European Robotics Forum

European Robotics

A white paper on the status and opportunities of the European Robotics Industry

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Executive Summary

The business potential for robotics is enormous, as already is partly realized in the existing robotics industry. Today European industry produces close to 40% of all systems delivered. The revenue of the EU robotics industry is at present more than 9600 MEuro and employs more than 55000 people in its core business units. Europe has therefore a leading position in manufacturing and use of robotics.

However, the sales figures in the traditional robot markets are tending to stagnate. A number of new markets are emerging both in terms of new areas of manufacturing and in terms of entirely new sectors, such as the service sector. Countries outside Europe (particularly Japan) are undertaking major efforts to identify and support innovative applications in these new markets.

In order to maintain the leading position in the world, it is necessary for the European industry to expand into the new markets, which in terms requires addressing a number of fundamental research and development problems that hinders the rapid deployment of robotic systems in new manufacturing fields and areas of immediate service to the regular citizen.

In this document, a brief summary of the state of the affairs in terms of robotics is presented, followed by the major mechanisms that drive the economic progress. Typical business cases are outlined to provide a motivation for the progress. To enable this progress a number of important R&D issues are identified, and finally a suggested strategy that will allow the EU industry to maintain or expand it market presence is outlined.

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1 Introduction

Automation has played a major role in economic development ever since Henry Ford introduced the assembly line into car production at the beginning of the last century. Over the last four decades, large scale manufacturing has largely been automated to reduce costs and improve quality. A major factor in the setup of automated production facilities has been the use of robots. They were introduced for production around 1960. The early robots systems were based on adaptations of the then emerging Numerical Control (NC machines). Subsequently robots have developed into advanced sensing-control-actuation systems that can be programmed for complex activities.

The introduction of robots into production took place in USA in particular for car manufacturing. The production of robots was also initially confined to the USA in particular by Unimation Inc. Around 1970, the Japanese started to produce robots (Kawasaki Heavy Industries). Early players in the Robotics industry were companies like Cincinnati Milacron, Comau, GEC, Siemens, ABB, Yaskawa, DEA, Fanuc and Olivetti. In a later stage Westinghouse bought Unimation and IBM, Digital Equipment, GM Fanuc entered the promising robotics market. Since many years Westinghouse, Cincinnati Milacron, GEC, Siemens, DEA and Olivetti have ceased or sold their robotics operations. Although the robot technology was invented in the US, the robotics industry of today is located primarily in Europe and Japan. As the computer technology and in particular embedded systems matured, the wide spread use of robots expanded beyond the car manufacturing area to application domains such as assembly, die casting, plastic moulding, conveyer transfer, palletizing, inspection, etc.

As this expansion in application domains took place, the robotics industry also matured and most of the initial actors on the market vanished. The European tradition of high-precision mechanics, advanced control, and sensing systems allowed a number of new players to enter the market. Today, two of the three major robot manufacturers come from Europe (ABB Robotics, KUKA Roboter), with the third one is based in Japan (FANUC). The initial market leadership by USA has gone to Europe with Japan as the second largest. There are a number of large efforts in Europe on robotics including: ABB, KUKA, Reis, Stäubli, and Comau. In total, the EU companies produce close to 40% of the total number of units shipped worldwide (see fig. 1). Consequently, Europe is clearly the market leader in industrial robots today.

