EPoSS
European Technology Platform
on Smart Systems Integration

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Strategic Research Agenda 2009

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Content

›› Preface

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Smart Systems are providing novel, enabling functionalities and are thus already today directly actuating product innovations. Smart Systems therefore are crucial for the competitiveness of companies and entire industry sectors. In a manifold manner Smart Systems development will be decisive for solving the big challenges of mankind related to an aging society, increasing energy demand, environmental problems, etc.

The global demand for highly integrated Smart Systems will increase dramatically in the years to come. High growth rates are particularly expected in the area of medical technologies, mobility and security, and in the consumer and communication sector. The need of higher resource efficiency, reduction of emissions and the increasing demand for "portable" solutions will further stimulate the Smart Systems market. Beyond high volume markets it is the high added value of Smart Systems manufacturing which makes this technology particularly attractive.

Today, European industry is still holding a leading position in the manufacturing of smart systems and products incorporating smart systems technologies. Keeping up with the world-wide pace of technological development - particularly in the light of the dawning economic crisis - requires a drastic increase of investments for smart systems research, not least to counteract the losses experienced in other key technology sectors.

This Strategic Research Agenda, compiled by the partners of the European Technology Platform on Smart Systems Integration, provides insight into envisioned strategic research targets of key European industry players for a timeframe of up to 15 years. The document in hand furthermore constitutes the basis for the envisioned future joint activities in the area of Smart Systems Integration and is thus essential for framing the landscape of Smart Systems research. It coherently evolves from its former version published in November 2007, but taking up current developments and extending the timeframe of the roadmaps.

I like to address my particular gratitude to all contributors from the EPoSS community for having generously provided their valuable input and comments. Last but not least, my sincere thanks are addressed to the European Commission as well as to the national authorities for their ongoing commitment and support of the Smart Systems vision.

›› Executive Summary

The globalised marketplace with its rapidly changing dynamics has brought about an environment of worldwide competition. This environment is influenced and driven by a set of worldwide social, natural and commercial effects, which concern every nation, company or entity. Severe international competition demands rapid product change, higher quality, lower cost and shorter time to market. Smaller and smarter by cross-disciplinary development will be one of the key issues in the future, with smart systems technologies and their integration being a major challenge.

But this competitive environment not only creates challenges. An immense number of opportunities for the expansion of already existing markets or – more importantly - the creation of new promising markets will appear, depending upon the mastering of appropriate technologies. Smart systems integration technologies play here the role of a key enabler. Forecasts show that up to 2020 smart systems applications can reduce 23% of global emissions with an equivalent of 9.2 Gt CO2e[1] by providing smart solutions for energy management and distribution, smart control of electrical drives, and the optimisation of logistic or energy-efficient facility management. This figure is equivalent to an impressive market value of 65 to 70 billion EUR worldwide. In the area of e-health market, one of Europe's' identified lead markets, Europe's market volume is expected to increase until 2020, bringing the total volume of the market to 30Bn within the EU. If this materialises, 360,000 new jobs in Europe in this sector will be created. Again, smart systems integration will be the all-dominant enabler for smart solutions converging medical devices and IT, for high level systems integration, rapid growth in networked applications and the extension of IT support to healthcare consumers.
The evolution of the critical dimension of technologies into the nanometre scale, together with the exploitation of completely new physical phenomena at the atomic and molecular levels has opened opportunities for groundbreaking solutions in bioengineering, environmental control, the human-machine interface, and beyond. The ability to miniaturise and integrate intelligence and new functionalities into conventional and new components and materials is particularly relevant for the implementation of the concept of ambient intelligence and to extend this concept towards 'ambient assisted living' in general. Europe's smart systems manufacturers are in a good competitive position to rise to these challenges. Due to structural and technological advantages, cultural background, rounded education, higher levels of R&D Investment, a strong home base of thousands innovative SMEs and an open business environment , European businesses and individuals are demonstrably highly creative. Process knowledge and application know-how ensure that customers world-wide can expect the best fitting technology tailored to specific needs. European manufacturers enjoy here an excellent reputation. As the result of a high proportion of value-add, smart systems manufacturing industries build upon hundreds of thousand highly qualified jobs, which form essentially the economic basis for the protection and the development of social prosperity in the European Union.

Europe has to turn its outstanding potentials in R&D, its infrastructure, as well as its technological environment, into successful product development in order to maintain its competitive edge. It has to master the key technologies that will allow people, businesses and governments to succeed and to seize the opportunities of the future. Without doubt, innovative technology concepts such as Smart Systems Integration will play a crucial role here.

Furthermore, by using leading edge technologies will Europe be able to strengthen its competitiveness whilst satisfying the core objectives of the Lisbon Growth and Job Strategy.
The essential task of a European Technology Platform is to bring together a wide spectrum of stakeholders, primarily key industrial players, researchers, universities, non-governmental organisations, intermediaries and civil society.

To accomplish this mission a large number of useful instruments are already available in Europe. Firstly the seventh Framework Program, supporting all research efforts beginning with fundamental research, to research for SMEs, the Competitiveness and Innovation Program to strengthen the more marked oriented research ability, and national support programs up to and including European measures for the improvement of infrastructure.

