EUROP european robotics technology platform

Appendix to:

"Robotic Visions to 2020 and beyond – The Strategic Research Agenda for robotics in Europe, 07/2009"

Application Requirements

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"Robotic Visions to 2020 and beyond – The Strategic Research Agenda for robotics in Europe, 07/2009" can be obtained from:

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CARE
Coordination Action for Robotics in Europe

Application Requirement	Application Requirements Development		
	short-term (~2010)	mid-term (~2015)	long-term (~2020)
sustainability	Satisfy regulations concerning environmental impacts of the production of the robot systems. Underwater: Reduced operation time of support ships through more productive ROVs with semi-autonomous features (eg. manipulation).	Satisfy stricter regulations concerning both the production of the robot systems and the resource requirements of the robot systems at run time. Energy and material optimised robotisation for wide-range of new processes (e.g. powder coating) reduces energy and material consumption (as already proven 30% for the case of painting) Surgery: reusable tools Space: semi-autonomous disposal or recycling Underwater: Greatly reduced operation time of support ships through availability of highly productive ROVs and reliable AUVs.	Adapt design of robot systems (including every aspect such as HW, SW...) to reduce the waste of resources looking at whole life cycle (production of the systems; run time of the systems including the different tasks performed; decommission of the systems). Surgery: reusable smart pills Space: autonomous disposal or recycling Underwater: Minimized operation time of support ships through availability of fully autonomous robots with capability for long-term operation.
	• *Sustainable raw material, Reusable material, optimised material consumption, e.g. coating* • *Sustainable production resources and utilities, reusable tools* • *Sustainability oriented design* • *Low energy consumption for product usage* • *Robotic production etc may help us to be more sustainable by allowing for different type of production*		

configuration	Manual configuration for a specific system or task at setup. CoWorker: Autonomous topologic learning of new environment during manual operation Surgery: Easy positioning of surgical tool on the patient Industrial: Configuration time: 3 days Underwater: Use of specialised tools	Manual configuration is simplified by a deployment tool. The configuration can further be adjusted through adaptation or self-calibration. → Rapid human assisted configuration Industrial: • Use laser scanner :robot calibration and application calibration (changing environment), • augmented reality tools, Plug & Produce hw/sw • Configuration time: 1 day CoWorker: Autonomous semantic learning of new environment during manual operation Underwater: Use of flexible multi purpose tools	SW tools for semi-automated finding and simulating configurations (use Plug & Produce) . Adaptation and self-configuration starts to eliminate the need for manual configuration (i.e., the system configures itself) CoWorker: Learning tasks by watching and asking Surgery: Assembly of complex structure inside the body for complex mini-invasive surgery (track of instrument moving from a part of a body to another) easly positiong of surgical tools (automatically tool changing). Easy configuring of patient position and robot equipment position Real time localisation of object using laser tracking or RFID. SW tool that can read this information and update the virtual environment Configuration time: 1h (excluding manual operation, like drilling for positioning the robot) Use virtual reality to develop/improve the sw tool used to configure /Augmented reality for configurationun Underwater: Autonomous operation of underwater dual arm manipulators on fully autonomous vehicles.
	• *Manual setup of system or task* • *Assisted configuration through manual influence with co-worker, assisted positioning, deployment tool (both SW and HW)* • *Adjustment or self-calibration of configuration* • *Autonomous semantic learning of environment, configuration through copying* • *Self configuration* • *Re-configuration of modular systems*		

adaptation	Adjustment of operational parameters (only software) to compensate for environmental changes. SW automatic configuration already possible for large platforms. HW configuration usually manual. Coworker: Robust obstacle avoidance in every day life environment Security: world model updates under human supervision. Manual hardware adaptations. Underwater: Automatic adjustment of operational parameters on the basis of environment sensors (SW). HW configuration via autonomous tool changing based on the automatic analysis of the task	Automatic adjustment of operational parameters (hardware and software) to compensate for foreseen environmental and task related changes. Post production automation: Semi-automated planning, CAD-based of individual steps Coworker: The robot is able to move cumbersome obstacles Security: Adaptation to unpredictable non-cooperative human behaviour. Underwater: Usage of highly flexible multi purpose tools. Autonomous gripping and tooling strategies.	High level of ability. Both software and hardware can adapt to complex changes of the environment and processes. Ability to detect the need for adaptation without human instruction. Post production automation: Automated planning of individual steps and semi-automated CoWorker: Autonomous collection of information in data base to deal with unknown objects Security: automatic adaptation of an individual robot to a multi robot system. Adaptation to future situations implies prediction capabilities. Underwater: Highly mobile, cooperative and flexible operation of autonomous manipulation vehicles
	• *Adjustment of software parameters* • *Manual hardware adaptation* • *Automatic adjustment of hardware and software parameters* • *Obstacle avoidance* • *Obstacle movement* • *Controlled adaptation under human supervision* • *Adaptation according to multi robot system* • *Full adaptation through autonomous information collection in database* • *Intrinsically stable mechanical systems*		