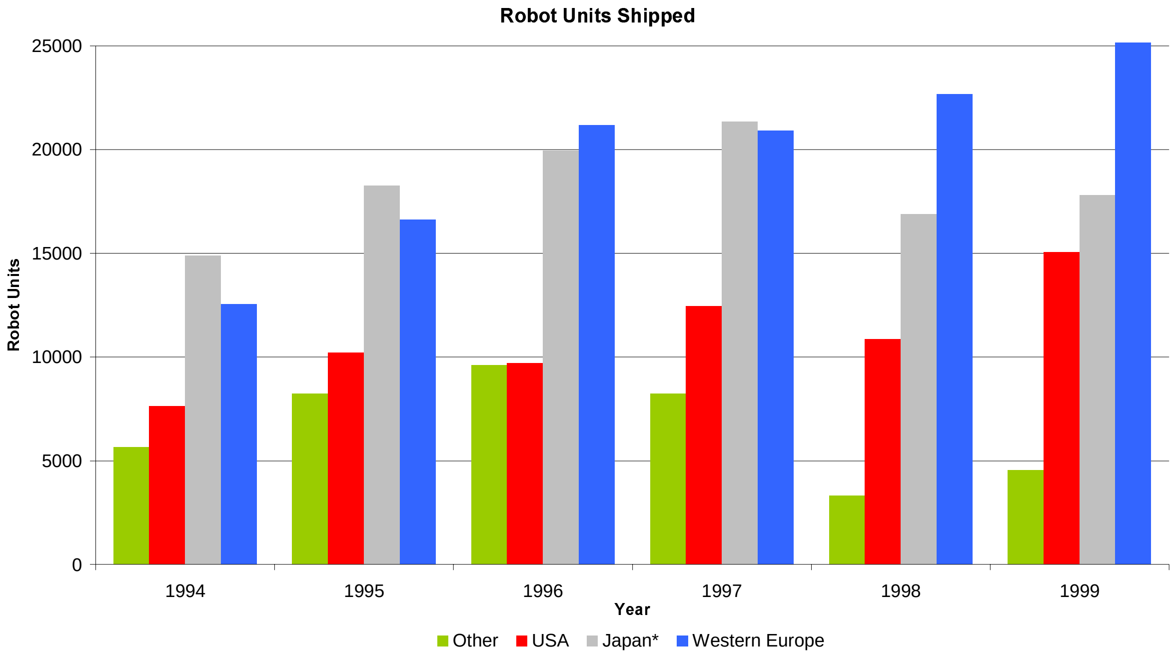


Figure 1: Development in number of units shipped per year over the last 6 years [WR2000]

The economic development of the robotics industry has come about through concerted efforts across the European countries, where the expertise in terms of mechanical systems, embedded systems, process integration, control, etc has been integrated to produce cost-efficient solutions to application demands for large scale production. A key catalyst to achieve market leadership has been international collaboration and far-sighted research on key competencies both in terms of technologies and human resources. This has in part been achieved through EU sponsored efforts in terms of R&D projects.

In this report, the prospects and drivers for economic development are outlined and the key issues that must be address to enable such development are identified through a number of business cases. To remove these obstacles, there is a need for R&D related to a number of basic problems, as outlined in section 4. These issues represent major problems to be addressed and it is judged that no single company will have the needed resources to address these issues on its own. Without a European effort on R&D related to robotics technologies, there is a risk that Europe might not be able to maintain its leadership.

2 Economic Prospects, Market Pull and Technology Push

2.1 Current Situation

The worldwide market for industrial robotics (only hardware) is today estimated to some 5100 MEuro [WR2000], while the EU market is estimated to represent 3200 MEuro [WR2000]. Including software, peripherals and system engineering, the robotics systems market is up to three times as large. This is up to 9600 MEuro for the European robotics system market for year 2000. Major areas of robotics use are: welding, assembly, material handling; painting, machining and palletizing/packaging. The distribution across application areas is shown in figure 2.

Traditionally, the car industry has been the pace setter for robotisation, as they have had a large number of production tasks suited for robot automation. In Europe this involves FIAT, Daimler-Chrysler, Renault, Volkswagen, GM, BMW, PSA, Ford, SAAB, Volvo, etc. Together with the automotive industry, general industrial applications for robots for production of bikes, motorcycles, welded goods, construction equipment, have added up to installed bases almost as high as the automotive industry. Because of the clearly expressed technical needs and purchasing power of the automotive industry, they have been dominating the specifications for the robotics industry.

