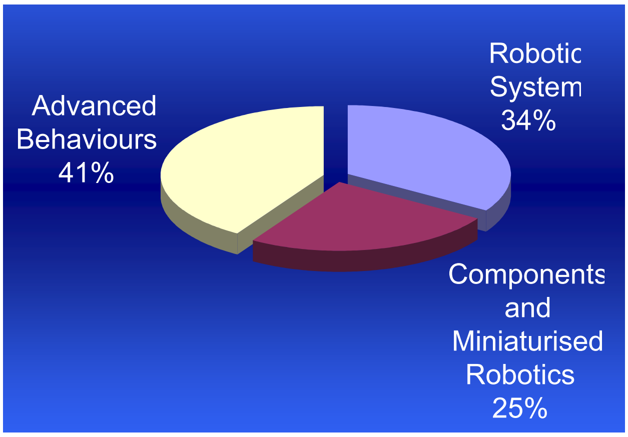


Breakthrough requirements

The goal of the second step of the methodology was to characterise major technical breakthroughs and their relevance to the products in each market segment. During a second workshop, main technological challenges were identified for each product, with consideration to their key features and development roadmaps. As a result, the platform managed to consider more than 120 challenges.

Industrial manufacturing	25
Professional Services	24
Security	19
Space	10
Domestic Services	49

These challenges were evaluated against each different technological axes to assess where breakthroughs are needed. As a result, we can observe a general trend of the breakthrough requirements across the six technological domains, as illustrated by the following pie chart.



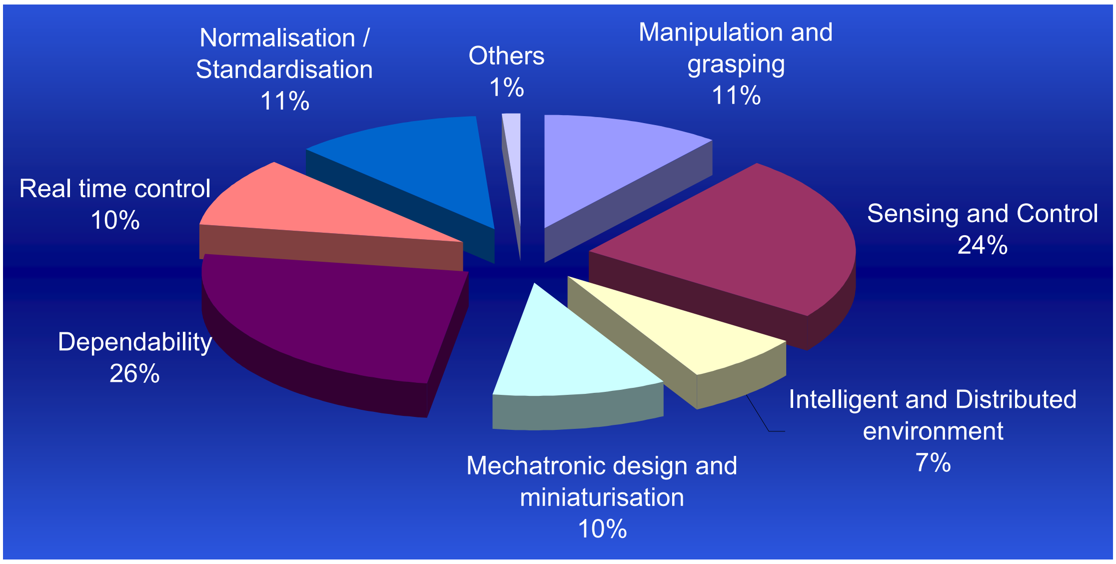
We notice that ***Advanced Behaviours*** and ***Robotic Systems and Technologies*** clearly stand out. This shows a requirement for technical advance in these areas with the development of improved robot performance resulting in smarter behaviours. Unsurprisingly, this trend will be a key driver in the market development. However, this is conditioned by robot dependability (safety, fault tolerance…) and the capability of integrating appropriate components. This is highlighted by innovation needed in ***Components*** and ***Robotic Systems Engineering***.

The need in ***Miniaturised robotics*** is less prominent perhaps mature research is already underway or that the products considered do not highly depend on these technology challenges.

TECHNOLOGY CHALLENGES COMMON TO MARKET SEGMENTS

Based on the EUROP SRA methodology described previously, a consensus was achieved among the different market segments on the main challenges to address in each technology axis. The outcomes of this first cross-fertilisation are presented in this chapter. First we present a pie chart of the breakthrough requirement distribution followed by the consensus of the common challenges and their prioritisation and justifications. A roadmap and its key elements will conclude each technology axis section.

Robotics System

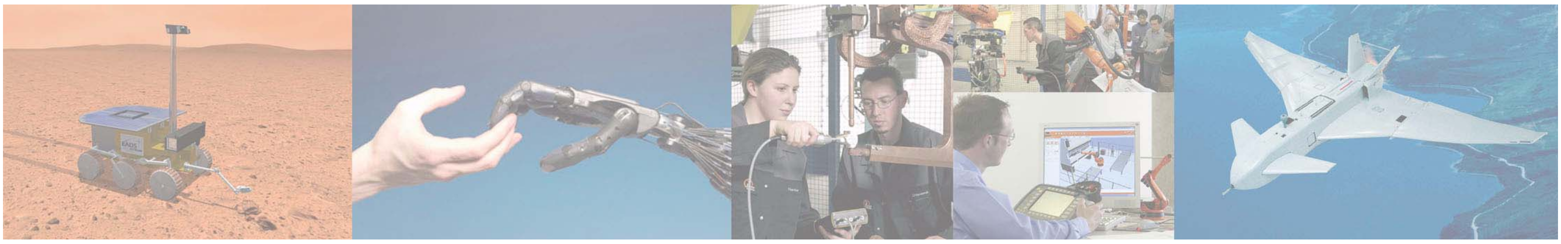


As illustrated by the pie chart, ***robotic system dependability*** appears to be the major concern, and on which both market access and robotic performances critically depend as does the mastering of advanced behaviours. The primary reason for this is that large scale deployment of robots, closely interacting with humans and deeply integrated into our society (at the workplace or at home), will stress the safety and reliability of robot systems. Closely follows ***sensing and control*** which is a technology axis largely present in product challenges. For the same reason, the development of optimised ***manipulation and grasping*** technology is considered an important action.

Breakthroughs in ***mechatronic design*** that will lead to increasing robotics design configuration and complexity, is also regarded as a field of further development.

Standardisation and normalisation, as well as ***real-time control*** considerations, will also have to be addressed. However, our survey reveals that these two areas are strongly related to systems engineering methodologies which would primarily address dependability analysis.

The ***intelligent and distributed*** environment was evaluated a field of importance primarily for security and in longer term for domestic service.



Manipulation and grasping

There are key common challenges regarding manipulation and grasping across the application domains. Furthermore, it is noted that the professional and domestic service and space will probably be the drivers and the other domains would benefit from them.

The main challenges lie in increasing the payload capability, precision, and speed of the manipulation and grasping while decreasing the cost. This is an important issue for the industrial, and services domain.

As basic technologies are almost ready and common between the different technologies, it will be necessary to reinforce the existing R&T Teams (e.g.: the last generation of dextrous manipulators surgical manipulators should find application outside of the laboratory).

The domestic and professional services seem to have the same breakthrough needs in manipulation and grasping and could therefore lead a common effort; other domains will benefit from this work.

Interface standardisation has also to be defined such that, for example, the same grasping device could be used in different applications.

It is also important to encourage the development of European companies specialised in the development and production of grasping parts with different payloads and application capability (e.g.: lifting of injured people, handling heavy parts).

This will help to reduce costs, enabling a growth of applications in "industry" and "domestic". This will of course boost the position of the European companies to become leaders in these different application areas.

Sensing and control

The breakthrough demands for sensing and control linked to dynamic obstacle avoidance and autonomous navigation were expressed by the majority of the market segments; and therefore makes a case for cross-fertilisation.