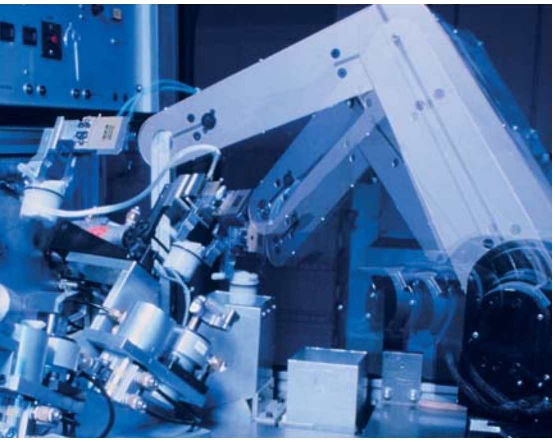
In a number of cases, the scope of the RTD objectives and the resources involved justify setting up long-term public-private partnerships in the form of a "Joint Technology Initiative" (JTI). JTIs aim to achieve greater and more strategic focus by supporting common ambitious research agendas in areas that are crucial for the competitiveness and growth of Europe, assembling and coordinating at European level a critical mass of research – and beneficiaries. They therefore draw on all sources of R&D investment - public or private - and couple research tightly to innovation. The effect is at least to create a single, Europe-wide and industrially-driven R&D programme that will help EU industry to achieve the best competitive position worldwide in selected fields.
The EPoSS stakeholders intend to set-up a European Technology Initiative based on industry priorities. Its primary objective consists in strengthening the technological competitiveness of national and European industry in the Smart Systems sector.

[1] Carbon Dioxide Equivalent

An EPoSS JTI will help to overcome the deficits of the existing fragmented landscape of public support in Europe at the various administrative levels and provide a coherent European R&D approach as outlined in these EPoSS Strategic Research Agenda.

The effect will be to create a single, Europe-wide and industrially-driven R&D programme that will help EU industry to achieve the best competitive position worldwide in selected fields. The JTI will combine a critical mass of national, EU and private resources within one coherent, flexible and efficient legal framework; it will also ramp up R&D investment in Europe by providing incentives to industry and Member States to increase their own, national or company-internal R&D expenditure.

›› 1. The Vision of Smart Systems



Definition

EPoSS is focussing on Smart[2] Systems, defined as intelligent miniaturised technical subsystems with their own and independent functionality evolving from microsystems technology. Smart Systems are able to sense and diagnose complex situations. They are “predictive”, they have the capability to decide and help to decide as well as to interact with the environment. They may also be energy autonomous and networked. Utilising a functional design approach, Smart Systems use properties of devices and materials in completely new ways. Smart Systems are or will be indispensable for the competitiveness of many future products and even entire European industry and business sectors.
Smart Systems can be described as integrated systems, which

- are able to sense and diagnose a situation and to describe it
- mutually address and identify each other
- are predictive and are able to decide and help to decide
- operate in a discreet, ubiquitous and quasi invisible manner
- utilise properties of materials, components or processes in an innovative way to achieve more performance and new functionalities
- are able to interface, interact and communicate with the environment and with other Smart Systems and which
- are able to act, perform multiple tasks and assist the user in different activities.

Such systems are often networked, energy autonomous, miniaturised, reliable and in some cases even implantable. They are becoming increasingly complex, and they involve different technology disciplines and principles. Notwithstanding their capability and complexity, the implementation of novel innovative user-friendly human-machine interfaces will make products using Smart Systems easier and more convenient to use..
New features like ubiquitous connectivity, security, ease-of-use and the integration of mechanical, optical, electronic, biological or more properties through different technologies have yet to be realised fully. Severe international competition calls for rapid product change, higher quality, lower cost and shorter time to markets. Smaller and smarter by cross-disciplinary development will be the key issue in the future, with smart systems technologies and their integration being a major challenge.
The evolution of the critical dimension of technologies into the nanometre scale, together with the exploitation of completely new physical phenomena at the atomic and molecular levels has opened opportunities for groundbreaking solutions in bioengineering, environmental control, the human-machine interface, and beyond. Furthermore, the integration of cognitive functions gives rise to a new concept of converging technologies (Netherlands Bioinformatics Centre). The ability to miniaturise and integrate intelligence and novel functionalities into conventional and new components and materials is particularly relevant for the implementation of the concept of ambient intelligence.

[2] Means mentally quick and original: alert, bright, clever, intelligent, quick, quick-witted, sharp, sharp-witted, but also amusing or pleasing because of wit or originality: clever, scintillating, sparkling, witty and also rude and disrespectful: assuming, assumptive, audacious, bold, boldfaced, brash, brazen, cheeky, contumelious, familiar, forward, impertinent, impudent, insolent, malapert, nervy, overconfident, pert, presuming, presumptuous pushy, sassy, saucy. Having or showing a clever awareness and resourcefulness in practical matters (S.:www.answers.com)