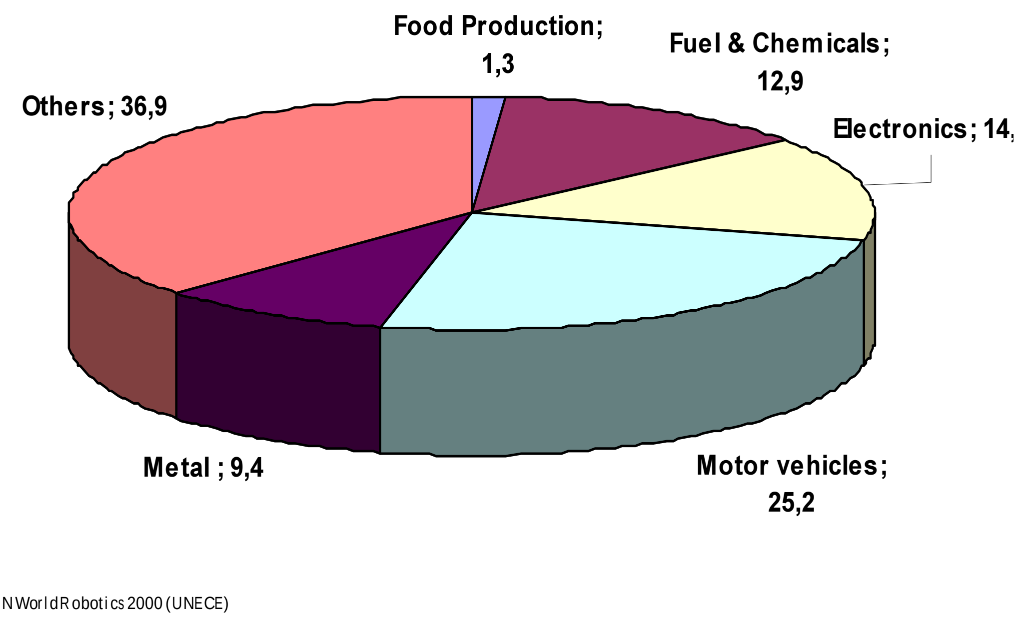


Figure 2: Use of industrial robots in different market sectors by 2000 [WR2000]

Together with the rise of the European robotics industry, a significant sub-supplier structure and a systems integrator business has evolved, altogether employing some 55000 people. This industry involves a significant number of specialised small and medium sized enterprises. Also producers of auxiliary robot automation equipment have expanded with the pace of the local robotics industry. This means that a significant number of persons are directly employed by the robotics producers and their supply and delivery chains.

The European suppliers are successfully competing with Japan on a highly competitive market. The American industry is mainly depending to European and Japanese robot technology except for the application segment where Adept is active. The European robot industry is seeking means to maintain and strengthen this situation.

Robot automation will not only be an extrapolation of a favourable development in existing application areas, but increasingly take a fundamental role in both new industrial applications and as new products for new markets as service robots in public and personal environments (market pull) which in part is driven by the potential of technological developments and trends (technology push). A market pull for solutions where new technologies, tools and system paradigms give automated systems that are more flexible, easier to use – i.e., intuitive human robot interaction and recovery from failures – at a lower investment.

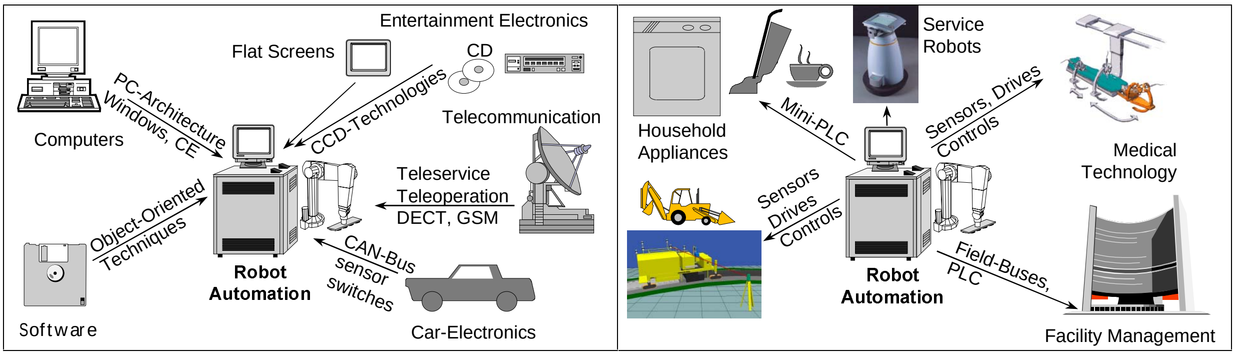


Fig.3: Migration of technologies into robotics from large volume markets (“technology push”, left) and vice-versa: Robotic technology migrates from manufacturing to new application areas (“market pull”, right)

2.2 New Applications and Industries (Market Pull)

a) Industrial Robots

Recently, significant growth areas in robot automation have emerged besides the classical car and electronic goods manufacturing:

- Especially food, consumer goods and pharmaceutical industries benefit from robot solutions for a cost effective and flexible production. There, applications aim at general handling tasks, palletizing, order picking, sorting and transportation.
- Mail order services, airports and postal services increasingly call for robot systems for flexible and reliable logistics automation.

