Building EUROP,
the European Robotics Platform

The High Level View

Juy 2005

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Executive Summary

The Vision of EUROP, the European Technology Platform in Robotics

A consolidated European strategy in robotics is a requisite for preparing a new generation of robots that will closely collaborate with workers and move out of the factory to conquer a new wave of novel service, security and space application markets.

As industrial, service and security/space robotics increasingly share the same research challenges and agendas, such an initiative would aim to maintain Europe's leadership in industrial robotics and expand it into the burgeoning service and security markets. It would also aim to ensure increased public and personal security levels as well as new levels of quality of life by providing technologies required to enable society to address challenges in terms of ageing and well-being.

Robotics is a technology at the cusp. Long accepted by industry to improve 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 decision 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 challenge for the 21st century is to develop robotic systems that can sense and interact with the human world in useful ways. 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 and result in a step change of similar impact to Internet technologies 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 worldwide 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.

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 aging 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. Europe has a strong 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 development 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. It is essential that Europe match or better this commitment.

Top executives from some 50 leading robotic industrial and research organisations have proposed and strongly endorse the need for a European Technology Platform in Robotics – EUROP (European Robotics Platform). 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. 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.

1 Introduction

For decades researchers have been striving to develop robots, i.e., machines that can perceive, reason and autonomously carry out tasks in their environment. Robotic machines, technologies and components aim at the development, installation and operation of:

- **Industrial robot systems** to achieve high-quality and cost-effective flexible manufacturing and logistics in all major industrial branches.
- **Service robots** to be found in all domains of our life: in domestic and leisure environments, in health and rehabilitation, in professional services and in hazardous environments.
- **Space and Security robots** concerned with the use of robots in land, sea, subsea, air, space and crisis or civil security management missions.

EUROP (The European Robotics Platform) is Europe's initiative in robotics research that addresses the above three application domains. EUROP brings together all the main European robotics stakeholders with the aim to formulate and implement a consolidated European robotics strategy. The first meeting of a high-level group of robotics academia and industries took place at the presentation at the UNECE in October 2004, followed by an intense workshop of the Robotics Action Group (a grouping of top executives from leading robotic industrial and research organisations) to develop a vision and a strategy towards a Robotics platform for Europe. This was followed by expanded group meetings in Brussels and Barcelona to establish the agenda for a European Technology Platform in Robotics. This report is the result of these deliberations.

2 A Vision for the Future

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; as our appliances, servants and assistants; as our helpers and elder-care companions; assisting surgeons in medical operations; intervening in hazardous or life-critical environments for search and rescue operations; cleaning and repairing pipes 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 and increasing their skill level. 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.

- *Robot companions in the home* that empower the infirm and the elderly to lead independent lives, providing them assistance by carrying out everyday tasks such as fetch-and-carry jobs, mobility aid, rehabilitation and multi-media services.
- *Robot servants and playmates* that empower individuals by carrying out their domestic chores, thus giving people more time and choice and interactively entertaining or educating them.
- *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 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.

However, the vision of people and robots interacting and working symbiotically together is still some way off. Today’s robots are far from being able to understand and reason about their environments, their goals and their own capabilities, to learn from experience and from what they have been taught.

The evolution of 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”. By embedding robots into such emerging ICT environments, they will be able to call upon an unlimited knowledge base, coordinate 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. The driving factor is that it will be Europe that will be at the heart of providing the technology, the systems and the standards for these next generation robotic technologies. European industry will thus extend its current leading position in industrial robotics to be the leading export-oriented producer of industrial, service and security robots. This industry will encompass a supply chain from SME customisation or component manufacture to large scale system builders.