The challenges in sensing and control are closely linked with the application environment of the future products. To operate in controlled and uncontrolled environments, there will be a need for sensor fusion and data distribution. The 3D mapping of a dynamic environment with changing obstacles and features will also demand a high level of sensing competence. Lastly, as the speed of robots will continue to increase, the sensing and motion control capabilities will need to improve accordingly.

As sensing and control are the key technologies for any future developments of new applications, it will be necessary:

- To work on normalisation and standards (safety); this will help in the development of "plug & play" solutions.
- To increase the information exchange between Companies with different specialisation (platforms like EUROP are the key for the success of this process).
- To develop better sensor and control systems that will be essential for all areas and are the basis for other innovation fields e.g. human machine interaction or improved grasping systems.
- To consider space and domestic applications. They both require a high reliability level despite very different applications; there should be a common effort to use the same strategies in other technologies.

This will help to improve usability and to reduce costs, enabling the growth of applications.

Intelligent and distributed environment

The standardisation of intelligent environments is a primary challenge for intelligent and distributed environments.

Standardisation efforts will be needed to achieve a greater exploitation of distributed environments; this could be an important step towards further developments in a number of related research fields.

Another aspect of the intelligent and distributed environment is closely linked with collective behaviours and is described below under advanced behaviours.

Dependability

In order to have access to new markets or to be competitive, robots will have to be dependable, achieve a smarter behaviour and work in closer collaboration with humans. Designing dependable robots is a major challenge for future robotic products in all application domains. As for systems engineering, generic definitions can be given to dependability: safety, liveness, timeliness, robustness, resilience, fault tolerance.

Some of these are commonly agreed in generic systems engineering standards (IEEE15288, EIA632…). However, dependable robots involve a large set of requirements but very specific design solutions. This makes existing standards too abstract to be efficiently applied. Dependability is essential to avoid human injuries as well as environment or robot damage. Hence, future business processes will strongly rely on the safety, robustness, availability and other criteria. Service, manufacturing and security markets will develop only if the business case is strong and robotic companies can provide evidence of dependability guarantees. As a cross-domain example, the whole sensing chain of the robot must be highly reliable, from raw data to symbolic levels.

Providing the evidence for dependable robots or measuring the level of guarantees are still open challenges which need a variety of expertise (sensors, actuators, subsystems…) and skills (software, mechatronic, physic, mathematics…). Many difficulties can be envisaged when tackling these problems. In particular taking into account human behaviour or biology as part of the robot environment will provide a complex challenge. For example, untrained personnel may be the source of many contingencies for the robots. Lastly, advanced behaviours, which emerge in many robotic domains (such as entertainment, security and space, manufacturing…) and involve complex algorithms (planning and scheduling, inference, knowledge management, learning, explanation, diagnosis…), tend to make dependability particularly difficult to assess.

Architecture design is also an important area of research. Fundamentally, architecture is the core of the solution to dependability requirements. To be adaptive and adequately responsive to business, environment and mission changes, robots will have to be modular and highly reconfigurable.

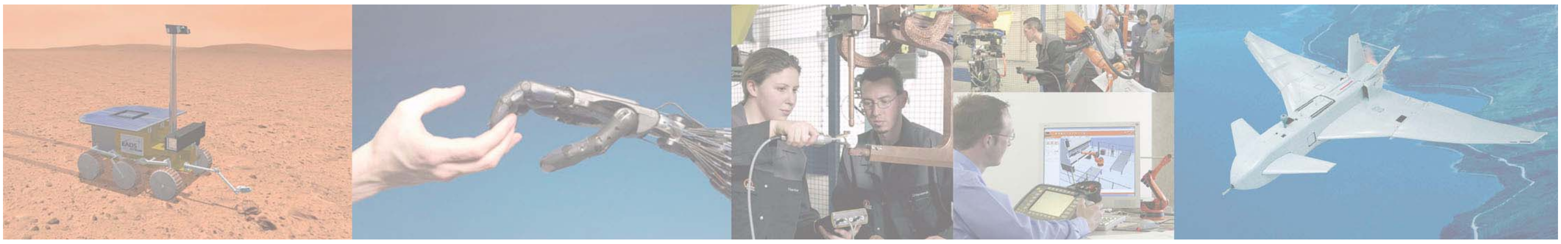
Indeed, sharing the workspace with human workers will also require new architectures, as robots will have to be integrated into our way of life at work, school or home. Similarly, performing collaborative tasks (with multiple swarming robots or with humans in the loop) strongly orient architecture designs towards decentralised designs. Examples can be found in swarming robots, which necessitate distributed control processes, in Simultaneous Localisation and Mapping, and more generally when the multiple robots have to share some knowledge about their environment.

As a first work segment, improving the methodology and engineering processes are fundamental to tackle architectural and dependability issues. These improvements have to suit the principle and practice of robotic engineering, and need to address the complete lifecycle. As a side effect, system technology and architectures will become part of an acquisition framework for the end-customer. Specific modelling and formalisation methods also need to be developed in order to guarantee dependability properties. As a second work segment, enabling systems and tools (design, virtual prototyping, dimensioning tools) need to support methodological concepts by exploiting modelling and formalisation efforts. Lastly, test beds and benchmarks will complete the acquisition framework. As a third work segment, specific research areas must be investigated to support the development of relevant methodology and acquisition framework:

- Requirement engineering.
- Fault detection, isolation and recovery.
- Proof techniques for dependability.
- Analysing the dependability of sensing architectures.

In order to develop architecture capabilities, modularity and new co-operative architectures have to be considered.

As a last work segment, a constant stream of standardisation processes, starting with general guidelines, shall be maintained. The goal is to stabilise the main invariant from methodology, processes, modelling, acquisition framework and enabling systems.



Real Time Control

These systems need to be able to operate in the respective environment (both safely and reliably). This puts requirements on the development process and qualification.

There is a need for real time capable processing-systems (with respect to. hardware and e.g. operating systems) that are optimised for distributed systems (multi robot or modular architecture inside one system).

The required technology currently is mainly provided from the United States.

There is a strong recommendation: that European activity in these fields is necessary in order to achieve a certain degree of independence (in terms of both hardware supplier and software technology).

There is a need for real time interpretation of sensor data (at various complexity levels). Similar requirements will be generated by sensor fusion demands (which are also heavily dependent on the degree of complexity).

Real time capabilities seem more important for applications at a low level than on a high level (w.r.t. system level). Progress in efficient software, algorithms, operating systems and hardware will be the