autonomy	Robot systems can carry out foreseen and pre-programmed tasks autonomously (under human supervision). Transport: Fixed mission defined by supervisor and selected by user for people transport Coworker: autonomous motion in known environments Cleaning: Navigation without beacons in structured but changing environment Underwater: a few days without human/energy; Semi-autonomous manipulation. Space: For 50% of mission time, the robot can operate without commands from ground stations Security: robot can deal with temporary loss of communication.	Robot systems can perform predefined tasks of various timespans and low complexity after human instruction or under human supervision aided through its sensors. Post production automation: Perception to understand structure and deviation from default. Coupling of sensing with automated planning, to carry out well definable steps autonomously. Autonomous transport: Dynamic reallocation of mission with human confirmation in multi-robot environment Coworker: autonomous execution of known tasks Maintenance: Automatic mission definition then automatic execution. Security: robot can deal with temporary/prolonged loss of communication. In case of prolonged loss of communications it can decide whether to continue or abandon the mission Space: For 75% of mission time, the robot can operate without commands from ground stations Underwater: Sustained operation through autonomous energy reloading with docking stations. Autonomous manipulation for complex tasks.	Robot systems can perform complex sequences of tasks in unknown environments without human intervention (neither at setup nor during runtime – maybe some human intervention will always be required?). Post production automation: Coupling of sensing with automated real-time planning, to carry out less well definable steps autonomously (cognition needed). Ability to interactively build up (with user support) upgrade/repair plans (realistically still of lower complexity 2020). Transport: Dynamic reallocation of mission without human confirmation in multi-robot environment Coworker: situation awareness Surgery: autonomous stitching of soft organs Underwater: energy reloading from natural sources. Highly flexible, autonomous dual arm manipulation. Security: Robot operation through high-level instructions or pre-established general missions. Robot can deal with temporary/permanent loss of communication. In case of permanent loss of communications it can decide to continue or abandon the mission Space: Entire mission without commands from ground stations

	• *Autonomous execution of fixed mission, autonomous transport with fixed mission* • *Semi-autonomous with defined interference through human* • *Compensate loss of interaction* • *Pure sensing* • *Sensing coupled with planning* • *Autonomous motion in known environments, autonomous navigation* • *Autonomous motion in structured and changing environments* • *Autonomous execution in flexible environment, stitching of soft organs* • *Autonomous energy supply for defined period of time, e.g. one day, one week, one month* • *Endless energy supply through autonomous recharging, e.g. from natural resources*		
positioning & mobility	Positioning of objects a robot carries and of the robot system (or parts of it) as such is largely based on accurate robot and environmental models. The end point accuracy and the faithful reproduction of the path are achieved through costly modifications of the environment. Mobility is mostly achieved through standard robot arms and mobile platforms. Industrial: endpoint within 0.5 mm, endpoint wide area accuracy 1mm@200k€, path absolute: 1 mm, end point repeatability, local accuracy, path wide area accuracy Autonomous transport: Navigation with fusion GNSS, inertial and video localization or laser localization (with beacon) in structured environment -- video localization after environment learning Position accuracy +/-20cm, speed 8 Km/h, Navigation sub system Cost : 15k€ Cleaning: same as above but +/-10cm and	The positioning accuracy depends less on accurate models, but on perceived environmental features. Propulsion mechanisms will allow the positioning of objects and the robot as such in more flexible ways and with higher accuracy. Less adaptation of the environment to the robotic system is required. Industrial: endpoint within 0.1 mm, endpoint wide area accuracy 1 mm@100k€, path absolute: 0.5mm, end point repeatability, local accuracy, path wide area accuracy Autonomous transport: Navigation with fusion GNSS, inertial and video localization (without beacon) in un structured environment - real time geometric environment modelling with vision in learning phase Position accuracy +/-20cm, speed 15 Km/h, Navigation sub system cost : 15k€ Cleaning: same as above but +/-5cm, speed 2km/h Coworker: localisation with cameras (1cm accuracy)	Multi-dimensional wide area positioning with high accuracy and without the need for any modifications of the environment can be achieved at low cost. Improvements with respect to other application requirements such as adaptation and perception will allow a positioning of robots without the need for environmental modifications. Mobility in any environment is achieved through a multitude of available propulsion mechanisms on all scales at low cost. Industrial: endpoint within 0.05 mm, endpoint wide area accuracy low cost 1mm@10k€/high end 10 um / 50 m, path absolute: 0.1 mm, end point repeatability, local accuracy, path wide area accuracy Autonomous transport: Navigation with fusion GNSS, inertial and video localization (without beacon) in structured and un structured environment - real time geometric environment modelling with vision in learning phase Position accuracy +/-20cm, speed 30 Km/h, Navigation sub system cost : 5k€ Cleaning: same as above but +/-5cm, speed