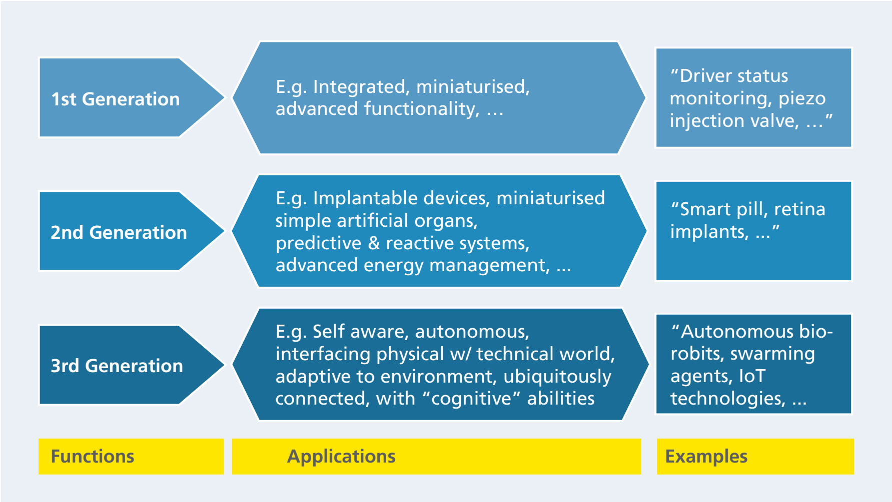


Figure 1: Continuing Revolution of Smart Systems Integration

Micro technologies, nano-effects, smart layers, nanosized components, cognitive functions, together represent an immense potential of new capability. However, they are not application-ready as such, as they have to be designed, integrated, manufactured and tested and in the end – used. The necessary functions of such elements must be selected and connected with the features and functionalitiesof other elements in a safe, reliable, controllable and integrated manner in order to create complex, smart systems with high technical and economic excellence. This is where investment in Smart Systems Integration proves its uniquely powerful place in economic and technical development.
Ultimately Smart Systems Integration will provide the functional connection of components and subsystems at the component level (manufacturing), at the system level (integration into a macro system, or "handling level"), at the application level (integration into the overall system, or "roduct level ") and at the the process level (integration of manufacturing processes including design, simulation, verification and testing).
Without doubt, Smart Systems will redefine the interaction between mankind and technology: Already today, 1st generation Smart Systems, like object recognition devices, driver status monitoring systems and multifunctional devices for minimal invasive surgery, give a first impression of the enormous application potential. 2nd generation Smart Systems like miniaturised artificial organs, advanced energy management systems, and environmental sensor networks will affect nearly all fields of our daily life. And finally, 3rd generation Smart Systems will combine technical "intelligence" and cognitive functions. In the context of the "Internet of Things" they will provide the indispensable interface between the virtual and the physical world.

›› 2. Smart Systems Integration – its Relevance for Europe

Societal

The globalised marketplace with its rapidly changing dynamics has brought about an environment of worldwide competition. This environment is influenced and driven by a set of worldwide social, natural and commercial effects, which concern every nation, company or entity. The outlook for the next two decades includes the following global issues and major drivers:

- sustainable development and climate change
- energy demand - efficient and secure access
- demand for fresh water
- global healthcare
- food safety
- global convergence of information and communications technologies
- the gap between rich and poor
- new security strategies to reduce conflicts and terrorism, and
- democratisation as well as global long-term perspectives
- demographic changes: urbanisation and ageing
- sustainable mobility
- employment in Europe

and others.

Addressing these challenges means retaining and strengthening our competitive capabilities. It means providing answers and solutions regarding to these challenges through developing and offering products and services which are innovative, market fulfilling, timely and cost effective.

Economic

But this competitive environment not only creates challenges. An immense number of opportunities for the expansion of already existing markets or – more importantly - the creation of new promising markets will appear, depending upon the mastering of appropriate technologies. Smart systems integration technologies play here the role of a key enabler.

By 2020, smart systems applications could reduce global emissions by 23%,with an equivalent of 9.2 Gt CO2e[3] by providing smart solutions for energy management and distribution, smart control of electrical drives, and optimisation of logistic or energy-efficient facility management. This figure is equivalent to a market value of 65 to 70 billion EUR worldwide.

The worldwide market for Monitoring & Control products and Solutions, one of the most important fields of smart systems applications, containing solutions for Environment, Critical Infrastructures, Manufacturing and Process Industry, Buildings & Homes, Household appliances, Vehicles, Logistics & transport or Power grids, is around 188 billion Euros. This value represents 8% of total ICT expenditures worldwide. It is identical with the whole semiconductor industry world revenues and approximately twice that of the world mobile phone manufacturers' revenues. The larger sub markets of integration, installation & training services, control hardware and maintenance represent together over 100 billion Euros. Currently Europe represents 32 % of the world total market value[4].

Already, the monitoring & control (M&C) market for Vehicles alone, comprising OEMs' costs for internally produced vehicle embedded solutions, e.g. ABS braking, air conditioning, airbags, automatic transmissions, adaptive suspension, engine control, etc., represents a total of approximately. 17Bn (in 2007). Because of demands induced by global issues as CO2 emissions reduction, hybrid motorisation, electrical and smart vehicles, and traffic management, an annual growth rate of to 5% during the next decade is expected. Smart systems integration will be the all-dominant enabler for pre-crash systems and predictive driver assistance features to reach the goal of the Road Safety Action Plan to halve the number of traffic deaths by 2020.

In the area of e-health market, one of Europe's' identified lead markets, Europe's market volume is expected to increase, bringing the total volume of the market to 30Bn within the EU by 2020. If this materialises, 360,000 new jobs in Europe in this sector will be created. Also here smart systems integration will be an all-dominant enabler providing smart systems solutions for the convergence of medical devices and IT, for high level systems integration, rapid growth in networked applications, and the extension of IT support to healthcare consumers.