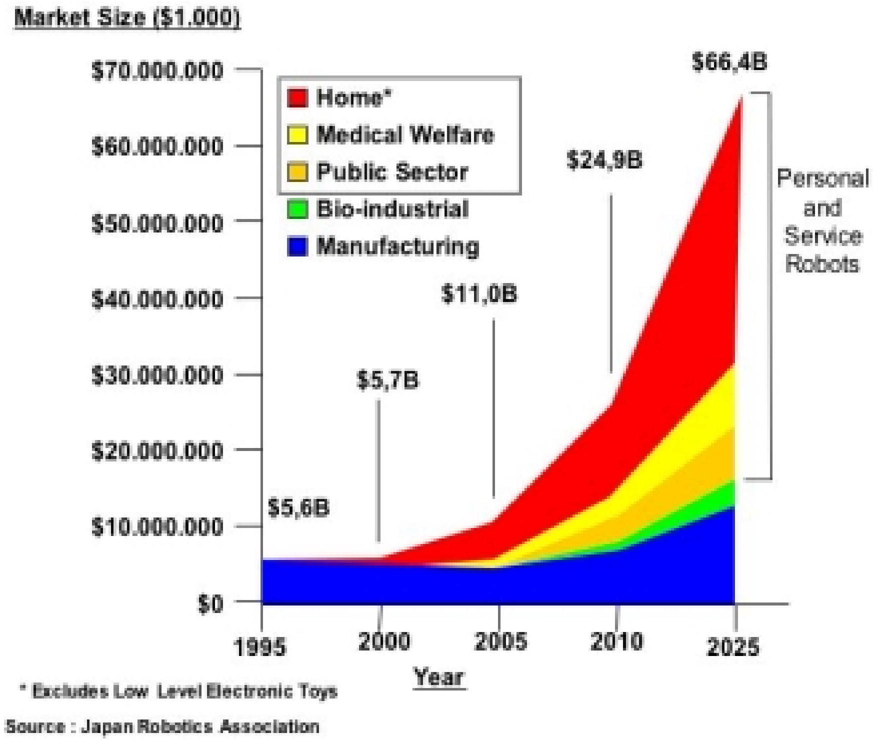
Robotics represents impressive feats of engineering. By developing robotic systems, companies can both demonstrate technological prowess and benefit from ancillary breakthroughs that emerge along the way. Robotics is highly interdisciplinary and with EUROP, there is a unique opportunity to integrate both across the involved disciplines and across the involved application domains a strong industrial basis that will ensure sustainable growth and maintain manufacturing jobs within Europe. Only through an investment in robotics can industry remain competitive for manufacturing while at the same time providing the basis for the new industrial domain of service and security robotics. Moreover, many other fields are likely to benefit from spill-over effects of such an initiative through cross-fertilisation.

3 The Industrial Perspective

As well as bringing significant benefit to European citizens, robotic products and technologies will be a source of economic prosperity for companies involved in the supply chain. To maintain an advantage in terms of increasing the productivity of European manufacturing industry and providing systems which meet the needs of European citizens, it is vital that a strong robotic industry is maintained in Europe and that it grows and adapts to the needs of the new markets arising from emerging technologies. This section examines the current and emerging markets for robotics that will be common mechatronic platforms, subsystems and components and is structured around the three big market segments addressed by EUROP, namely Industrial, Service, and Security & Space Robotics.

3.1 *Current Market Status and Future Growth*[1]

The business case for investing in robotics can be put simply. Europe is a currently a major player with significant expertise, and the robotics markets are set to grow quickly and become large economic sectors in their own right as well as providing the means for both manufacturing and service industries to become more effective. Figure 1 shows this anticipated growth.



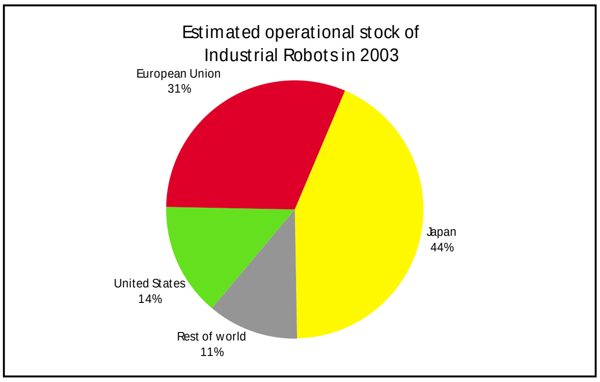
3.1.1 Industrial Robots

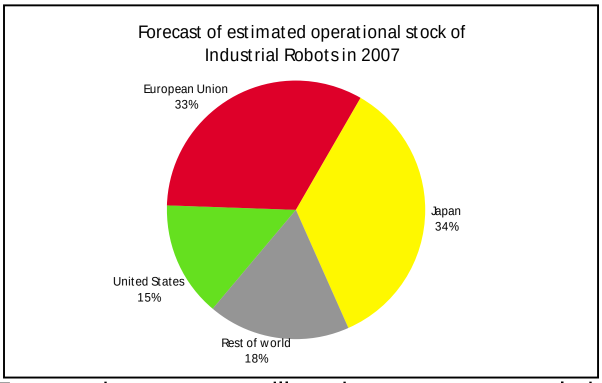
Europe is one of the world's leading producers and users of industrial robots. Europe's push towards greater productivity is increasing the dominance of this position. Overall, the industrial robotics market has experienced a steady growth over the last decade and today about 30,000 new units are installed each year in Europe, representing about 3.1B robot sales, or some 33% of global sales. When taking into account sales of robot components, system integration and other services, total annual revenues add up to some 13B. In terms of economic indicators such as export share, R&D budgets, growth rates, and employment, the robotic industries stand out as a role model for successful European industries. For users, industrial robots bring increased productivity and quality which enable European companies to remain competitive and retain jobs in Europe while responding to the challenge of low wage economies.