	1km/h Coworker: localisation with vision (10cm accuracy) Underwater: Improve navigation precision and robustness (when external positioning system fail) Maintenance: 1% accuracy at end effector with artificial beacons Security: - accuracy like autonomous transport - Satellite-based 2D positioning for UGV. - 3D positioning through GPS, differential GPS supported by proper sensors for UAV - Speed motion with dynamic control and landslide management. - Frame with semi active suspension.	Underwater: Efficient relative navigation (precision and robustness) without any external relocalization (no USBL, LBL, GPS) Maintenance: 1% accuracy for position of end effector without beacons Security: accuracy like autonomous transport. - Satellite-based 2D positioning supported by local 2D modelling based on the robot's sensors (UGV).. - 3D accurate positioning through GPS, EGNOS, Galileo (UAV) - Mapping based on data fusion (Vision, INS …) - Active perception (fast reaction with direct relation perception-action). - Obstacle avoidance at nominal speed - Obstacle avoidance at high speed (UAV) - High manoeuvrability in unstructured environment (ex: debris)	3km/h Surgery: Autonomous locomotion for smart pills in biological environment Underwater: Topologic navigation using environment classification (without any geographical coordinates) Maintenance: 0.5% accuracy for position of end effector Security: accuracy like autonomous transport - 3D accurate positioning through satellite, robot sensors, local deployed sensors or radio beacon. - Real-time mapping. - Active perception (fast reaction with direct relation perception-action). - Obstacle avoidance at high speed.
	• *High endpoint accuracy, e.g. industrial accuracy as standard, endpoint accuracy* • *High repeatability* • *Active perception* • *Autonomous locomotion* • *Autonomous transport* • *Navigation through external re-localization* • *Relative navigation* • *Obstacle avoidance*		

manipulation & grasping	Grasping and handling of objects with specific properties: known, rigid objects. Specific application grippers and limited dexterity general purpose grippers Affordable (5k€) multiple finger hand Surgery: 3 degree of freedom tool Cleaining: one hand, rigid objects Maintenance: Dynamic control of end effector at 5cm/s without payload Care: visual servoing with 1cm accuracy Security: - sensor driven manipulation and grasping (e.g. small feedback loop of some kind). Underwater: Visual servoing for semi-autonomous gripping.	Grasping and handling of objects with specific properties: known classes of rigid and deformable objects. High dexterity grippers and general manipulation planning Surgery: 6 degree of freedom tool Cleaning: 2 hand, rigid objects Maintenance: Dextrous grasping of large rigid parts Security: - grasping and handling of known or parameterised objects with full force feedback. Underwater: Integration of haptic sensors in flexible multi purpose tools. Grasping also in (very) turbid water.	Level of dexterity allows the grasping and complex manipulation of all kinds of objects to a level equivalent or better than a human (this includes aspects such as skilful manipulation, speed, precision, strength, scale of manipulated objects, two hand manipulation...). industrial: Handling wires and tubes! Cabling and Un-cabling. Coworker: Extraction of object affordances from grasping. Integrated visual and force based object modelling. Multiple finger tool for mini-invasive surgery Cleaning: 2 hand, soft objects Maintenance: Dextrous grasping of large and deformable parts, manipulation of cables Security: - 2 hands dexterous grasping and handling of known and unknown objects combined with heavy payload. Underwater : Autonomous dual arm manipulation on mobile platforms with flexible mulit purpose tools. Incorporation of several sensor modalities.
	• *Grasping rigid objects with specific properties* • *Grasping flexible objects, e.g. cables* • *Handling rigid objects with specific properties* • *Dextrous grasping* • *3 degrees of freedom* • *6 degrees of freedom* • *Visual servoing*		