European manufacturers are strong leaders in some of the above mentioned applications. In the M&C application field for vehicles or for process industry European companies compete with US and Japanese firms. In other new sectors such as facility management or healthcare, competition is wider. The technology leaders are European, US as well as Japanese based. The above few examples show emphatically the high capacity of smart systems integration technologies to provide solutions for the challenges now facing mankind. Similarly, in other application fields, currently dominated by European players, such as environmental control and sustainable energy, Equally compelling opportunities appear for the application of smart systems integration. Mastering the technologies of smart systems integration is becoming a highly important issue for the future of Europe's economy - these are the technologies which will underpin the provision of innovative, sustainable and economical products and services.

Smart systems integration technologies will leverage and invest further in those key technologies in which Europe's position is already strong and world-wide competitive to provide high added value. The overall value of MEMS based systems; only one part of smart systems, is a typical example. In 2012 the forecast turnover generated by MEMS components will be around 10,5 Bn . However, the turnover generated by MEMS based systems will grow to 77,8 Bn .

A rough estimate for the share of electronic systems in the automotive value chain is 20 percent. Recognising that a major part of this value chain concerns wiring and non-intelligent electronic systems, one can safely assume that a share of at least 5 percent of the total automotive value chain can be targeted by smart systems. This amounts to a market of approximately 34 Bn for smart systems in the automotive sector alone.

Such leverage means that smart system integration technology will be underpinning sales volumes of several hundred billion per year, comparable with the situation as for microelectronics about 20 to 30 years ago. Due to the proportion of value-add in Smart Systems, in contradiction to high technology component-based industries, they support hundreds of thousands of highly qualified jobs, which form essentially the economic basis for the protection and the development of social prosperity in the European Union.

Technical

The evolution of the critical dimension of technologies into the nanometre scale, together with the exploitation of completely new physical phenomena at the atomic and molecular levels has opened opportunities for groundbreaking solutions in bioengineering, environmental control, the human-machine interface, and beyond. These innovations represent

[3] Carbon Dioxide Equivalent

[4] RPA, 2008

Moreover, each of these innovations must be linked with the features and possibilities of other innovations in a safe and controllable, integrated manner in order to create complex, smart systems with high technical excellence.

Due to its role as a linking technology between nano-, micro- and macro-world smart systems integration has become a vital enabling and intermediary function for product development and manufacturing. By establishing and maintaining extensive know-how in smart systems technologies European manufacturers will be able to identify and provide solutions for global challenges, solutions which go beyond the capabilities of components alone.

With this increased know-how manufacturers will not only be able to find solutions to conventional problems; they will be able to use smart systems expertise to initiate new markets featuring innovative new products to challenge established market leaders from abroad.

Smart systems integration technologies for global challenges, solutions which go beyond the capabilities of components alone. With this increased know-how manufacturers will not only be able to find solutions to conventional problems; they will be able to use smart systems expertise to initiate new markets featuring innovative new products to challenge established market leaders from abroad. Smart systems integration technologies will provide European products with the new functionalities and features that are urgently required to compete in a global environment.

European

Without capitalizing on smart systems integration R&D, substantial opportunities in important application fields will be lost; and – as a consequence – a new potential for European market share and economic power will be lost forever.

Within the last few decades examples can be found to illustrate this effect, for example the lost of markets in mass storage devices, displays or brown goods. In every case Europe led in R&D efforts but failed to draw profit from products.

But with smart systems integration, which is based upon expertise rather than simply mass manufacture, the conditions are different. Europe's smart systems manufacturers are in a good competitive position. Due to structural and technological advantages, cultural background, rounded education, higher levels of R&D Investment, a strong home base of thousands innovative SMEs and an open business environment , European businesses and individuals are demonstrably highly creative. Process knowledge and application know-how ensure that customers world-wide can expect the best fitting technology tailored to specific needs.

Despite a high degree of automation, man's know-how is still essential to make the best connections between products and the applications environment in which they are used. Moreover, the conditions under which products are made are becoming increasingly important to the customer. European manufacturers enjoy an excellent reputation in both these matters.

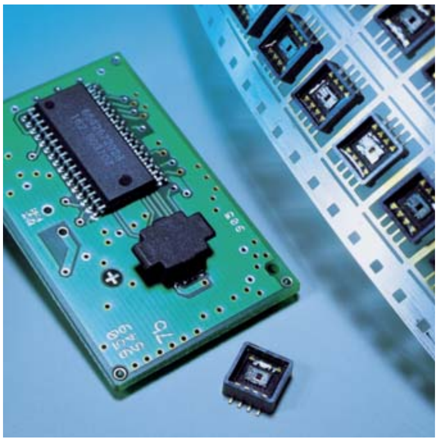
Europe has to turn its outstanding potentials in R&D, its infrastructure, as well as its technological environment, into successful product development in order to maintain its competitive edge. It has to master the key technologies that will allow people, businesses and governments to succeed and to seize the opportunities of the future. Without doubt, innovative technology concepts such as Smart Systems Integration will play a crucial role here.

Efficient production of innovative products and use of ICT is the key to modernising an advanced economy. Investment in smart systems technologies drives innovation and technological progress. It enhances productivity growth and creates new markets and improves business processes. Furthermore, by using leading edge technologies will Europe be able to strengthen its competitiveness whilst satisfying the core objectives of the Lisbon Growth and Job Strategy.