Changing consumer behaviour results in new manufacturing challenges which impose new chances for robot automation which in many cases are associated with new business models:

- Uncertain production volume and uncertain product life-time: Especially consumer goods which have to be produced in large quantities are subjected, due to their increasing association to life style and fashion, to an uncertain market response (examples: mobile phones, household detergents)
- Mass customization: The use of the internet for product ordering and configuration (Business to Customer, B2C) calls for customer-individual products manufactured on demand at series-comparable prizes. Required flexibility in the manufacturing processes favour flexible robot automation.

The concept of virtual enterprises, now a development in the IT sector, will also enter the manufacturing field:

- Manufacturing networks and flexible supply chains
- Production capacity as a service (on demand) for enterprises
- Networked to the customer (up to the vision of a customer controlled enterprise).

Generally, future industrial robot applications require solutions which should open up new horizons concerning:

- Extended flexibility: The ability to adjust to product variants, lot sizes, product life time and processes.
- Agility: A rapid deployment of configuration of manufacturing systems at minimal costs

- Computational intelligence regarding a quality controlled manufacturing, autonomous adjustment to tolerance given by work pieces, processes and material flows.
- Networking: Seamless access to process data and integration into factory control
- Man-machine-interaction promoting new forms of semi-automated operation (hybrid work places, teleoperation).
- Cost-effective operation of assets given a general increase in uncertain product volumes and life-cycles.

b) Service Robots

Service industries (cleaning, maintenance, surveillance, health care etc.) increasingly depend on intelligent aids for better working conditions, improved quality and cost. This development extends to the vision of using robot as commodities in public and in our personal environment.

The western world will experience a significant ageing over the next few decades. This will result in 50% more retired people in Europe and a doubling of the number of people of more than 80 years of age. In parallel, the birth rates across Europe are decreasing, which implies that the workforce will be reduced. To maintain the current level of economic development or improve it, there is consequently a need for more efficient production methods; in addition the ageing society will need new types of services to ensure that the elderly and handicapped can maintain a reasonable quality of life. This will call for improved services in the home and at the workplace. Examples include mobility support, cleaning, logistics, and monitoring. In this area it can be expected that an entire new business sector in terms of services to the citizen will emerge over the next two decades.

At present, the primary developer of such technology is Japan both in terms of academic research (sponsored by MITI) and through companies such as Sony, Honda and Hitachi. Active participation in this domain might generate major new opportunities for economic development. At present, the need is here for basic research that cannot be sponsored by the manufacturing industry or the health sector. In this context, it should be noted that an ageing workforce will depend on intelligent working aids as well. Workers over 50 are considered experienced and reliable, but their physical condition is often characterised by reduced mobility and physical exhaustion. Adequate aids to compensate these limitations will be required to maintain the productivity of an ageing workforce.

2.3 Technology Push

Robot automation is increasingly subject to technical developments stemming from large volume markets as Figure 4 indicates. Large production quantities which are typical for infotainment, automotive and other industries justify the development of cheap high performance hardware (sensors, controls, interfaces) and software as key components of intelligent products.

- IT technologies from these mass markets form the backbone of digital networking between enterprises (B2B), its customers (B2C) or within the enterprise from a management level to manufacturing processes ("vertical integration"). Robots as the most flexible production components take on a central role in a digital manufacturing environment.
- The performance/cost ratio of key robot elements namely sensors, computer-controls and man-machine-interfaces (graphics) has been increasing dramatically thus adding performance in terms of flexibility, robustness and user-friendliness.
- IT systems engineering increasingly enter the manufacturing environment:
    - Platform-independent languages and software-technologies (JAVA, Jini, CORBA etc.)
    - Plug-and run functionality of components
    - Object-oriented technologies for distributed automation with configuration and programming environments
- Prototype-suitable processes will be used and for large series production volumes
- Components and systems will get smaller and more highly integrated towards MEMS (Micro Electro-Mechanical Systems) as intelligent distributed function elements of robots and equipment.

It is obvious that the technology push emphasizes the increasing significance of efficient integration aspects in robotics on two levels:

- The robot system as an embedded system
- Robotics and automation components in an intelligent environment

From this, the necessity arises to define standards or adopt the-facto interfaces with respect to communication, component integration and configuration and use of user-interfaces.