robot-robot interaction	Pre-defined / pre-scripted coordinated interaction through a centralised control. Underwater: Data exchange for consecutive missions Security: - Robot-robot: 100MB/s, one robot manufacturer. - Collaborative operations like interchange of data, communication flow, etc. at prototype stage.	Centralised control with limited autonomy of individual robot systems. Security: - Robot-robot: 1000MB/s, communication on instruction set (motion based) only, increase communication between robot mobile platform to form a Team to complete the task. - Hierarchical interaction between nodes with functional limitations of robot systems. Underwater: Robust robot-to-robot communication and limited interaction (e.g. energy- and data exchange)	Collaborative, autonomous operation. Security: - Robot-robot: 10000MB/s, different European manufacturers with communication on instruction level (motion-base), beginning communication on higher level (coordinating jobs on quality and underlying task models, not motion alone) for a restricted set. - Collaborative autonomous operation to improve mission effectiveness through collaborative robotics sensorisation of operating zones. Underwater: Collaborative autonomous interaction of multi-robot teams (heterogeneous and/or homogeneous)
	• *Centralised control* • *Temporary data exchange for installation or configuration* • *Continuous data exchange* • *Functional classification within robot system* • *Hierarchical interaction within robot system* • *Autonomous collaborative operation*		

human-robot interaction	Human interacts with the robot using defined interfaces the human has to learn. Industrial: by language (voice recognition is solved but human has to use certain limited, domain-specific commands) Surgery: based on a priori images Security: - High level remote control (semi autonomous motion with definition of traffic corridor without no-surmountable obstacle). Underwater: Simplified HMI through semi-autonomous robot control (e.g. for manipulation, navigation)	Human interacts with the robot using some "human" channels and domain-specific interfaces. Industrial: by constrained natural language Surgery: augmented reality Security: - Mission motion programming at the beginning of mission and only remote control for mission process (laser designation shoot, feedback vision of area…). Underwater: Direct HMI with exoskeleton	Task programming. In the very long term humans will interacts with the robot like with another human. Industrial: by natural language Non verbal communication / Non invasive brain computer interface / gesture recognition (pragmatic) / Intention recognition Surgery: 360° immersive augmented reality system Underwater: Full virtual immersion control of underwater vehicles with high manipulation capabilities.
	• *Interaction through defined robotic interfaces* • *Interaction through voice with limited commands* • *Interaction by natural human language* • *Interaction through vision* • *Remote control* • *Augmented reality*		

process quality	In some sectors the robot system output is significantly better than human performance, in others significantly worse. Autonomous transport: 90% are delivered in time Surgery:75% intervention completed in robotized mode (by teleoperating, Human assisted): better than human intervention Cleaning: 50% of cleaning job performed by the robot Maintenance: 20% faster than human, same quality as human (to be clarified: maintenance of some structure by a robot?) Security: - Robot systems carry out the most risky, and dirty tasks of the mission but full human intervention is necessary to achieve mission effectiveness. Underwater: Robots are more efficient than humans for operations at large depths. 10% of manipulation tasks can be performed semi-autonomously.	The robot system output is better than human performance in more domains than 2010. Autonomous transport: 95% are delivered on time Coworker: 10% failure in autonomous tasks Surgery: 90% intervention completed in robotized mode. Procedure have to be developed Cleaning: 75% of cleaning job performed by the robot Maintenance: 30% faster than human, 10% better quality than human Security: - High process quality and mission success depends on the combined effort of robots and human operation. 50% of the tasks performed without human intervention. Time reduction at the mission completion. Underwater: Robots are more efficient than humans at all depths. 50% of manipulation tasks can be performed semi-autonomously.	The robot system output is equal to or better than human performance for manipulation robots and for some products from other application scenarios. New processes with unique robot only solutions can often be realised. Autonomous transport: 99% are delivered on time Coworker: 1% failure in autonomous tasks Surgery: 99% intervention completed in robotized mode Cleaning: 100% of cleaning job performed by the robot Maintenance: 40% faster than human, 30% better quality than human Predict real performance on task (99%) 75% of the tasks performed without human intervention. Underwater: Robots are able to perform 90% of all tasks autonomously. Humans are only needed for high-level control and very specific and complex tasks.
	• *Level of interaction/ intervention of human in order to assure process quality* • *Accuracy in delivery time of transportation: 10%, 5%, 1%* • *Process stability above*		