›› 3. Implementation Options

The primary objective of a European Technology Platform is to boost the competitiveness of European companies and Research entities. It focuses on a number of strategically important issues upon which achieving Europe's future growth, competitiveness and sustainability objectives are dependent. It works towards issues with major research and economic impact and high societal relevance, and where there is strong public interest and scope for genuine value added through a European level response.
The ETP's task is to bring together a wide spectrum of stakeholders, primarily key industrial players, researchers, universities, non-governmental organisations, intermediaries and civil society.
To accomplish this mission a large number of useful instruments are already available in Europe. Firstly the seventh Framework Program, supporting all research efforts beginning with fundamental research, to research for SMEs, the Competitiveness and Innovation Program to strengthen the more marked oriented research ability, and national support programs up to and including European measures for the improvement of infrastructure.
All these efforts are useful and necessary to master upcoming challenges successfully, but furthermore new, highly-targeted measures are necessary, especially measures able to activate and synchronise the potentials and capabilities of European private companies with those of public entities.
In a number of cases, the scope of the RTD objectives and the resources involved justify setting up long-term public-private partnerships in the form of a "Joint Technology Initiative" (JTI). JTIs aim to achieve greater and more strategic focus by supporting common ambitious research agendas in areas that are crucial for competitiveness and growth of Europe, assembling and coordinating at European level a critical mass of research – and beneficiaries.
They therefore draw on all sources of R&D investment - public or private - and couple research tightly to innovation. A JTI may become operational by setting up a Joint Undertaking under Article 171 of the Treaty.
The effect is primarily to create a single, Europe-wide and industrially-driven R&D programme that will help EU industry to achieve the best competitive position worldwide in selected fields. A JTI will combine a critical mass of national, EU and private resources within one coherent, flexible and efficient legal framework; it will also ramp up R&D investment in Europe by providing incentives to industry and Member States to increase their own, national or company-internal R&D expenditure.

›› 4. Technology Challenges



During the last two years the research community has been very active in the field of Smart Systems Integration and recent endeavours show a consolidation of research activities around major campuses that attract academic teams as well as industry research.

These are changes in the European research landscape that consolidate in order to cope with the most important challenges: heterogeneity, complexity and multidisciplinarity. More than ever, innovation lies at the frontier between different areas: physical scales of phenomena, disciplines, hardware and software, micro technologies and neurosciences, heterogeneous association of materials… a revolution is on its way and Europe is strongly poised to take full benefit thanks to its intrinsic diversity of cultures and its understanding of how to draw them together.

Technically, smart systems are still driven by the progress of manufacturing processes and especially by the rapid growth of technologies that provide systems manufacturer with new low cost functions for implementing intelligence in their products and creating added value for the customer. This evolution is illustrated by the rapid adoption of 200 mm platforms by Microsystems foundries (ST Microelectronics, Silex, Freescale, Bosch) in response to the accelerating adoption of Microsystems by consumer market domains such as automotive, mobile communications and consumer devices.

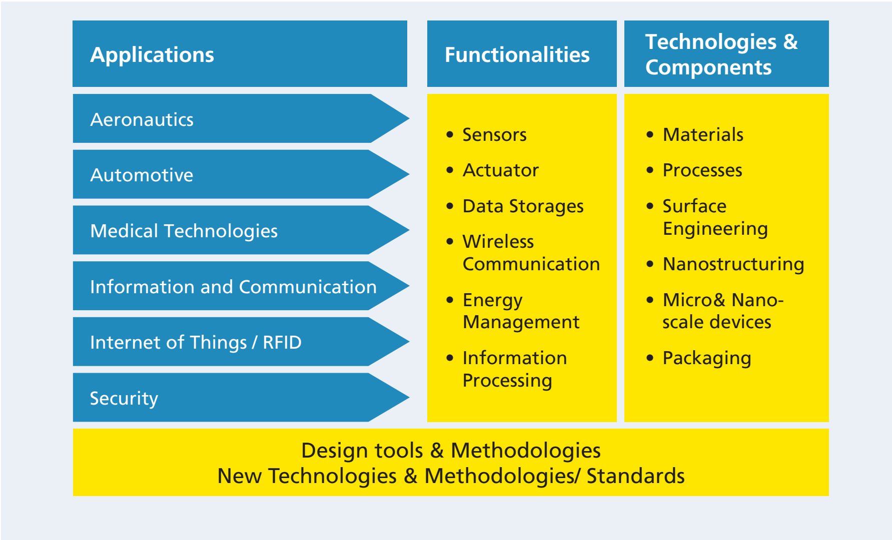


Figure 2: Smart Systems Application Fields vs. Technological Portfolio

Core Technologies & Enabling Functionalities

In addition to the development of generic technologies by the microelectronic and the Microsystems industry new technologies require special attention:

- are able to sense and diagnose a situation and to describe it
- Specific materials and associated fabrication processes such as ceramics, glass, polymer and meta materials are enablers for low cost or high performance solutions
- The developments of new functions thanks to the emergence of nanoscale objects such as nanopowders, carbon nano tubes, nano wires and Nano Electro Mechanical systems are still slowed down by the difficulties of embedding them in large scale systems using collective processes that comply with reliability, cost and volume requirements.
- Smart systems still require advances in packaging techniques where the progress of advanced semiconductor techniques must be associated with new solutions for integration into specific environments: flex technologies, functional packages for high temperature applications, biocompatible layers for implants and in vivo systems, energy absorption layers for smart devices embedded in mechanical parts, and many more, as chips escape from the circuit board to the real world at large.
- Design tools and methodologies that allow a quick evaluation of the best solutions to provide intelligent functions in complex cross-disciplinary systems are still missing
- Smart power management: The autonomy of smart systems depends upon their capability to scavenge energy from their environment, to store it and to make an efficient use of it. Energy sources for scavenging techniques range from PV to heat through EM and vibrations. For miniaturised systems where form factor is the main constraint nanostructures are the main priorities for research: nanomaterials and nano layers such as super lattices for thermoelectricity, multi layers of nano materials for multi spectral miniaturised PV cells and nano structured surfaces for low voltage high efficient mechanical harvesters. Storage techniques include ink batteries, micro batteries, supercapacitors, and micro fuel cells where the use of 3D nanostructures and nano materials are mandatory for energy density optimisation. Energy management will be of the essence for both ultra low power (wireless sensor) and high power conversion systems (power semiconductor). Advanced control algorithms will depend on the designers' ability to mix analog and digital IPs into IC circuits and their knowledge of the physical behaviour of each component and subsystem.

The ability of new intelligent systems to process information is not enough: efficiently coupling this ability with decision making approaches based on data processing or data fusion algorithms, on advances in data structures and upon the knowledge of each application environment will require a long term investment in generic technologies and ambitious applications scenarios.

Finally, smart systems will benefit from advances in security solutions driven by the smart cards industry and in reliability. Combining hardware miniaturisation and physics of failure knowledge, smart devices will be able to diagnose degradation linked to determine whether failures ares catastrophic or parametric and thus to provide lifetime forecasting. Reliability has also to be guaranteed from the viewpoint of security subsystem.

Key Functions for 2012 & beyond

Over the past few years global trends of the economy coupled with the progress of science and technology has led to the emergence of new social needs, new requirements of public bodies for managing large infrastructures and to new expectations from industry. As a result of these converging forces we believe that new topics need to be addressed as major issues for the next decade:
Energy conversion systems will enable the development of energy aware solutions for transportation, heavy industries.
Smart power monitoring will allow the efficient use of energy in consumer products as well as in electronic goods and equipments. Biological and chemical sen-

sors both in gas and liquid phases will address health, environment and security issues.The emergence of smart fabrics and large area low cost printed systems will address body-worn functions as well as smart sensors for the built environment. Finally, the convergence of imaging techniques in multispectral domains with the capacity of embedding optical and signal processing functions directly into detector arrays will favour the emergence of multiple new applications in various application fields such as security, building automation and transportation.

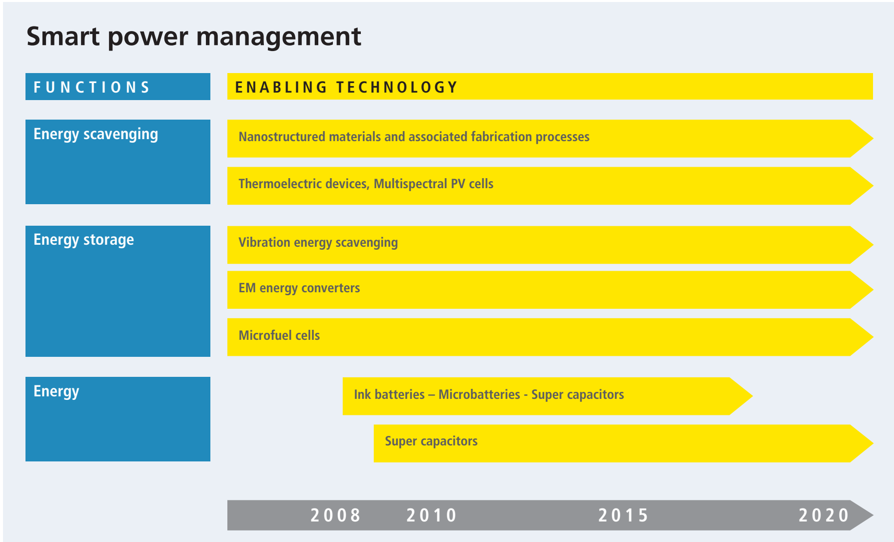


Figure 3: Smart Power Management Roadmap

	Medtech & Healthcare	Internet of things	Telco	Security	Aeronautics	Automotive
Energy Conversion		Green ICT	Green ICT		All electric Plane	Hybrid & electric Vehicle
Smart power management	Wireless Implants & autarktic sensors	Wireless sensor networks	Power management			Wireless sensor for smart road Air quality monitoring
Chemical & biological sensing	Point of care systems Breath analysis			NRBCE detection	Cabin Air quality	Power train control, air quality monitoring
Printed systems	Flexible	Low cost RFID	Low cost antenna systems	Smart clothes	Maintenance fleets	
Smart textiles and foils	Smart clothes & home monitoring			First responder safety		
Vision systems	Photosensors for fluorescene		CMOS imager for mobile phone	All in one camera		Pedestrain detection

Figure 4: Application Fields of Smart Systems vs. Key Functions

Energy conversion systems

The increased energy needs of the global economy have dramatically increased the attention of systems manufacturers for energy efficiency: the European automotive industry is now committed to Hybrid and Electric Vehicle roadmaps, the rise of PV systems for powering professional and private building calls for optimised power converters, and heavy industries are now convinced that optimised power control of electric equipments may reduce by up to 40% the power consumption of their manufacturing facilities.
Power conversion systems will be facing three main challenges in the future: the development of industry compliant wide band gap semiconductor materials (SiC, GaN,…), the design of new architectures of power converters and, finally, innovative solutions for packaging and thermal management on system level. These three topics will generate specific integration challenges at both technological and system levels.