3 Business Cases

To illustrate the current efforts in the robot sector, four different cases are presented here: i) the automotive sector that traditionally has been the strong hold of robotics, ii) the food industry that has a significant short-term potential, iii) SME manufacturing case, that holds a tremendous potential for the European market and iv) the service robot sector that has a tremendous long-term potential.

3.1 Automotive Manufacturing

In today's modern automotive plants, most of the processes concerning the manufacturing of the car chassis in the body shop are highly automated. In the following steps of the production process, however, manual labour does still prevail: in a car factory with a work force of 6000 employees, some 4000 workers may be concerned with manual assembly tasks. According to the estimate of a major European automotive manufacturer, at least 10 – 20% of these assembly tasks can be automated without major changes to the current design of the vehicles. A much higher percentage could be automated if the constraints of an automated assembly process are taken into account already in the design of the vehicle.

The primary goal of an increased level of automation in the assembly of vehicles is not to directly replace personnel by industrial robots. Practice shows clearly that particularly monotonous and un-ergonomic tasks are error-prone when performed by humans. Such tasks lend themselves first to automation. Thus, one of the primary goals in the automation of assembly tasks is an increase in process repeatability and, consequently, product quality.

From a technical point of view, the automation of assembly tasks requires that some of the sensory "intelligence" of the human being is incorporated into the next generation of industrial robots. Vision and/or force information needs to be taken into account when handling work pieces with tolerances in position and geometry. Means need to be provided to program intricate robotized assembly tasks in a simple way. The same holds true for troubleshooting and diagnosis of such complex systems. Generally, humans and machines will need to co-operate much closer than it is common today. This has multifaceted implications from robot control to system safety.

Fig 4. Robots at work in a car manufacturing line

3.2 Food Industry

The food industry employs significant amount of labour for repetitive tasks. Today it is also a significant user of hard automation. Production pace is closer to the process industry where production cycles is in the range of 1 to 10 seconds while the typical cycle time in the automotive installations is in the range of 45 to 90 seconds. Hard automation is well suited under these conditions, however the economic risks for hard automation is high. In a situation where a new product is launched to the market and the production takes place in hard automation equipment, a failure of the new product makes the hard automation obsolete and significant investments are jeopardised. With programmable automation, like robotics, the production equipment can be re-used, the risks reduced and the competitiveness regained.

The primary goal of a higher level of automation in the food industry is - besides the overall demand for cost efficiency and competitiveness - a strive to significantly improve the ergonomic situations where high speed, repetitive jobs cause the society significant costs and the individual severe pain. Over the years, attempts have been made to automate the work by slaughters, milking cows, fish rinsing, cutting sheep etc. etc. so far with limited success. Further development of components and products as well as food industry automation competence and systems skills is needed. The automation need is huge as well as the importance of this industry.

From a technical point of view, the automation of the food industry is limited by the lack of equipment suitable for the production cycle time, the modularity and the flexibility needed with respect to: robots, sensors, grippers and systems layouts. Compared with the automotive industry the food industry typically has less competence regarding the installation, specification, maintenance and running of highly automated production. This implies further needs of systems and products regarding speed, user-friendliness, flexibility and modularity as well as systems and products that can withstand the "wash down" standards and cold areas combined with an extensive competence build-up within the food industry. The need for further technological development to increase the programmable automation of food industry is therefore significant.

Fig 5. Example robots for palletizing and food sorting

3.3 SME Manufacturing

Industries dominated by large, multinational enterprises such as the automotive, electronics, and pharmaceutical industries have been the pace setters for robotisation. Though, a large part of European manufacturing is performed by small and medium sized enterprises (SMEs), and where the large enterprises are demanding more flexible, easier to use automation, this is even more evident for SMEs. The SMEs are often sub-suppliers in a flexible supply chain, and currently the large enterprises are narrowing down the number of suppliers and demanding closer co-operation in R&D and manufacturing processes, which puts increased pressure on the SMEs for flexible automation.