dependability (reliability, safety, security, availability, maintainability, robustness, integrity)	The extent of the fulfilment of dependability requirements is adjusted to the task. Since not all modifications to the process or the environment (in particular with respect to safety) are possible in the context of the task, only certain tasks are feasible. The reliability and availability of the system is often ensured and increased through human intervention. Autonomous transport: Obstacle detection with slowdown speed and stop if not moving obstacle (nominal speed 5 km/h) Coworker: time out on task realisation Maintenance: robustness to lighting changes Security: Failure Detection Identification Intervention and reconfiguration (FDIR) (Currently not on small platforms) Cheaper secure communication Space: FDI but results in delay in mission Transport: Electric propulsion. One day autonomy Underwater: MTBF more than 1 week	Dependability of robot system components is increased resulting in less human intervention and greater robustness. Human-robot interaction is safe without fences. Close human-robot collaboration becomes possible because of this development. Autonomous transport: Obstacle detection with slowdown speed and stop (nominal speed 15 km/h) Coworker: Failure awareness, task interruption, ask for assistance Surgery: as reliable as classical tools Maintenance: robustness to temperature changes Security: Advanced faults prediction and fault tolerant systems. Cheaper secure communication and data protection Space: FDI without delay to the mission (by means of graceful degradation of functions) Autonomous transport: Fuel cell energy – one day autonomy Underwater: MTBF more than 1 month	Dependability aspects are thoroughly considered in the design phase of the robot system. The engineering of such a system for a specific application is much easier as the individual components (i.e., robots and peripherals) have greater dependability. Self-diagnosis and control (structural or motion and parameter adjustment) result in graceful degradation of the system and thus extend the time to maintenance. Autonomous transport: Obstacle avoidance with nominal speed at 30km/h. Operation in city centre environment Coworker: Failure awareness, re-planning of the task Surgery: more reliable than classical tools Security: Prognostic systems, graceful degradation, reconfiguration Self repair and system recovery. Autonomous transport: Fuel cell energy – one week autonomy. Underwater: MTBF more than 1 year
	• *Autonomous transport* • *Reliable regarding task realisation* • *Robust to temperature changes* • *Robust to lighting changes* • *System recovery, system self repair* • *Failure detection intervention system*		

	• *Failure awareness* • *Failure percentage* • *Mean time between failure: one week, one month, one year*		
physical constraints	Robot systems are designed to fulfil market requirements at large. Development of such systems is still costly. Coworker: 50cmx50cmx1m / safe backdrivable mechanisms Surgery: sterilisable tools (2cm) Maintenance: 10m long, 10kg payload Security: - Existent robot designs are adapted according to market needs. Space: sensors temperature range: -40 to 150 °C Space: work towards the following three points where it impacts on robots: • Prevent biological contamination of both planetary and Earth biosphere (bacteria from/to Earth) • Prevent contamination of both planetary and Earth biosphere (chemicals, rocket exhausts, etc.) Satellite designed to minimize space debris by controlled disposal (re-fuelling, docking by other systems, etc.) Underwater: Manipulation requires high power hydraulics on remote operated vehicles (ROV)	Robot systems can be designed to fulfil physical constraints for a specific application (i.e., individual customer requirements), but at great cost. Coworker 50cmx30cmx1m Surgery: 1cm Maintenance: 20m long, 30kg payload Space: sensors temperature range: -40 to 200 °C Underwater: Reduction of required power for manipulation which enables short time operation on autonomous underwater vehicles (AUV)	Robot systems can be designed to fulfil individual customer requirements at economic cost. Autonomous transport: Efficient holonomic translation system Surgery: self sensing 1cm tools Maintenance: 20m long, 100kg payload Space: Consolidated hardware/software engineering techniques to allow employing multiple low-cost commercial processors in place of one radiation-hardened processor. Space: sensors temperature range: -100 to 300 °C Underwater: Further reduction of power requirements for manipulation which enables long time operation on AUV