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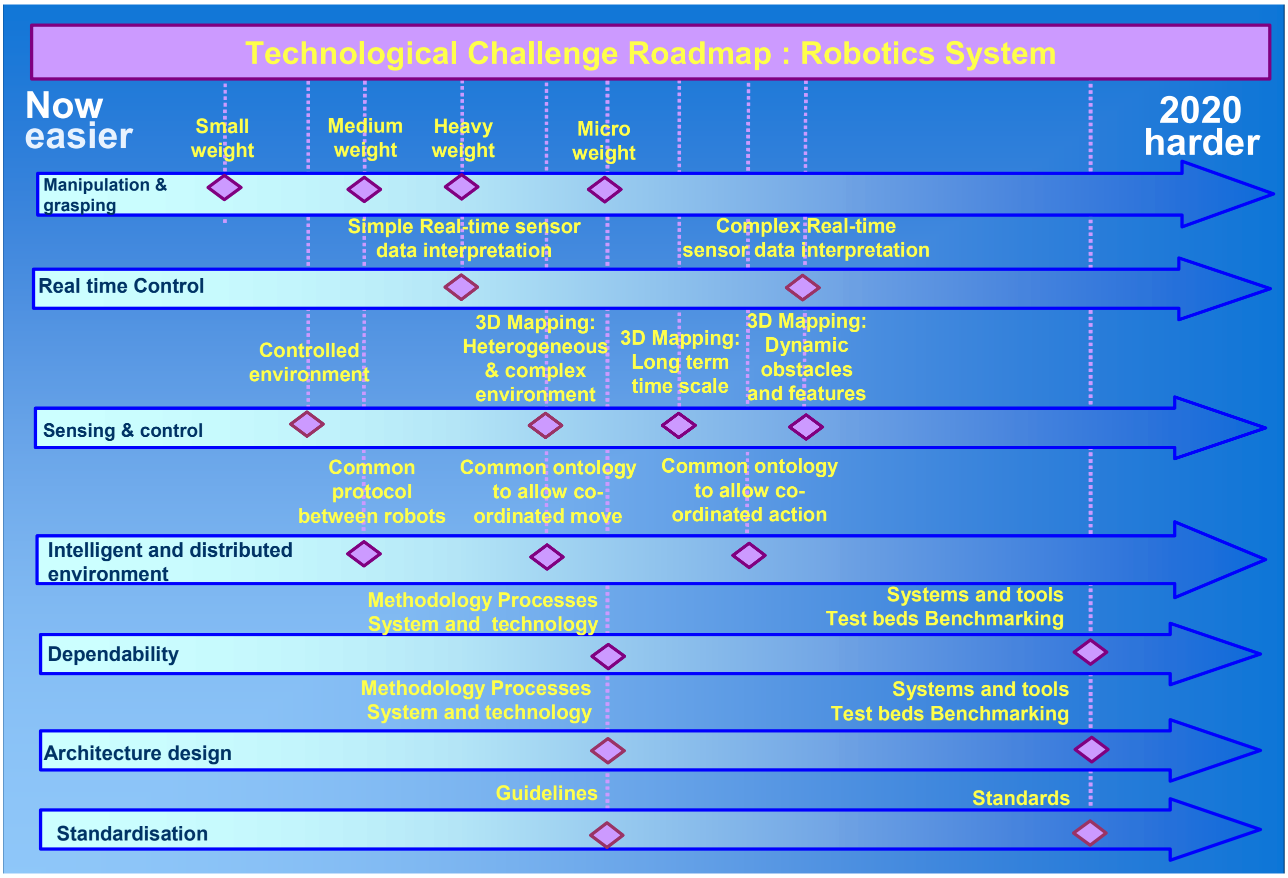
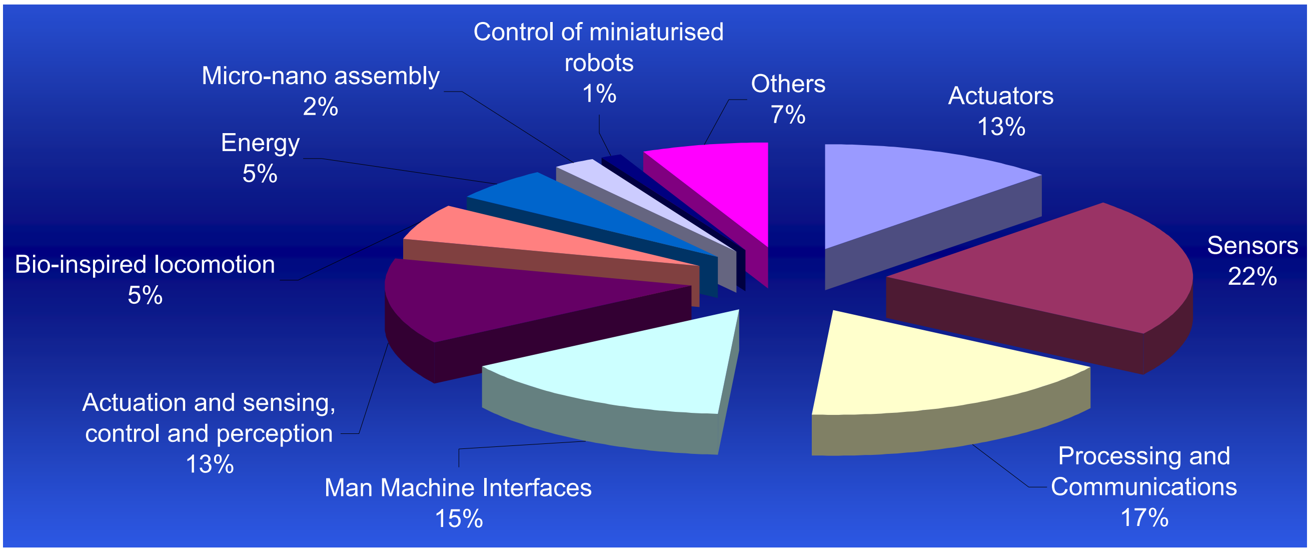


Components and miniaturised robotics



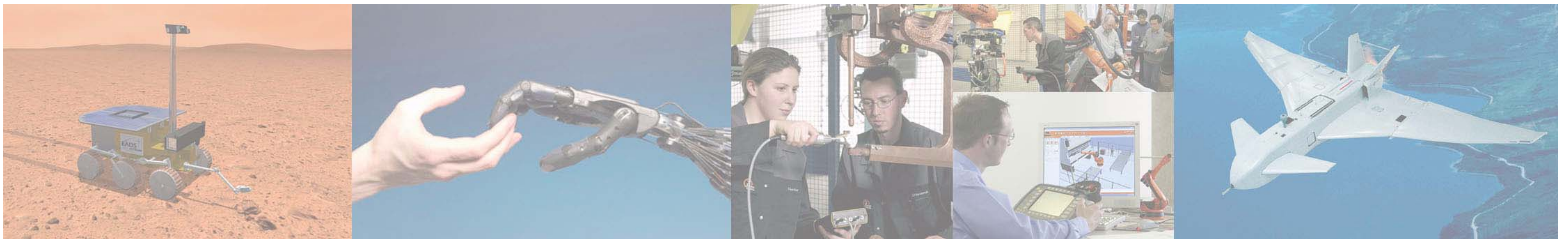
Component breakthroughs will contribute to the increase in performance of many aspects of robotics. As expected, Sensors demonstrated the most needed breakthroughs as they are undoubtedly a key component for autonomous robots. There is a fairly equal distribution over ***Actuators, Processing and Communications***, and ***Man Machine Interfaces***. This shows that these three technological fields needs to receive equal importance of consideration.

To achieve growth in European robotics cost effectiveness and competitiveness, research, development and production of strategic & innovative components in Europe are key-factors. Nowadays, every European robot company invests time and money to develop proprietary solutions regarding almost every single component and function or buys strategic components (for performance and/or value) mainly from the Far-East.

The establishment of a European component industry for specialised robotic parts is an important step in the development of a European Advanced Robotics industry. The diverse and complex technical nature of advanced robots means that it is unlikely that a single company will have access to all of the technology needed to produce an advanced robot within a given market. For this reason, as in the automobile industry, there is likely to be a strong reliance on subassembly and component part manufacturers to supply the companies assembling final products. The types of components supplied are likely to range across the technical spectrum of parts from mechatronic assemblies to high-level software components such as mapping systems or user interfaces.

The research objectives of component technologies have an important link to standardisation both in terms of defining the mechanisms for technical integration through interface standards and in terms of performance specification. Concentrating on defining standards will help to ensure the broad cross-domain applicability of common parts. A further goal that underlies the supply of components is the development of methodologies for the design and engineering of dependable components.

Mass-market robotics will not become a reality until the individual components that make up an advanced robot can be manufactured in volume cost effectively for each market and with guaranteed performance levels.



Within the area of component R&T the key focii are:

- To discover technologies that maintain an upward trend in power density while improving cost effectiveness, efficiency and satisfying the need for smaller more compact components.
- To increase the levels of component integration in order to drive cost effectiveness and provide the basis for common component interfaces.
- To drive the process of standardisation of interfaces and performance specifications.

Miniaturisation in the field of ***actuation and sensing, control and perception*** was clearly regarded as the most important breakthrough field required. This can be explained by the need for developing increasingly light weight or more complex robots where miniaturised components are required.

Energy is an important aspect of robotics to increase the mobility and operation time. It is therefore logical that this aspect was considered an area of importance.

Bio-inspired locomotion will hold an increasingly important role in the future. There is a strong motivation to develop robotics, which resembles or mimics human or animal motion.