Uncertain production volume, uncertain product life-time, small batch production, large variation and tolerances in work pieces are all aspects to be considered when automating manufacturing processes in SMEs. Great technological advances have been made over the last decade and the price of an industrial robot has in the same period decreased by 50%. Better and more flexible ways of programming robots, and new sensor technologies have broadened the application areas for robotics considerably. These new technologies are of course also available to SMEs, but although a robotised manufacturing system might be supported by an attractive economic calculation, very few SMEs, considering the overall risk, have the financial capacity to invest in such a system. Therefore, there is a strong need to make flexible automation even more economically attractive.

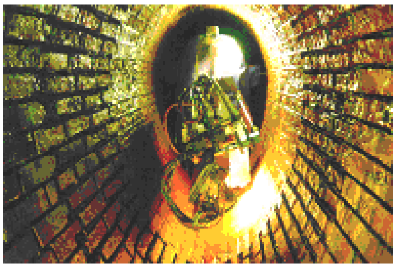
Compared to the large enterprises, the SMEs do not only suffer from a lack of skilled workers, they are also lacking the engineering skills necessary for installation, running and maintenance of new manufacturing technologies. Future robotics therefore has to have standardised and easy to operate interfaces and built in diagnostic devices to ease service and support.

3.4 Service Robots

Since the mid -90ties the potentials of service robots have been widely recognized. In 1999 the total stock of their installation market reached approximately 6.600 units. Some 50.000 installations, not counting household robots, are expected by the year 2004. A survey by the UN/ECE among some 80 European service robots manufacturers confirmed that the majority of the companies offering products and services in the field of service robots are small and medium sized, extremely innovation-driven and very well networked to technology providers such as universities and research organizations. It is to be expected that in the wake of the IT-start-up era, the number of start-up companies in this field will increase significantly in the near future. This will certainly result in a dynamic market of interesting future products where Europe will stand in a tight competition to enterprises from both the US and Japan.

Although service robots are as diverse as the applications they are designed for, three categories can be distinguished:

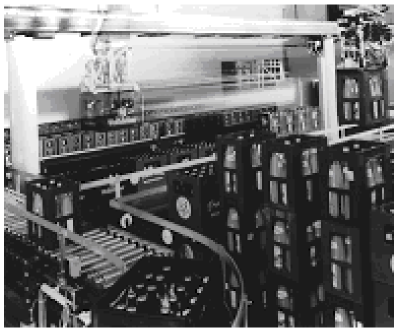
- Modification of classical robots for application outside of the manufacturing environment which is increasingly pursued by robot systems integrators looking for new markets. Examples being refueling robots, automated warehousing or medical robots, where the system basis is deduced from industrial robot technology.
- Service robots such as cleaning, inspection robots often result from the upgrading of specialist existing machines. Here established machine producers use advanced robot technology for the automation of their high-end systems.
- Product designs which are done “from scratch” especially for large volume markets (robot household appliances, entertainment robots etc.)


Service robots as low volume specialists: floor cleaning, sewer inspection, entertainment



Robots as household appliances for large volume markets: Lawn-mover, Vacuum cleaner and tennis ball collectors

Service robot systems based on conventional robot arms: refueling, orthopedic surgery, automated drink terminal

Fig 6. A number of different service robot applications.

In most cases companies have to adopt or built up advanced robot technology to meet the system requirements concerning functionality, cost effectiveness and quality of task execution. The way towards a competitive and marketable system depends on the following factors:

- **Development and system costs**. Contrary to industrial robots, service robots are designed for specific tasks generally taking place in an unstructured environment with the possibility of direct human-machine-interaction. Cost advantages can be achieved by using application-independent components or subsystems with key-functionality. In this context components are both hardware and software.
- **Technical requirements**. Numerous components of service robots can be adopted from industrial robot technology. However, the need for significant extensions in functionality and increased performance of components or subsystems are obvious for many applications:
  - environmental perception and modelling
  - navigation
  - task planning
  - interaction and communication with human and the environment.
- **Safety.** In many cases task execution by service robots takes place in public areas and therefore requires well defined human-machine-interaction. Existing safety regulations are often difficult to apply and may also limit the available workspace considerably.

A large variety of service robot applications with significant installation numbers seem now to be within reach. To address these applications a coordinated and integrated approach to research and development within a network of service robot-users, research organizations, and component- and system manufacturers is needed.

4 R&D Challenges

In general the continued expansion of robotics is expected to demand products and systems that are easier to use, install, program, optimize, and operate. This is equal to reduction of operating costs. In addition to this, new technologies are needed for the deployment of robots in emerging application domains.