	• *Economic cost* • *Size: dimension of system, working tolerances, system miniaturization* • *Autonomous transport* • *Payload* • *Self sensing* • *Wireless power transmission* • *Wireless signal transmission* • *Resistance to extreme conditions: peak, range, gradient, cycling (of: pressure, radiation, temperature, vibrations, chemicals)* • *Modular system design to lower the cost and increase the re-use and reliability (spare parts)*

ELS (ethical, legal, social)	Robots and humans sometimes work beside each other and depending on the application without/with fewer barriers. Autonomous transport: Moving in reserved area or private area Extraskeleton to lift objects Surgery: Acceptability by 10% of surgeons of robotized surgical tools. Cleaning: robot works when people are absent Underwater: International Maritime laws for AUVs and USVs. Securtiy: Human and robot work on one mission but on different tasks.	Robots and humans interact and share space with each other, at work and at home. Autonomous transport: Regulation for moving in public area and mixing with pedestrian at reduced speed in specific area Extraskeleton to lift humans Surgery: Robotized surgery taught at surgery schools Cleaning: robot works when around people Underwater: Semi-autonomous underwater vehicles support the exploration and mining of deep-sea resources and reduce the ecological impactAVOID use of weapons Security: Regulation for motion without operator in the motion loop in unprotected area Need of having legal framework for security	Robots and humans manipulate each other. Autonomous transport: Regulation for moving in public area and mixing with pedestrian other vehicle Surgery: Robotized surgery available in 50% of surgical hospital Security: Full interaction between robots and humans forming only one operation group. - Widespread robots acceptance by the public opinion. Underwater: Autonomous underwater vehicles with high manipulation capabilities enable the sustainable usage of deep-sea resources .
	• *Robot active with human being absent* • *Human and robot work beside each other* • *Cooperative work between human and robot, space sharing* • *Full interaction forming one operation group* • *No operator in motion loop* • *Social acceptance of robots*		
standardisation	Safety standards exist for industrial robot applications. Some standards exist or are being developed for service robots. Underwater: For more efficient COTS integration and prototypes developments	Safety standards exist for domestic applications. Some robot components (software and hardware) are standardised and may be used off the shelf for individual robot systems. Autonomous transport: Standard navigation	Standardised robot data formats, interfaces and modules. Surgery: standard robotised surgery protocols. Underwater: For global robots and structures cooperation, space sharing, interactions,

	Securiy: Industrial: - Individual drive train components. - MMI standardization. - Safety standards for robot behaviour and definition of standards for robotics components .including interfaces. User view: SW open source	devices Surgery: Standardized surgery tools for different robots Underwater: For cooperation and robots interactions Security: Industrial: - Standardised European payload (tool and sensors)gear box. - Standardized mounting / dismounting mechanical and electrical component. - Safety standards exist for robotics applications and definition of standards for robotics systems. Programming and Operating of industrial robots is starting to get harmonised (but not in terms of programming languages, but task parameters, languages for task "programming", graphical interfaces).	priorities, resources utilizations, … Securtiy: Industrial: - Cheaper, better, highly integrated robotics systems - Standard protocols for missions and multi robot system architectures. Programming and Operating of industrial robots is harmonised / standardised (?). Try to cover many different application requirements in a uniform way, probably as ISO documents.
	• *Safety standards in different sectors* • *Standards for navigation of robots* • *Standards for inter-robot communication* • *Standards for robotics protocols (for plug and produce) "inter module compatibility".* • *Standards for robotic behaviour (?) from perspective of a user: what are the operation procedures, e.g. in an assembly task* • *Standards for human-robot interaction; standardising the way a user operates a robot and "programs" it* • *Standards for robotic components and complete systems in various application fields (e.g., underwater)* • *MMI standardisation*		