Micro-robots can be defined by their dimensions, the largest measured in tens of millimetres and the smallest measured in nanometres. The commercial reality of micro-robotics is critically dependent on size, with millimetre scale robots likely to be a viable niche technology within a 15-20 year time frame while nano-scale robots still lie in the realm of scientific investigation.

The primary application areas are in small systems inspection, for example inspecting small bore pipes such as water or gas pipes, investigating building voids, or in search and rescue activities. There are also a small number of medical applications where subminiature manipulators and tools have an application, however medical robotics and particularly autonomous medical robotics are likely to represent a later market opportunity possibly outside of the time frame of the current SRA.

Miniature robots have a number of niche applications in security and inspection tasks where their small size allows them to enter spaces where larger machines cannot go. They may also have advantages in tasks where the co-operation of many small robots may be more effective than the use of fewer but larger machines. For these applications to flourish the means of assessing the advantage and viability of using many small machines must be established. It is also highly likely that the discovery of novel means of locomotion, actuation, sensing and communication that are highly energy efficient and compact will enable particular market niches. For these reasons the research into miniature robotics needs to be carefully focused.

Actuators

The primary challenge is the integration of sensing and control directly into actuators making them "smart actuators". This will reduce control loop delay times, thus increasing the responsiveness of the actuator. Packaging the actuator with joints and linkages coupled to sensing and control will result in tighter final product integration.

A further challenge is the increasing of efficiency, and power density in drive mechanisms and actuators particularly for products using portable power sources and the reduction of noise particularly in smaller actuators used in everyday human environments.

Miniature end effectors used in tele-operation systems are likely to provide an initial commercialisation of the underlying technologies for miniature actuators and sensors as in these types of application the constraints of miniaturised power supply, processing and communications are reduced by the umbilical cable.

The key research goals focus on:

- Finding the technologies required to progressively improve power density, and to maintain a cost reduction progression for a given specification.
- To find technologies to allow low speed actuators that exhibit high dynamic properties allowing finer control under variable loads.

Coupled to this are goals related to cost reduction, where mass markets can be opened up by being able to supply high performance parts at low cost. These goals may well require the use of novel materials to achieve their target specifications.

Key to many future Advanced Robotic products are improvements in actuator technology. At one end of the product spectrum the delivery of low speed high torque components with high accuracy will enable the construction of high performance robot arms for manufacture and space manipulation applications.

The delivery of lower costs and higher power densities resulting in smaller packaging coupled with standardised interfaces and integrated sensing of the joint mechanics will enable applications such as a domestic fetch and tidy robot to become a cost effective reality. Such developments will also enable the provision of standard modular manipulators for easily reconfigured assembly operations.

Sensors

Sensors are one of the critical components where it is important to maintain a high level of innovation within Europe. The key common challenges across the different market segments are:

- Cost effective and fast 3D volume sensing systems able to detect, locate, track and identify objects within their field of view at fast frame rates.
- Low cost ultra-low drift compact inertial sensors.
- Large area contact and pressure sensing systems

Current prototype systems are all limited by the quality and rate of 3D sensing. In all applications from automated transport to domestic appliances the knowledge of where objects are in the environment around the robot is critical to carrying out its task. The quality of 3D sensing is also critical to the dependability of advanced robotics, and the lowering of costs is critical to the opening up of a mass market.

The development of ultra low drift inertial sensors is important to both industrial and space applications for advanced robots where precise knowledge of linkage location/orientation and body location over long periods of time without the need for recalibration will allow the development of more self-aware systems.

The development of large area contact and pressure sensing systems able to localise the point of contact are critical to achieving the high levels of dependability that will be demanded of co-operative systems.

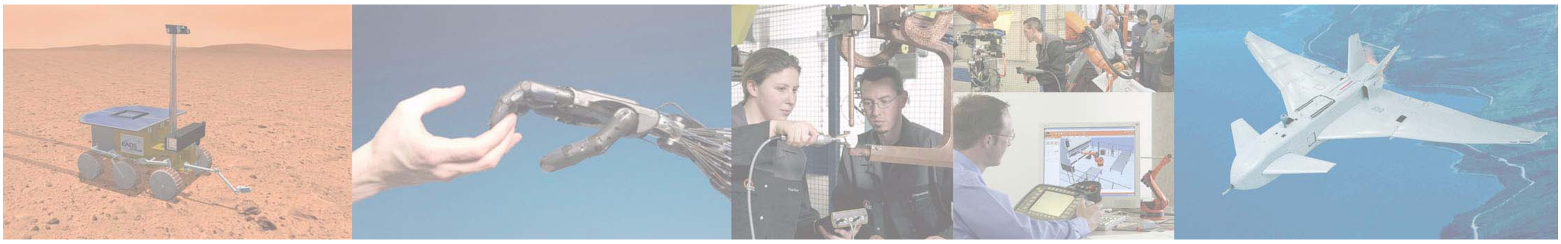
Processing and Communications

There are significant common challenges in this area. In particular the development of software and interface standards is critical to the development of a cross domain component industry enabling it to deliver high level advanced robotic components such as navigation systems, or 3D sensing systems able to connect to a common platform standard.

Further challenges come from the development of integrated sensor processing systems that require specialised computer architectures to implement signal processing tasks at high speed. The cost-effective production of these components is critical to the development of a volume market for Advanced Robotic products.

In communications the development of ad-hoc peer to peer protocols for dynamic networks is of significant interest to multi-robot applications where many robots must communicate to achieve a common task, such as in search and rescue applications or the moving or organising of amorphous materials, such as grain or sand, over large areas.

Key research goals are based on the common agreement of interface standards at both the hardware/software boundary, and in particular the development of layered interface standards that respect the flexibility of the boundary in different implementation schemes; and the development of interface standards at the higher level processing layers. High-level interface standards will enable 3rd party provision of complex software components such as navigation, map construction and human interfaces will allow the sharing of technical IP through a component market.



Human-Machine Interfaces

The Human-Machine Interface represents one of the most significant challenges in Advanced Robotics. Without intuitive and easy to use interfaces the primary goal of having robots collaborate and cooperage with humans in everyday environments cannot be achieved. Critical to co-operative interaction between humans and Advanced Robots are intuitive interfaces that allow a human co-worker to instruct and programme the robot to carry out tasks without having specialised knowledge of the operation of the robot. In some environments this can be achieved through an HMI that allows the robot to mimic the actions of the user in order to learn a particular process.

In other application environments the instructions will consist of higher level commands relating to functions the robot inherently knows how to perform. Each of these types of HMI requires significant research breakthroughs to be accomplished with the levels of dependability that will be required.

Complex machines require simple interfaces if they are to be operated efficiently and safely. The communication process must be bi-directional with the advanced robot being able to communicate its actions, decisions and problems at a human level.

This bi-directional communication may be carried out through different modes of communication, physical, spoken visual, gestural; each requiring different levels of research breakthrough to become a component technology.

High-level intuitive interfaces for human-robot "on-line" interaction, multi-modal interaction (speech, gesture, haptics, emotion recognition), immersive "off-line" virtual programming tools, solutions based on wireless signal transmission together with the definition of a low cost HMI with commonality to domestic devices, will permit a better diffusion of robotics into SME organisations and use by untrained people.