4.1 Robot Mechanics, Dynamics and Accuracy

Today, the weight/payload ratio for most robot manipulators is on the order of 10 to 100. The involvement of large masses results in a significant inertia, which makes it difficult to increase speed and at the same time such systems are not well suited for operation in the presence of humans. There is therefore a need for new designs of systems with a low weight/payload ratio (preferably in the order of 1). This requires an entire new approach to design, the use of new types of advanced materials, new actuators (e.g. direct drive) etc.

Robot manipulators with an optimised weight/payload ration will generally be more “elastic”. In some cases, the added mechanical elasticity is also desirable (e.g. to allow operation in cooperation with humans). Such mechanically elastic robots can only have repeatability and performance similar to existing robot through use of sensory feedback in combination with new methods for control.

Today’s robots have an extremely good performance in terms of repeatability, which is one of the major reasons for the significant development in robot sales. One problem is, however, absolute accuracy in the presence of variations in load, temperature, wear etc. To enable progress on absolute accuracy there is a need for improved (model based) methods for control and introduction of new methods for sensory feedback.

4.2 Robust Perception

A major limitation in many of the systems used today is limited sensing capabilities, in particular for handling of non-standard objects such as food. A notorious problem has been lack of robustness in advanced sensing systems such as computational vision. New safety concepts for production environments that allow for a high degree of interaction between human and machine will necessarily rely heavily on input from intelligent sensors. In the area of service robotics the need for perception is equally important for cooperation and coexistence with humans and other intelligent creatures. There is a need for new sensing methods that provide robust 3D information that can be used for control and manipulation. A major issue here is also robust systems that are competitively priced. In addition, new intelligent algorithms have to be developed utilizing the sensor information to improve process output. Such algorithms could guide the robot motion and avoid collisions, provide the operator with robot path scenarios in interactive programming, etc.

4.3 Sensory Feedback, Adaptation and Learning

Most of the robot systems deployed today are pre-programmed to carry out specific tasks using particular objectives such as position, speed, trajectory, … As more flexible materials are to be handled (such as food) there is a need for an added degree of adaptivity both in terms of control and utilization of sensory feedback. Other examples are deburring or assembly operations, where a high degree of adaptivity is needed to handle product variation. Sensory feedback will also be needed in semi-automatic operation of robots assisting the worker in manufacturing environments. This calls for major new methods for adaptive control and (semi-)automatic learning of task sequences. For richer application domains, there is a significant need for combination of sensory feedback with adaptation. In addition, there is a need for utilization of learning methods for instruction of robots as explained below. This issue becomes particularly important in emerging fields such as service robotics, where robots are to be used by regular citizens.

4.4 Human-Robot Interaction

A major bottleneck to more widespread use of robot systems is flexible human-robot interfaces. Today robots are often programmed using dedicated languages that require extensive training of the operator and the level of flexibility in task programming is rather limited. There is here a need for development of more flexible (and intuitive) interfaces that allow use of the latest methods in human-computer interaction for programming and interaction with such systems. In particular, as the market for robots expands into areas with a more diverse labour force, there is a need to have interfaces that can be used after minimum or no prior training. This poses one of the major challenges for robotics.

The programming of individual robots could be significantly improved by supporting the operator by real-time simulation, “virtual” and “augmented” reality techniques. Intelligent online-documentation integrated with the graphical user interface would mean another major step forward. On the plant level, programming of different devices needs to be harmonized and integrated. For example, both robots and PLCs could be programmed in similar ways using a icon-based programming language. Generally, the amount of programming work necessary also needs to be reduced (configuration instead of programming).

A clear need for improved human-machine interaction is also seen in the field of maintenance and diagnosis. Ideally, oncoming failures should be recognized automatically long before they occur and instructions about corrective actions provided to the operator. Methods for preventive failure detection with or without additional sensors need to be developed and their robustness tested. The display of information is most efficient if provided in an intuitive form during the action itself. Again, potential for major improvement through the use of virtual and augmented reality techniques is seen.