Robotics has, for at least three decades now, been widely used in engineering industries[2], which account for some 70% of all industrial applications. However it is estimated that only 15% of possible applications are currently automated, with SME's being particularly under-represented. The current generation of industrial robots is also often challenged by new application areas such as the food industry, where a higher degree of hygiene and increased productivity can be achieved by minimising human handling of the raw food items, and the recycling industry for consumer goods.

[1] The numbers provided in this section are primary taken from the United Nations Economic Commission for Europe, UNECE, statistical report *World Robotics 2004*, by Jan Karlsson, Geneva, October 2004. ISBN 92-1-101084-5.

[2] Engineering industries consist of the branches: metal products, machinery, electronic, electrical and optical equipment, and transport equipment.





Future robot systems will not be a mere extrapolation of today's often complex and costly robot technology but rather follow new design principles required by a wider range of possible applications. Their operation will increasingly depend on information generated by sensors, worker instructions and/or CAD product data. Gradually, these future robots will become the workers' assistants serving them at the workplace. They will carry out the repetitive and strenuous parts of a worker's task and will increasingly safeguard workers from accidents and other relevant health care problems, thus alleviating the concerns of rising health care costs, particularly for small manufacturers. 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. These next generation industrial robot systems will have significant socio-economic impact in four stakeholder categories: end-user industries, existing robot automation manufacturers and system integrators, new start-ups in robotics and product related service-industries.

For end-user industries, the objective is to maintain competitiveness and create high-quality jobs. New robotic technologies will contribute in both these. New designs and technologies will allow accelerated expansion of new branches of robot automation such as food and drink[3], logistics[4], recycling etc.

Regarding robot manufacturers and system integrators**,** robots will remain a growth market for the foreseeable future, as manufacturing will depend on further productivity gains. The creation of technological advances is vital for robot manufacturers and system integrators, since it will permit them to stop relying upon robotic technologies that are tailored only to automotive applications. Examples of expected benefits and options include:

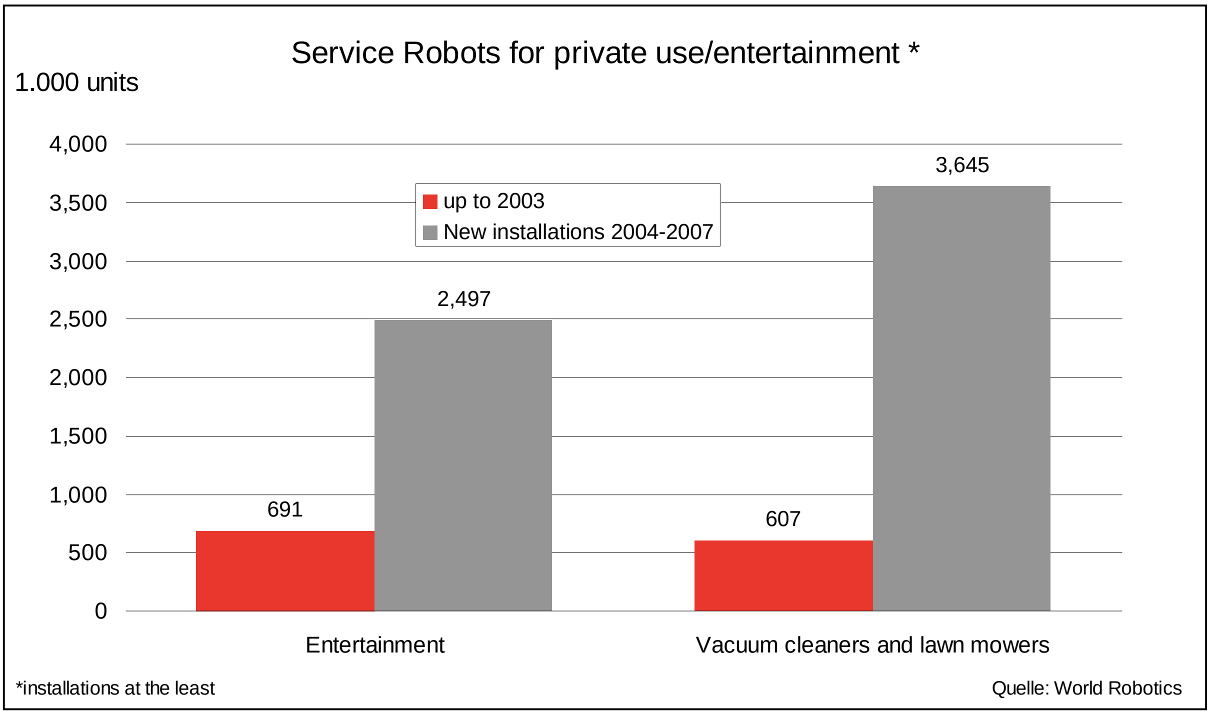
- Increasing productivity in labour-intensive industries through robot automation.
- Penetration into flexible and small scale manufacturing and in crafts by introducing assistive robots.
- Some new and very specific robotic products may be outside the product portfolios of existing robot manufacturers. These new technologies will be provided by innovative spin-offs.
- Life-cycle-oriented approaches in the planning, implementation and operation of robot systems offer chances for new services and businesses in a growing market.
- A new generation of highly accurate, flexible, mobile robots with sub-millimetre geo-location.