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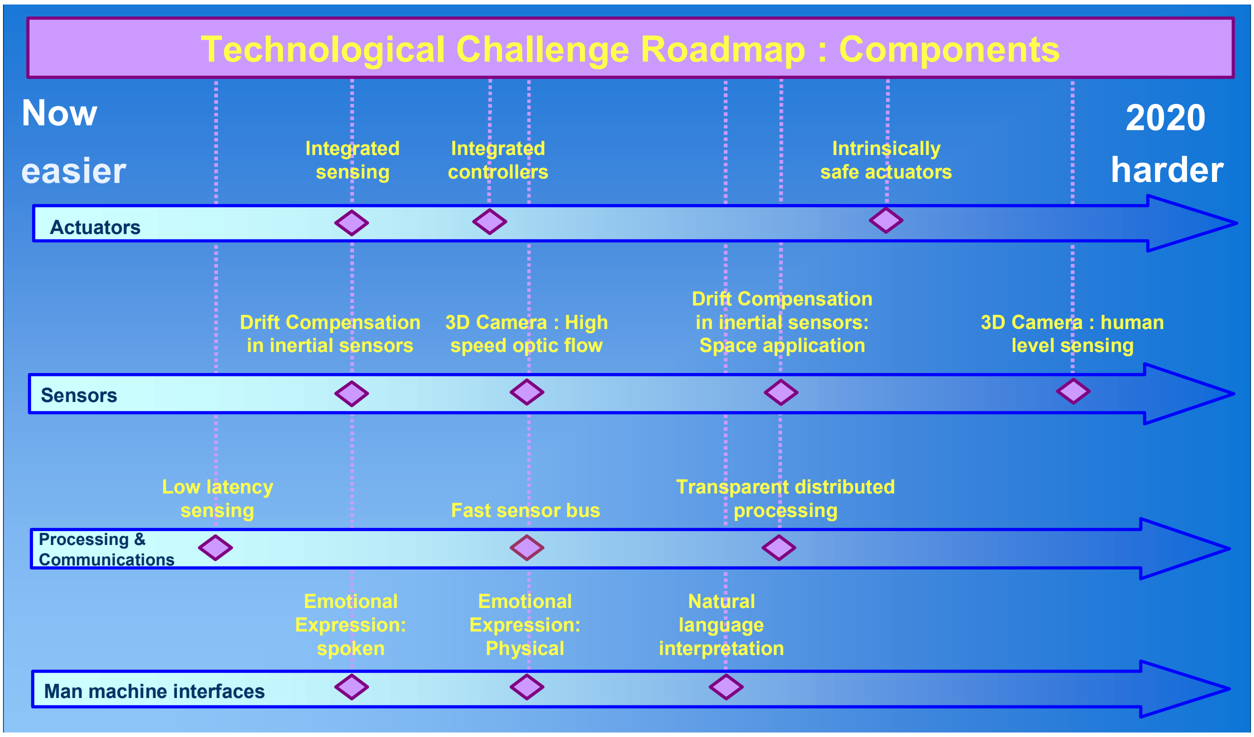
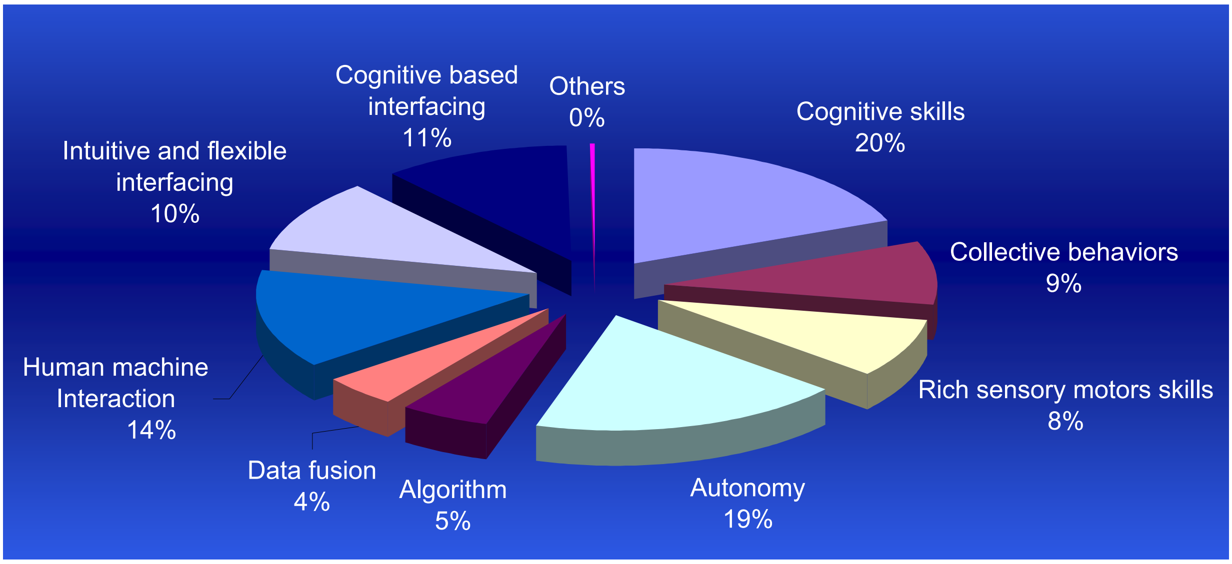


Technological Challenge Roadmap : Components

Advanced behaviours



More than in any other domain, the advanced behaviour domain exhibits fragmented research and development areas. Significantly, breakthroughs encompass a very wide range of challenges and involve cross-domain technologies in many ways. Improving ***autonomy***, developing ***cognitive*** approaches, and determining ***Human machine interactions*** are the key breakthroughs to achieve complex and efficient behaviours and to ensure the integration of robots in our modern society. Other relevant challenges in ***sensory motor skills*** and ***collective behaviours*** will also widely impact the feasibility of such objectives. At a less important level, research into various classes of cross-domain algorithms (data fusion, for example) will also support these objectives.

Cognitive

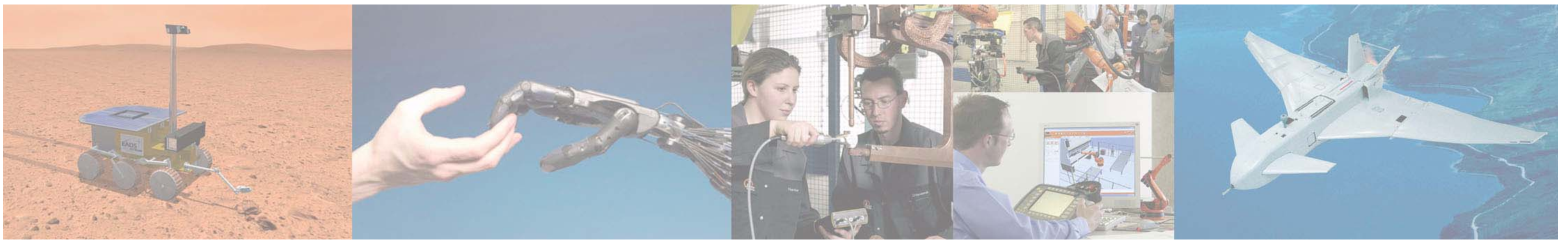
There are four classes of key challenges to achieve advanced behaviour using cognitive technologies. These are crucial to reach the necessary level of cognitive functions that enable the robots to reason, act and perceive in changing, incompletely known, and unpredictable environments in a human-like and comprehensive manner.

Human-robot interaction & legibility

Cognitive interaction and perception models are essential to the development of smooth co-operative behaviour between robots and human. This involves application domain representations that need to be acquired. Furthermore, this also entails shared semantics between robots and users.

New capabilities are expected:

- Recognition and generation of emotions.
- Behaviour inhibition or emphasis.
- Compliance with social norms.



Knowledge management and modelling, learning, decision-making

Increasingly complex problems (information interpretation, scheduling, diagnosis,) make knowledge modelling highly difficult to formalise for the various robot tasks. Traditional supervised learning approaches, however, will not scale to challenges in foreseen robotic application scenarios. In the future it will be necessary for robots to learn world models in an unsupervised fashion while providing a suitable representation for decision-making and task execution.

Situation and environment awareness

Merging and understanding of both the external situation and internal status are required to support cognitive models and knowledge management. The situation awareness depends on the heterogeneous information provided by various sensors and actors that can be co-operative or not.

The system must aggregate, elaborate, and interpret this information based on cognitive models, dealing with bias, erroneous data and incomplete semantic.

Cognitive Architectures

Cognitive architectures have to integrate in consistent framework situation awareness, knowledge management and human machine interactions.

Integration of these high-level cognitive modules needs to structure behaviours such that different levels of reactivity co-exist in a fluent manner.