- Technology integration will focus on specific technologies for wide bandgap devices (doping, contacts, MOS gate), partial and total SOI, dry deep silicon etching, thin wafer technology for power vertical devices, vertical conductive vias and 3D interconnects, wafer bonding, deposition of specific materials (dielectrics, piezoelectric, high K, magnetics) and 3D wafer level packaging.
- As far as system integration is concerned the following topics will be prioritised: wide bandgap devices (SiC, GaN, diamond), intelligent power switch integrating control and protection function, galvanic insulation, thermal management, DC-DC integrated converters with passives devices (inductors and 3D capacitors), high temperature drivers, energy sources and energy scavenging.

Particularly, regarding the integration of new materials in power management applications, SiC and GaN will fully take advantage of the intrinsic added-value of wide bandgap semiconductors technology over Silicon. SiC device technologies have been installed in the power electronics arena since 2001. GaN technology, coming from blue LED and laser diode development, could be an alternative to SiC. The first commercial prototypes have shown a 30% reduction in cost over the same SiC device. The opportunity for progress in GaN-based power electronics is significant.

The positioning of SiC devices in the Silicon Scenario mainly refers to high-voltage, high-temperature and high-frequency applications. In this sense, new packaging solutions, considering active cooling solutions, and new isolation techniques have to be addressed to fully take advantage of the outstanding properties of this material. In addition to the wide bandgap nature of SiC, its mechanical properties, its chemical inertness and biocompatibility could be also relevant for smart system based devices and systems that have to work under harsh conditions (automotive, aeronautics and space, etc.) and biomedical applications.

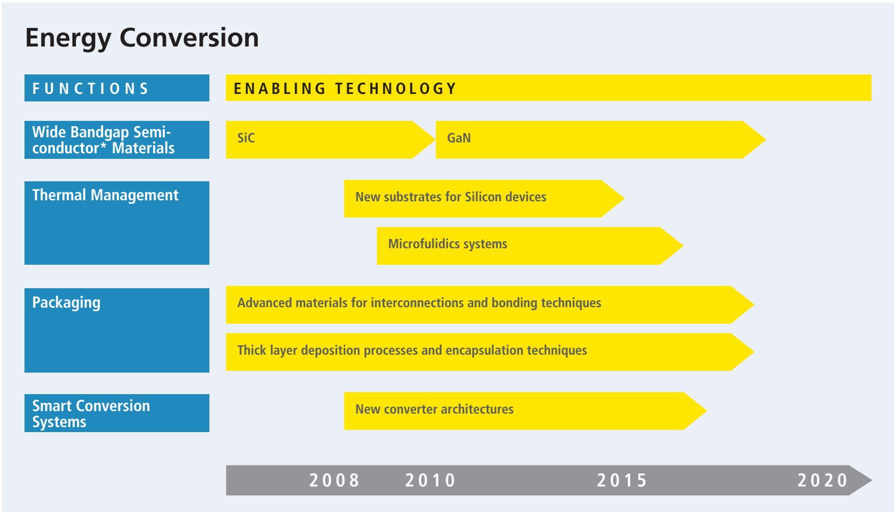


Figure 5: Roadmap of Energy Conversion Smart Systems

Chemical and biological sensors, analytical systems

Developments in the past have focussed on miniaturised chemical sensors and multi-sensor systems. In the field of gas sensing a lot of work has been devoted towards developing novel kinds of sensing materials, notably metal oxides and gas-sensitive polymers. In these materials-science investigations, a general trend towards nano structured sensor materials can be observed. A wide variety of MEMS micro heater technologies has been developed to enable low power consumption gas sensor arrays. Further progress into the direction of low power operation has been achieved by employing heat pulse techniques with pulse durations ranging in the millisecond domain. Applying methods of multivariate signal analysis to the multi-sensor outputs, a multitude of miniaturised electronic nose-type systems have been developed and demonstrated.

Research on fluid monitoring devices has largely focussed on classical devices such as SAW (surface acoustic wave) or silicon-based devices such as ion sensitive field effect transistors, electrochemical multi-electrode systems, flexural plate wave devices etc. Interesting developments involve devices building on wide-bandgap semiconductors such as diamond or GaN.

Wide-bandgap semiconductor devices offer wider electrochemical windows, higher stability in harsh environments and lower noise than similar Si-based devices. Sensitivity to stimuli other than pH has been achieved by employing surface functionalisation techniques involving the grafting of relatively small molecules up to complex bio molecules such as proteins and DNA. Further enabling technologies for fluid monitoring devices are microfluidic components (microchannels, microvalves, micropumps…). iThere is usually a performance gap between MEMS-based miniaturised sensor systems and high-performance laboratory instruments.