3.1.2 Service Robots

[3] The European food and drink industry, which buys and adds value to around 70% of all EU agricultural products, is the largest manufacturing sector in the EU. Its production volume in 2001 was 620B, which amounted to 13% of total manufacturing and 13% of employment in manufacturing.

[4] The European logistics market (warehousing, transport, etc.) is valued at 710B (including 320B, which is outsourced), equal to 8% of Europe's GDP, employing over 5 million people and generates a turnover of 1.8B. Source: "Global Logistics," Philippe-Pierre Dornier and Michel Fender.

In parallel with industrial robots, a new breed of robot has emerged, to be used outside the manufacturing field, termed service robots. By end of the year 2003 some 21,000 service robots were used in professional applications worldwide, in addition to more than 1.3 million service robots for personal and private use (lawnmowers, autonomous vacuum cleaners, robot toys, etc) with strong future forecasts (6.7 billion turnover expected for 2004 to 2007). Over the last 5 years there has been an exponential growth in service robotics for private use in homes. For example, since the introduction of the autonomous vacuum cleaner in 2000 the market has grown to more than 600,000 units shipped per year. The area is at present experiencing an exponential growth with an increase of more than 400% per year in some market segments. Some 220 companies (about 70% of these are new start-ups) develop and distribute service robots thus forming a new innovation driven, high added value industry.



Service robots will be found in all domains of our future life. They represent not only a hope for a more convenient world but also a massive new market for high technology industries. This sector offers significant opportunities for European industry. Service robotics can be conveniently divided into in three market segments (professional applications, domestic use and entertainment) that handle very different situations.

In the professional market, a number of robots are already successfully operating in field areas like forestry, agriculture, cleaning, surgery and rehabilitation, mining, autonomous transport of people and goods and freight transport, demolition, nuclear power plants, etc. Future potential applications range from transportation (smart cab) to prosthetics and (remote) medical interventions and 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 setup 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.

In the domestic sector, the market is expanding very rapidly, as has been seen in USA and Korea. When the current product lines were introduced, Europe was the leader in this domain. However, today the leadership is primarily in USA or Asia. One needs here to recognize some important changes. In the white goods industry the lifetime of products has typically been 5-15 years. The lifetime of newer types of service robots is typically 1-3 years. The differences in business style between old and new types of products are thus significant. Traditionally, Europe has very strong brand names in white goods and domestic services through such companies as Bosch, Dyson, Electrolux, Husqvarna, Kärcher, Miele, Philips and Siemens. Companies outside of the EU have been faster though to adapt their business models to be in line with the new market dynamics (iRobot, Aquaproduct, LG, Samsung). It is here crucial for Europe to build strategic alliances between the traditional companies and the technology providers to ensure market leadership. The new product areas will be in areas such as home appliances, advanced cleaning robots, sports trainers, and smart caddies (e.g. in supermarkets or airports) but one of the significant sectors will be associated with care of the elderly.