Cognitive interfacing

Cognitive interfacing allows robots to reason on human behaviour and adapt behaviours, human interactions and interface schemes accordingly.

The challenge is to address more deeply, human characteristics in the design of intuitive or cognitive interfaces. Firstly, interfaces should be able to be more organic (like see-through viewers) and anatomically adaptive (such as haptic interfaces). Secondly, multimodal interactions and dialogue capabilities have to be explored in a broader way. Thirdly, robots need to be capable of identifying emotions and mental cues, for example to define a non-intrusive course of actions.

Autonomy

Enabling autonomous robots to perform in dynamic environments, deciding when to interact with humans, infrastructure, or environments, necessitates reliable localisation, higher anticipation and self-recovery.

Localisation and navigation

Localisation can be achieved by using different data incoming from proprioceptive sensors, external information such as GPS/Galileo or infrastructure broadcast. Fusing these different sources will provide a more reliable localisation both indoors and outdoors. The detection and localisation of mobile objects and the anticipation of their behaviours will augment navigation capabilities. This involves new algorithm for situation interpretation, motion planning and execution in real-time and for all environmental conditions.

Robots self diagnosis and recovery

Autonomous self-diagnosis and recovery is essential for the completion of the tasks and safe operation of the robot. The robot must reason on failure sources, reconfiguration possibilities and, for example, decide between the safe continuation of operation (downgraded mode) or aborting operations (shutting down).

Collective Behaviours

For performing collaborative tasks such as collective sensing, teamwork will require advanced communication, information sharing and mixed-initiative planning. In the following, it is assumed the components for communication will provide ad-hoc networking for the mobile robot with sufficient quality of service.

Collective perception

The collective interpretation of sensor data from multiple sources is necessary to achieve a common and relevant understanding of the operational environment and its status. This is a key enabler in collaborative decision making and relates to explicit knowledge acquisition.

Information Sharing

Data sharing refers to the distribution of relevant information (sensor data, knowledge, situation awareness, and resource level). The problem is to guarantee information integrity and consistency, in spite of complex data models, and aperiodic updates. The challenge is to automate the building of common data models which are shared by the different robots, systems and human actors.

Multi-robot Co-operative & collaboration

Sharing different goals between robots and humans with limited common resources is a key to achieving advanced collective behaviours as well as efficient teamwork. One area of investigation is the generation and maintenance of plans (including task allocation) during operations. Another area is the achievement of co-operation without explicit action representation, for example in the case of swarm behaviour using relative navigation. In both methods, the dynamic maintenance of mixed team of humans and robots is a common driving challenge.

Mixed initiative planning, scheduling and execution

As previously highlighted, planning, task scheduling and execution are critical to manage resources and to co-ordinate collective actions of robots and humans. A shared ontology of plans and elementary tasks is essential to determine robot and human roles and initiative levels. Planning, scheduling and execution must encompass allocation problems, resource usage, dynamic reconfiguration and deal with contingencies (goal updates, sudden lack of resources, failures, and environment changes). The issue of accountability should be addressed at the system engineering level.

Human machine interaction

Human machine interaction is a long-established technological axis in the development of robotics. In the scope of integrating robotic systems in our daily life, the interaction between the robots and people whether trained or un-trained will be a subject of great importance.

Normalisation, standards and safety will become the key challenges to be taken into account, in parallel with the end-user demands. It is also essential to push for early standardisation to prevent imposed standards from competing countries (Asia, United States). A platform like EUROP can enable this kind of activity stressing the definition of "common rules" applicable for different robots. A dedicated committee could be organised to pursue this goal.

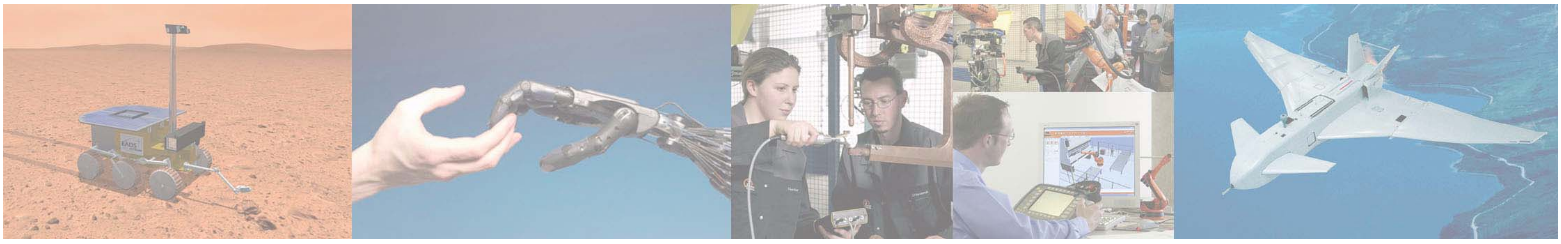
As the industry segment has already reached a "critical mass" of robots, it will be beneficial to use the industrial experience as a starting point for future developments.

Data Fusion

This challenge is a cross-technology one, addressing collective behaviours, autonomy and cognitive area of research. In these areas, performing distributed data fusion and interpretation in real-time will have to cope with complex combination of symbolic representations, cognitive models, numerical and statistical data.

Rich Sensory Motor Skills

The goal is to increase the complexity of tasks performed for sensory motor components (e.g: for complex environments). High performance and updating rate are needed to complete dynamic and agile behaviour (e.g.: Obstacle Avoidance, walking robots). Moreover, this has to be integrated with cognitive and autonomous modules, such that overall system co-ordination is achieved.



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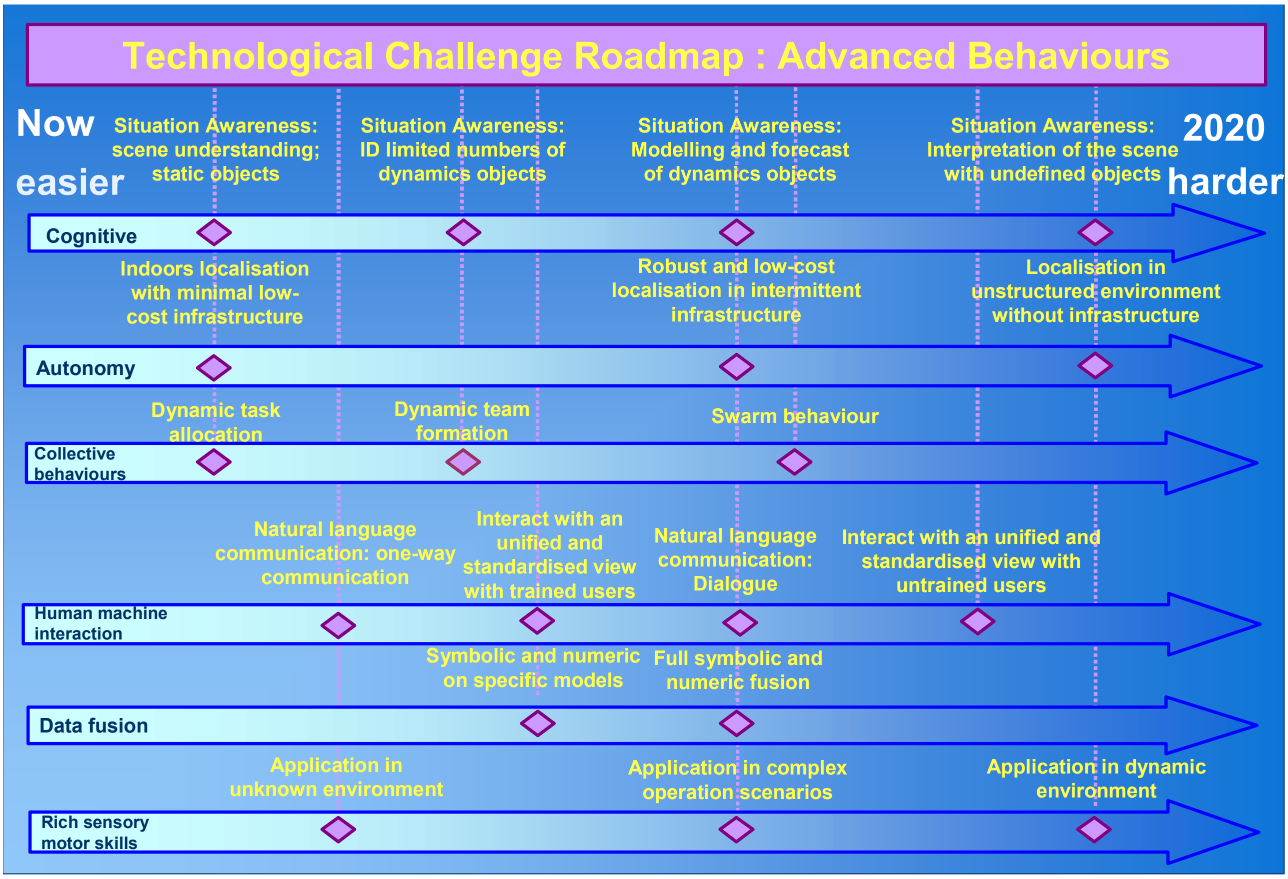