4.5 Mobility

By far most of the robot systems deployed today are stationary manipulator type systems. One advantage of such a setup is that the surrounding environment can be engineered so as to simplify the control task. There is, however, a gradual interest in adding mobility to these systems. Today, many such tasks are carried out by AGV's (Autonomous Guided Vehicles). These vehicles utilize artificial beacons as guide wires for navigation in the environment. For general environments, there is however a need for more flexible mobility systems for flexible production systems, but also for operation in other environments such as supermarkets, offices, and the home. It is not immediately obvious that there today are solid solutions available that are economically viable. There is a need for major new research on mobile systems that can be utilized in a wide variety of domains and applications. A major open problem here is a long-term solution in terms of power, which requires new methods in terms of fuel-cells. Fortunately, this is a highly active area of research in the automotive sector.

4.6 Open Control and Communication

The control systems and interfaces provided by different robot manufacturers are proprietary and often specific to the particular business unit. This is an obstacle to integration into process automation and plant level systems which causes considerable cost during setup and configuration. The plant level control is often structured in centralized and hierarchical form, which is less suited for the increasing variability of products being manufactured. There is a need for decentralized and open control systems that allow for flexible integration of robotics systems into integrated production systems and intelligent environments. This may involve the development of platform-independent communication models as well as the use of new technologies (software agents, etc.)

4.7 Business Process Integration

As production systems mature, there is an interest in added integration and JIT (Just-In-Time) manufacturing. To accommodate such needs it is necessary to integrate robot systems with the logistic and economic infra-structure of a business (or home), which provides information that can be used as part of a robots operations and performance parameters can be fed back to the logistics systems and/or the economic planning. This calls for new methods for business level integration of systems, which involves all aspects from communication protocols and control, to planning and reporting. The economic benefit of such integration is, however, expected to be significant.

5 Mechanisms to maintain European Leadership

To ensure that the European leadership can be maintained both in existing and emerging industrial areas, it is necessary to address the issues outlined above. In addition, R&D related to these issues is expected to generate major new market areas both in traditional production and in new areas such as health care and domestic robotics.

Each of the issues outlined above involves deep engineering problems that cannot be addressed by any single company or country. There is a need for a European level R&D effort that can ensure that the present market position can be maintained or expanded. The leadership of the European industry is in many respects due to the foresight in terms of technological development generated by the CEC programmes in the area of IST. To ensure continued growth, it is necessary to set up R&D programmes that address:

- The establishment of pan-European R&D programme that will enable the current robotics companies to embrace the next generation of robotics applications in terms of emerging markets, such as the food industry. Here particular emphasis should be placed on integration across established companies and new small and medium sized enterprises to facilitate integration across the range from sub-suppliers to system integrators. Such integration can only be achieved through an international effort where the best practise across the community can be exploited.

- Setup of long-term R&D programmes that address fundamental problems in terms of mechanical design, perception, control, human-computer interaction and integration. This calls for major new progress in each of the component areas. To this end, an integrated R&D programme on medium term issues in which there is a strong co-operation between academia and industry to ensure developed of fundamental new methods and commercial exploitation of such results. The involvement of academia is equally important for generation of the human resources needed for the continued industrial growth.

- Setup of a programme to address longer term issues in terms of service robotics to ensure that European industry (and society) is prepared for the setup of a new industrial sector in response to the demographic challenge that the society will experience over the next two-three decades.

None of these issues can be adequately addressed by national efforts and at the same time the issues have significant economic impact on everyday life, which motivates the involvement of the Commission of the European Community.

6 Summary

Today, the European industry to a major provider of robotics technology both in terms of industrial manipulators, manufacturing systems and service platforms. The industry has a revenue of about 9000 MEuro and is rapidly growing. At the same time, a number of new market segments are emerging in terms of new types of manufacturing tasks, and a diffusion of technology into everyday life both at the workplace and in the homes. The market is extremely competitive, and it is by no means certain that the European industry will be able to maintain its leadership position in the future.

To embrace the emerging market segments, a number of R&D challenges have to be addressed. These challenges involve all aspects of robotics from mechanical design over control to software systems and integration. Many of these R&D challenges involve deep scientific problems that cannot be addressed by any single company or nation. There is thus a need for an integrated EU effort to address these problems. so as to ensure that the industry can maintain its current market position.

Such a unified EU initiative will enable the industry not only to maintain its current competitive position and generate new jobs and industries that can solidify the economic progress across Europe, but it also has the potential to generate new business sectors in particular in the area of service robotics. A new R&D programme should not only consider the immediate generation of methods for industry, it will also have to consider training of human resources that can be involved in the integration of new technology into a diverse set of domains.

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