The entertainment sector has without doubt the most interesting economy. That is probably why Japanese industry was involved very early in this domain. More than 300,000 units have been sold of AIBO, the famous Sony's dog robot. Other major Japanese companies, such as NEC and Sanyo, have developed high quality offers in this domain. These companies have dominated the mass-market part of the segment and there is a rather limited history of an entertainment industry in Europe. When allied with the emerging educational robotics applications however, this sector has the potential to become economically very substantial. New product areas will include educational toys, specific skill trainers, smart figurines and robot companions.

In the service robot sectors the main stakeholders to derive socio-economic benefit are the robot system builders, the end-user industries, the service providers and consumers. For system builders and their supply chain, the potential of the service market is greater than the industrial robot sector. There is a clear case for Europe establishing a significant share of this high-value industry. For the service robot end-user industries the benefits gained are those that previously could only be obtained within the manufacturing industries, i.e. increased quality and repeatability, increased productivity, in-built traceability and improved health and safety conditions for employees.

Although there are many intangible and social benefits to consumers, the overwhelming business case is associated with the welfare and support costs arising from enabling infirm and older people to lead independent lives. Robot companions which can perform basic everyday tasks and monitor the well being of these people could extend the time a person can live in their own home by a considerable factor and reduce the support costs.

This simplified presentation hides a very heterogeneous set of applications and a complex market. Some of them will undoubtedly generate massive revenues in the future, but will also be very competitive and highly versatile. The key problem is to really understand the market agenda and the role of key-technologies in order to anticipate growth in this area.

3.1.3 Security and Space Robots

Robotics has also the near-term potential to become a major technology in a host of security and space applications.

Today, the primary driver for deployment of ***security robots*** in civilian applications is to avoid bringing harm or risk to the people involved. A 2004 study from UNECE, reported that about 1000 Unmanned Ground, Aerial and Underwater Vehicles (UGV, UAV and UUV respectively) have so far been put into use worldwide in civil security applications. At present, such robots are used for Explosive Ordnance Disposal (EOD), demining, chemical spraying and dusting in large agricultural areas, and subsea inspection and exploration. The sales forecast for the period 2004-2007 is for around 2,700 units (300M). In Europe, significant civil markets for Unmanned Ground, Aerial and Underwater Vehicles are still to emerge, with only limited niche applications being currently available.

Today the civilian security robotics market is small compared to the military one[5]. Indeed, the latter is growing fast thanks to initiatives such as the US Department of Defence (DoD) vision of having 15% of its ground transport under autonomous control by 2015 and a growing demand for military UAVs. It is significant to note that with the massive investment of DARPA and the strong ties between Industrialists and Research Labs, the US are constructing a significant industrial capability. Europe also needs to build upon the projected European defence spend on robotics (e.g. a UAV spend of 5.5B between 2004 and 2012) to leverage civilian industrial applications from dual use technologies.

Experience in the USA, Japan and other non-European nations shows that civil applications will soon emerge in application areas such as surveillance, border watch, agriculture (spraying and dusting), off-

[5] Defence systems are increasingly integrating robotics in the design of present and future combat systems, like networked drones and other air- and ground-unmanned platforms, but also exoskeletons for empowering soldiers, etc.

shore production and pipeline inspection. In the next 10-15 years, the expectations for market growth of civil and commercial robotics security applications are very high, driven by the increasing need for homeland security.

In the coming years, security enforcement, particularly on large borders, will rely more and more on automated systems. In the first instance, civil security missions will include surveillance of critical infrastructure (telecommunication and power lines, water, gas and oil pipelines, etc.) and extended border and coastal patrol boosted by the shift of EU borders to the East and the need to monitor illegal immigration fluxes. In the longer term, other major application drivers will include maritime surveillance (traffic control and monitoring of ship movements, supervision of illegal fishery), crime monitoring, search and rescue operations, environmental monitoring (fire detection and fire fighting, oil spill discovery, etc) and surveillance of hazardous materials.

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, versatility 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 application of ***robotics in space*** is unique in that it forces the robot to operate without direct human assistance and acts as a platform for the projection of human capabilities to remote and hostile environments. Robotic applications in space fall into two categories: assembly/repair in space and planetary exploration:

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 International Space Station also currently requires the regular operation of two astronauts for configuring external equipment, connecting services and carrying out maintenance operations. The recent emergence of highly dexterous 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 is one of the key technologies for space exploration and for addressing one of the most exciting scientific endeavours of the 21st century: the search for life elsewhere. Both NASA and ESA have plans to colonize the moon and send astronauts to Mars within the 21st century. The potential for robots is here enormous. 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. The NASA vision has been upgraded based on the recent success of the Spirit and Opportunity vehicles that operated on Mars for more than 6 to 9 months. The next mission is expected to include fully autonomous deployment and recovery of a vehicle for return of specimens from Mars to Earth by 2009. 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.