Technological Challenge Roadmap : Advanced Behaviours

Now

easier

2020

harder

Situation Awareness: scene understanding; static objects

Situation Awareness: ID limited numbers of dynamics objects

Situation Awareness: Modelling and forecast of dynamics objects

Situation Awareness: Interpretation of the scene with undefined objects

Cognitive

Indoors localisation with minimal low-cost infrastructure

Robust and low-cost localisation in intermittent infrastructure

Localisation in unstructured environment without infrastructure

Autonomy

Dynamic task allocation

Dynamic team formation

Swarm behaviour

Collective behaviours

Natural language communication: one-way communication

Interact with an unified and standardised view with trained users

Natural language communication: Dialogue

Interact with an unified and standardised view with untrained users

Human machine interaction

Symbolic and numeric on specific models

Full symbolic and numeric fusion

Data fusion

Application in unknown environment

Application in complex operation scenarios

Application in dynamic environment

Rich sensory motor skills

EUROP platform

Supporting Lisbon Strategy

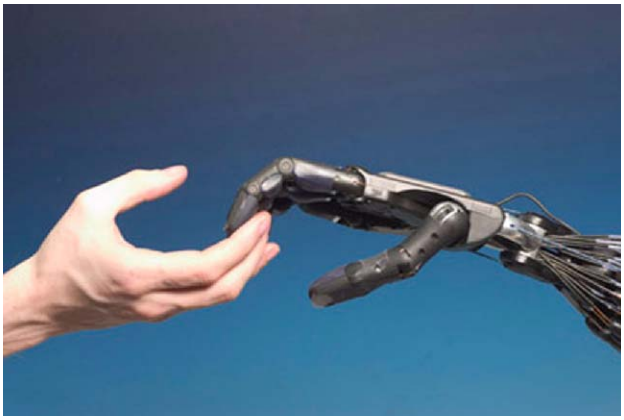
Europe deserves a strong and visionary SRA in robotics to tackle the main challenges expressed in the Lisbon Strategy. The platform will address the following major objectives of the Lisbon Strategy:

- ❑ Boosting competitiveness and growth by generating break-through innovations in robotics.
- ❑ Maintaining European manufacturing robotics in a leading position, and developing new companies and supply networks to meet the new technology needs.
- ❑ Resolving many of the future economic and social challenges faced by European society, in particular ageing and well-being.
- ❑ Encouraging companies from different sectors to work together to become more competitive and develop new products and services for the benefit of economy and employment.
- ❑ Facing EU enlargement problems by providing leading edge security systems in the face of illegal immigration, crimes and other trafficking.
- ❑ Supporting the development of a kknowledge based society.

Complying with i2010 programme

The platform will promote the **cross-fertilisation** of robotic research. The objectives will be to leverage significant **knowledge-based** employment and education at a large scale through European Industry, Services and Education infrastructures.

The platform will also be a major facilitator of a holistic ICT strategy and will aim at structuring and co-ordinating the different research activities related to the different technology domains considered.

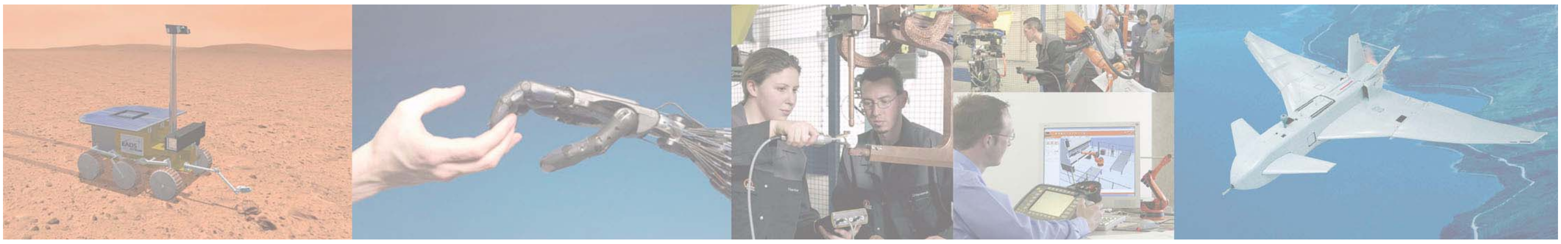


EUROP initiatives in line with political vision

EUROP brings together large, medium and small companies as well as research centres, all with the common objective of promoting the strength and development of robotics activities in Europe. The foundation of EUROP, comprising of more than 80 members, endorses the platform which is still attracting a growing interest.

EUROP covers the complete robotics picture including industry, service (both professional and domestic), security and space with the following aims:

- ❑ Develop a Strategic Research Agenda for robotics in Europe addressing in detail the technological challenges with a strong focus on research & technology cross-fertilisation in order to facilitate the synergies in the community and to optimise the resources. This Strategic Research Agenda (SRA) covers in particular the road mappings, business plans and trends facilitating implementation. Development of the SRA will involve a large representation from the European Robotics Community working under an adequate methodology and organised in dedicated working groups able to provide relevant and consistent recommendations to the Commission.



- Propose and put in place initiatives to build and consolidate the European Robotics Community with a relevant dissemination process and an active communication plan.
- Address the relationship with ETPs in regard to robotics, such as Manufuture for robotics' need in manufacturing, Artemis with respect to embedded system software, Eniac concerning the micro and nano technology objectives, and Networks of Excellence like EURON in order to interact positively with the Strategic Research Agenda.
- Address the broader impact of advanced robotics on society assessing the legal, social and ethical issues surrounding the introduction of advanced robots that directly interact with their users in everyday human environments. It will also assess the educational issues surrounding the introduction of advanced robotics both in terms of public understanding and the higher educational needs of a developing robotics economy.
- Address international co-operation issues within Europe and outside by examining the interaction between national and EU research funding and the necessary co-operation with competing industrial economies that will support the construction of a European robotic economy.
- The platform will assess the coverage of on-going standardisation activities regarding architecture, safety, interface, middleware… Guidelines will be issued in the non-covered areas and it will contribute in the on-going standardisation development. Co-ordination with existing groups on topics such as certification process, criteria and regulations could be undertaken by the platform.
- The platform will have an active role in competitive benchmarking, as well as in the definition of the systems and modules benchmarks to enable objective comparative evaluations. So doing, benchmarking can influence the standardisation process.
- One of the main roles of the platform is to promote good robotic systems engineering practices in education, industry, and services. This benefits the quality of the products and related services. The platform will promote best practices, standards, propagate common process frameworks.

Set up a strong mirror group able to address cross-fertilisation of European and national interest in robotics (political, budget issue). The mirror group is a two-way information link between the platform and the rest of world (research community, non-robotics industry, government, the commission, other European and non-European entities). Information exchange will include research programmes, objectives and their implementation. The mirror group is a vital component in the building of a European wide consensus on robotics and a facilitator in the research defragmentation process suggested by the platform.

Facilitate dual use for the benefit of the development of robotics. As the use in the defence, nuclear and space fields has demonstrated, robotics will also play an important role in areas such as the fight against terrorism and crime, civil protection and security, monitoring of illegal immigration and space exploration.

Over the last twenty years, considerable effort and investments have taken place worldwide to provide suitable and satisfactory solutions to the scientific and technological problems associated with space and security robotic applications.

Overcoming these challenges demands concentrated, focused R&D efforts to create breakthrough intelligent robotics technologies and systems, and to define and apply best available software practices to intelligent robot development.

EUROP will address how to stimulate the development of dual use technologies and avoid duplication of research efforts in Europe in the proposed cross fertilisation methodology.

Stimulate SME involvement as a key factor for the development of robotics in Europe.

For the vision of EUROP to be fully realised it is necessary to stimulate the development of an Advanced Robotics supply chain network. Key to this is a thriving, growing and competitive SME sector which will widen the availability of component products, reduce the price of robot system build and more quickly open up new and niche markets.

There is already a strong, albeit emerging, SME Advanced Robotics community. As evidence of this, 75% of the original EUROP platform members were SMEs. However, to compete on an international level this sector of the supply industry needs to be grown and strengthened. The key actions which will help to establish and nurture this strong SME presence in Europe include:

- Agreement of common information architectures and component (module) requirements.
- Agreement of detailed (plug and play) module interfaces.
- The establishment of medium to long term key supplier arrangements between robot builders/ system integrators and SME component suppliers.
- Access to finance on favourable terms for newly formed SMEs in their first two years.
- Support mechanisms for newly formed Advanced Robotics companies and, particularly, for university spawned start-ups.
- The establishment of European-wide Advanced Robotic system support facilities for end-customers.
- The availability of new market development support mechanisms.

Defragment research guided by applications.

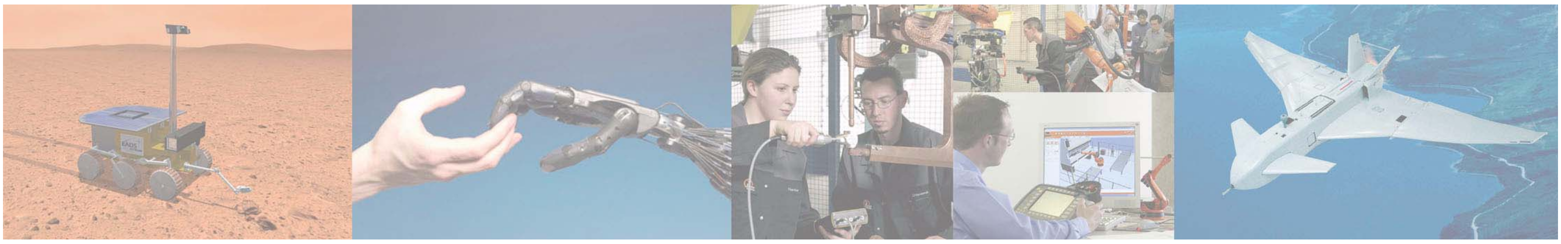
The major expectation from the industries is to develop innovative robotics products in the different market segments by 2020. Inherently, these products will present several technological challenges to be resolved, and thus will need breakthroughs in several technological axes.

One of the first objectives of the EUROP platform is to identify the technological axis where cross-fertilisation will benefit and provide technological solutions to robotic products in the defined market segments. Indeed, the objective is to highlight the technological axis where common research efforts should be focused.

The platform will promote the defragmentation of these research efforts by suggesting the creation of co-ordinated programmes to a particular technological axis. Different levels of team integration and effort balanced between academic research and industry will be proposed. This will necessarily match the FP7 time-scale and maturity levels.

Develop new business models for growing service and security market involving robots. With regard to the new robotic markets, the platform will define the appropriate business model including the supply chain, funding, resources, enabling services, standardisation, social and societal issues, and by-products (technology, services…).

CONCLUSIVE SUMMARY



Industry has strong expectations for EUROP, as we need to answer new requirements in service and security markets, both inside and outside the Union. European industries must be ready and strong enough to play its role by anticipating market development and by developing adequate supply chains in the different robotic sectors. The future prospects motivate current Japanese, Korean and US efforts. Today, it is fundamental to develop industrial capabilities, under a unified approach, in order to match and exceed these initiatives.

From a different angle, EUROP aligns with the Lisbon Strategy, and will be a very useful tool, in the context of i2010, to address global societal challenges. To tackle the over-ageing society and improve life quality of the physically challenged, new services, machines, tools and especially robot assistants can be developed. They will enable these persons to make use of their skills and experience without the full physical strain. The development of products with high added value will support economic growth and the development of knowledge-based employment. Similarly, productivity can be consolidated by producing more and at lower cost. The manufacturing industry can become an asset to fight accelerating international outsourcing. Furthermore, robotic services can help tackle immigration and security problems, which are increasing with both EU enlargement and global terrorism. In addition, robotics will be an essential part of future information & communication society: as Japanese experts quote "robots will become the physical Web".

The EUROP vision can be translated into missions, to be fulfilled mainly in the FP7 time scale. The first step consists in continuing to develop and agree on a consistent Strategic Research Agenda around convergent objectives. The second step proposes initiatives to federate industrials, academics and public institutions to generate innovations and breakthrough in the robotic domains. Evaluating and stimulating new markets is also essential to balance technological objectives and to set relevant benchmarks. Finally, the platform will propose improvement of existing business models for industrial and space markets and produce new ones for the emerging service and security robotics market.

This can only be achieved by delivering co-ordinated and collaborative efforts between industrial stakeholders, academics, SMEs and public authorities.

ABBREVIATIONS

C

CAD	Computer Aided Design

E

EIA	Electronic Industries Alliance
ESA	European Space Agency
ETP	European Technology Platform (cordis.europa.eu/technology-platforms)
EU	European Union
EURON	EUropean RObotics Network (www.euron.org)
EUROP	European RObotics Platform (www.robotics-platform.eu.com)

F

FP7	Framework Programme 7

G

GDP	Gross Domestic Product
GPS	Global Positioning System

H

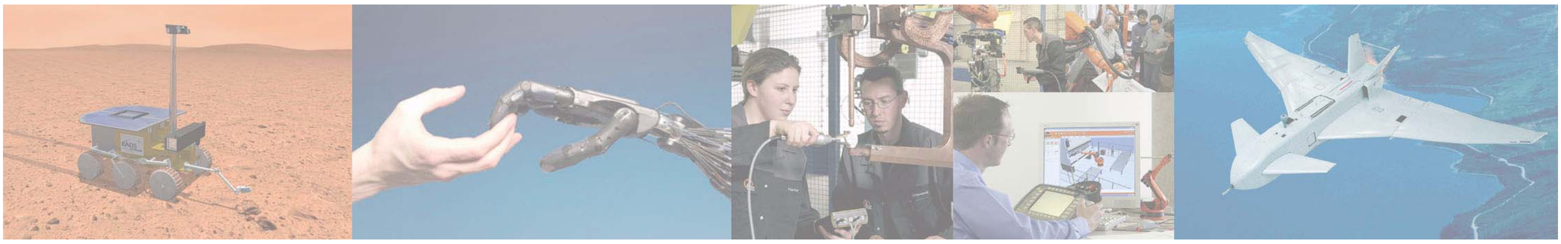
H/W	HardWare
HMI	Human-Machine Interface

I

ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronic Engineers
IFR	International Federation of Robotics
IP	Intellectual Property

N

NASA	National Aeronautics and Space Administration



P

PASR	Preparatory Action in the field of Security Research

R

R&D	Research and Development
R&T	Research and Technology
RTD	Research Technology Development

S

S/W	SoftWare
SME	Small and Medium sized Enterprises
SRA	Strategic Research Agenda

U

UAV	Unmanned Air Vehicle
UGV	Unmanned Ground Vehicle
UNECE	United Nations Economic Commission for Europe

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