4 Challenges Ahead

Europe faces the challenge to stay at the forefront of robotics development, production and use. This calls for a coordinated action involving all stakeholder groups, in particular from technology, systems and market developers.

4.1 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 domains regarding manufacturing, service, and security and space applications. Examples of the main technological challenges are as follows:

Manipulation and grasping Very flexible and dexterous arms with a payload/weight ratio of 1:1 or better would be required to enable safe operation in the service sector to assist people with clearing of a table, assisting a person to get up from a sofa, or in human-worker cooperation.

Autonomy and dependability 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.

Intuitive human-robot interaction The transfer of information and instructions of tasks, skills, objects or environments between human and robot should be as intuitive and efficient as the communication between two persons. 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 cooperating industrial robots.

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.

Mechatronic design and miniaturization Mechatronic design principles stress encapsulated functional modules, their miniaturization and integration within standard hardware and software architectures. Besides opening up new options in cost and functionality of components, new mini or micro-scale miniaturised robots evolve in the area of distributed intelligence such as micro aerial robots or micro-vehicles for medicine and exploration.

Future robotic systems design and application depends on implementing a coherent agenda addressing RTD regarding ***components, behavioural requirements, human factors, miniaturization and system engineering***. The interdisciplinary nature of robotics requires that efforts are multidisciplinary and involve electro-mechanical, control, hardware, software and systems engineering together with ergonomics design, artificial intelligence and materials engineering. General algorithms, methods, engineering practices and standardization efforts have also to be considered.

4.1.1 Components

Key to establishing a pan-application robot producer base in Europe is the concept of common low-cost components and modules that can readily be incorporated into standard architectures. This "economy of scale" effect supports specific low volume system designs at attractive life-cycle costs.

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 capabilities in term of computing and communications 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.

Man-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.

4.1.2 R&D for breakthrough in behavioural requirements

Nearly all future robotic applications require that robots operate in unstructured environments, make real-time planning decisions, deal with a wide range of objects and interact with people and other robots. This necessitates major breakthroughs in the following areas:

Cognitive skills For operation in poorly structured environments, 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.

Collective behaviours 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.

Real time control and physical actuation, also includes different forms of control beyond traditional open / closed loop control paradigms.

4.1.3 Human Factors

A system's acceptance is a combination of apparent user benefit, pleasant appearance, safety and ease of use. Ergonomics in robotics is concerned with geometric dimensions, kinematic and kinetic properties of the robot and comprises a physical and an informational interaction. Major challenges that remain critical here include:

- To equip robots with more intuitive and flexible user interfaces in order to allow citizens 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.
- Cognitive skills are 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, etc.

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

4.1.5 Robotic Systems Engineering and Energy Issues

Robotic system engineering 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, etc.), 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 robots evolving in everyday environments, dependability will be a crucial design parameter and 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 action. Standards will enable a much higher degree of flexibility in the design of such systems.

4.2 Other Challenges

4.2.1 Education and Skills

Robotics is seen as “fun” for students and is attracting them at a moment when many countries are experiencing a decline in admission to engineering educations, due to lack of interest. By definition robotics must consider the full scope from basic mechanical design to control and intelligence so as to provide an acceptable solution. The combination of systems engineering and “fun” can be utilized 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 education of a new generation of engineers. 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 sectorial 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 breed 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 the education must however not be at the expense of depth, as the problems to be addressed are fundamental and difficult. Team-work will also be a requirement for the integration of systems.

4.2.2 Societal and Structural Challenges

The Lisbon strategy, committed to establish the EU as the most dynamic and competitive knowledge-based economy in the world, 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 the 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 achieving good progress in crisis management (such as floods, earthquake, forest fire), through search and rescue missions. Also, monitoring illegal and clandestine activities, border surveillance and everyday security concerns can benefit from robot systems.

The introduction of robotics into new domains poses though a major 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 sectors 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 evolution into civil applications of many large companies that are today purely defence-oriented or again or if the result will be an entirely new industrial sector. Either ways, the economic growth could be very significant.

The establishment of a service and security robot industry in particular faces a number of specific structural challenges. These are illustrated in the following table:

New business models	**For addressing both the growing pervasiveness of technology in all product and service markets as well as the short but financially significant product life cycles.**
Support infrastructure	Emerging applications of service and security robots will demand little skill or training of the user and will require very different customer support mechanisms.
Integration across traditional commercial barriers	In many new application domains, there is little interest from the domain experts to own some of the core technologies. These domain experts have the sales and support structures in place, but they will to acquire key competencies from technology experts. Such marriages across technological and business areas are necessary to entry into new markets.
New robotic solutions in emerging market segments	Robotics has so far primarily been applied in high-tech, high volume markets. New and emerging areas are also in market segments that are traditionally dominated by the use of limited-complexity technology. These areas represent huge opportunities for new roles for SME's and for integration of a variety of components, and are likely to generate entirely new industrial sectors.
Acceptance of robots in society	A concerted effort is needed to communicate the real value of robotics to the public and change its rather negative general view. – Need to change the general view that "robotics is replacing the workforce to reduce cost". In most cases the labour cost issues is secondary or non-existing. In addition, robots take away dangerous and dull jobs and protect human lives or remove tasks that may cause sickness if performed by humans. – Some technology related ethical issues need also to be considered, given that the media heavily bias the public view of robotics in a predominantly negative way.

5 Conclusions and the way ahead

In Europe, there exists today a wide consensus among robotics industrial and academic stakeholders on future challenges regarding robotics research and on economic opportunities which is reflected by a solid statistical framework, White Papers and roadmaps. The formation of a joint robotics platform is expected to provide a number of core technologies that can be used in many application domains. European leadership in robotics technology, manufacture and application can only be assured through use of a common platform for the R&D efforts.

No activities are known in the USA that could lead to the setup of a comparable platform. In Japan the emphasis has been on robots that have a structure that is similar to humans – so called "Humanoids". It is, however, judged that this platform is too complicated to control and the benefits compared to traditional wheeled robots are rather limited. 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.

However, Europe has a very strong base in robotics both from an industrial and research points of view. By uniting all the main industrial and academic robotics stakeholders and public authorities around a common vision and approach, the ambition of EUROP is to permit Europe to maintain its leading position in robotics and develop new companies and supply networks to meet the new technology needs. Europe has the necessary ingredients to meet successfully this ambition:

The main strengths of Europe in Robotic Technologies

Leader in manufacturing robotics	**Europe has an innovation-driven and export-oriented industry that has established itself during the last 25 years but is now facing very strong competition from Korea and Japan.**
Fast growing service robotic market	**Europe has a buoyant and exponentially growing service market dominated by high tech SMEs. Some 100 high tech SMEs were created the last 5 years. There are also strong brand names in white goods and domestic services but at present the market leaders are US and Korean.**
Well positioned in	**Europe has many large industries excelling in integrated robotic**

security & space applications	**systems especially for defence and space applications and is thus well positioned for leading the emerging civil security market.**
Several world leading academic teams in robotics research	**More than 200 universities and research institutes offer education and research in robotics. They create an unparalleled basis in qualification and knowledge**
There exist some main robotic networks	**Robotic networks such as EURON[6] and professional organizations such as EUnited Robotics[7] contribute to improve the coordination of European research (EURON) and innovation-related activities in industrial automation (EUnited Robotics)**

Furthermore, for several years now, many 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.

Mission and Governance
So far, more than 40 companies, including both high-tech SMEs and large companies covering a wide spectrum of robotic robots and applications, have endorsed the initiative for a European Technology Platform in Robotics. Annex I provides the list of participating entities.

The initiative will have as its mission to undertake the following activities:

- To drive forward the robotic vision by developing a Strategic Agenda and accompanying technology roadmaps, as well as ensuring their implementation.
- To unite all the main industrial and academic robotics stakeholders and public authorities around this common vision.
- To align the fragmented R&D efforts at Community, intergovernmental, national, regional levels in the European Research Area along the common Strategic Agenda.
- To set up and implement a communication activity to ascertain the key role of robotics in modern economies and society.
- To develop and promote an educational programme that will establish robotics as a major interdisciplinary topic of training.
- To steer the development of new legal structures that might be needed to ensure the effectiveness of EUROP as a public-private partnership.
- To launch an activity to enhance the innovation environment, producing a policy for benchmarks, standards and for open source, providing advice on structural, educational and regulatory matters and stimulating new ventures and markets.
- To link with relevant initiatives outside the EU.
- To build on European strengths in research communities related to Robotics as well as on results from the existing network EURON.
- To promote mechanisms for collaboration between industry and academia in order to favour the transfer of R&D results.
- To stimulate the development of civilian dual use technologies by exploiting synergies between the civilian and defence sectors.

A governance structure for EUROP and the terms of reference of its operations are being put in place. The guiding principle is that the initiative will be open and can be joined by any new European industry involved in robotic activities. The governance structure of EUROP is intended to ensure the realisation of its mission and objectives and will consist of:

6 http://www.euron.org
7 http://www.eu-nited-robotics.net

- A Steering Board, to define and update the Strategic Agenda and oversee its implementation. The board will include decision makers from leading stakeholders from the private sector and academia, as well as representatives from the Mirror Group of Public Authorities.
- An Executive Board, as a smaller executive and operational representation of the Steering Board.
- A Mirror Group, ensuring the participation of Public Authorities at national, regional and European levels in their function as policy makers, regulators and funding bodies. The aim of this group will be to develop synergies between national and European programmes and policies, pool resources to support the implementation of the Strategic Agenda and promote a fertile innovation environment and a state-of-the-art research infrastructure for Robotics in Europe.
- A Group of Public Institutions, to provide decision making support based on scientific analysis and ensuring the participation of the scientific community (public research institutes and universities) excelling in Robotics research.
- An End-Users Forum, including representatives from industrial sectors that are major users of robotics technologies (aerospace, automotive, food, but also security applications), in order to state expectations, requirements, and validation principles.
- Working Groups for specific predefined tasks, either permanent or on an ad-hoc temporary basis.
- An Office that will provide permanent secretarial, operational and public relations support for EUROP.
- An annual event, the *EUROP annual gathering*, to provide the means for all stakeholders of the platform and beyond to interact and discuss progress achieved in the different working areas.

Next Steps

The next important steps will be: to create the so-called “mirror group”, to be composed of all those public institutions and authorities supporting robotics RTD and wishing to participate in the initiative; to form the group of public institutions to be composed of universities and research institutes willing to join the platform’s activities; and, to bring in other relevant actors from the private sector willing to commit to a combined strategy that is, at least, partially funded by private means. In addition, the EUROP Office will be created and the rules of procedure and functioning of the different bodies of the platform will be agreed.

Finally, efforts will soon concentrate on building the Strategic Agenda on the basis of this Report and its Annexes. The agenda should contain an action plan for addressing the major challenges of the platform in terms of research activities, human resources, benchmarking and standardisation issues and financing.

Annex I. The EUROP members

List of entities that have endorsed EUROP

ABB AB	Ansaldo	Armstrong Healthcare Limited	BAe Systems plc
Bluebotics SA	**CEA**	**Cimcorp OY**	**Comau SpA**
CSEM SA	**Dassault Aviation**	**Deltatron OY**	**EADS Astrium**
EADS NV	**Electrolux SE**	**ENEA**	**EUnited Robotics**
Finmeccanica	**Fransys Sas**	**Fraunhofer IPA**	**Genova Robot Srl**
Galileo Avionica	**Hellenic Technology of Robotics**	**Indra Systemas SA**	**Israel Aircraft Industries**
iTechnic Limited	**K-Team SA**	**Kuka Roboter GmbH**	**Neuronics AG**
O C Robotics Limited	**Oxford Technologies Limited**	**Polo della Robotica di Genova**	**PGES**
Philips Electronics NV	**Qinetiq plc**	**R U Robots Limited**	**Reis Robotics**
Remotec (UK) Limited	**Robosoft**	**Robotiker Tecnalia**	**Saab AB**
SAGEM SA	**Seebyte Limited**	**Shadow Robot Company Limited**	**Sinters SA**
SIRI Italian Robot Association	**Telespazio**	**Thales**	**The Acrobot Company Limited**
Trasys SA	**Zenon Automation Technologies**		

The present document has been prepared by:

Giovanni Barontini and Giulio Segurini, Finmeccanica
Albert van Breemen, Philips
Thilo Brodtman, EUnited Robotics
Rob Buckingham, OCRobotics
Henrik I Christensen, KTH
Sakos Ikonomopoulos, ZENON
Rodolphe Gelin and Raymond Fournier, CEA
Chun-Yuan Gu, ABB
Christophe Guettier, SAFRAN
Martin Hägele, Fraunhofer IPA
Lucia Isasi, Robotiker
Ralf Koeppe & Rainer Bischoff, KUKA Roboter group
Bruno Patin, Dassault Aviation
Geoff Pegman, RURobots