The reason is that low cost sensors often build upon different sensing principles than those used in laboratory instruments to achieve a specific monitoring functionality. For instance, arrays of inexpensive metal oxide gas sensors with a wide cross sensitivity profile are used to sense gases and vapours in remote locations. With regard to performance such miniaturised low-cost techniques compete only weakly with highly specific spectroscopic techniques such as gas chromatography, ion mobility or mass spectrometry. This per-

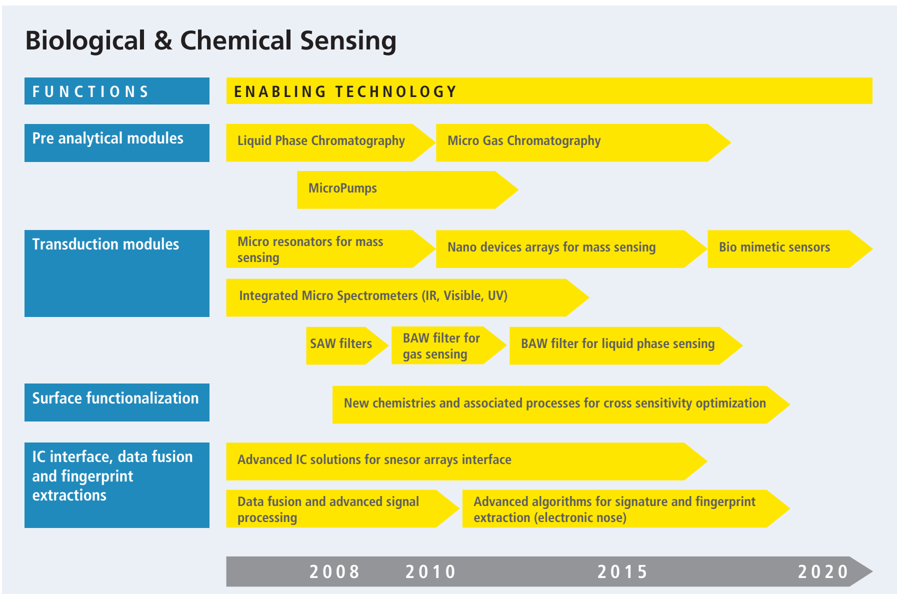


Figure 6: B&C Sensing Roadmap for Smart Systems Integration

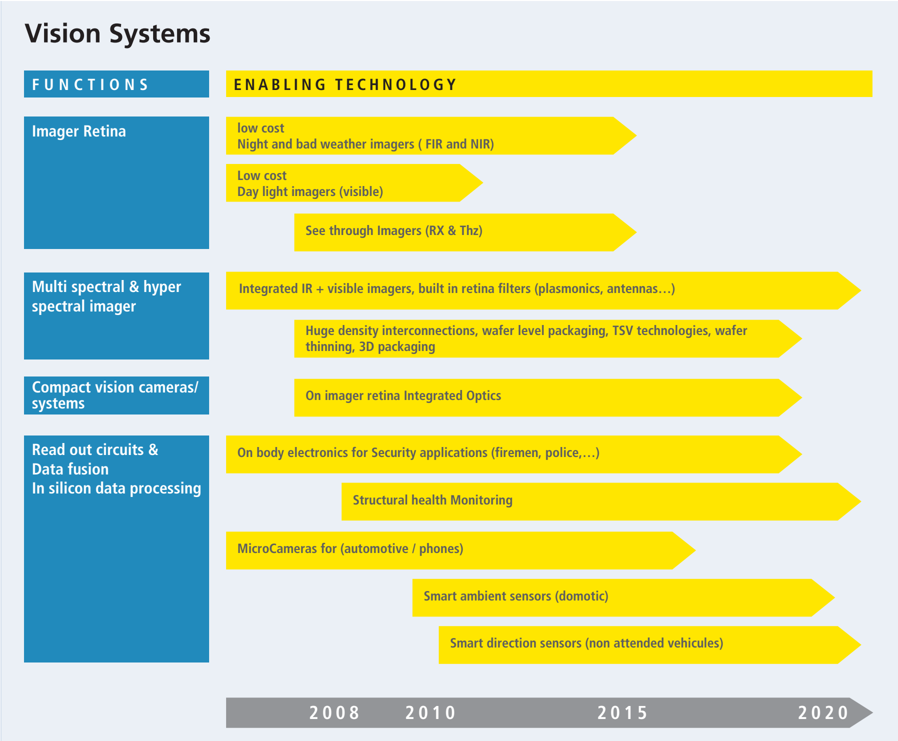


Figure 7: Smart Vision Systems Roadmap

formance gap and the disparity of underlying detection principles often presents an acceptance barrier that prevents miniaturised sensor technologies to be applied in applications traditionally served by much higher-performance but also bulkier, heavier and more expensive laboratory instruments.Currently there are three major trends in the development of smart analytical chemical sensor platforms: compact and reliable chemical analytical systems based on micro-spectrometry approaches (physical-optical/chemical), autonomous distributed analytical systems (sensing / actuation / communication / self calibration), and RFID tags including chemical sensors. All three topics aim at satisfying requirements on the robustness, size, cost and energy constraints that are imposed on analytical systems that increasingly need to be operated for prolonged periods of time in remote locations without the intervention of trained human operators.

Vision sensors

Nowadays electronic imaging is widely used. A long journey has been made since the first movies were recorded using CCD cameras and today, where CMOS imager technology in synergy with memory and computing technologies has opened a wide range of applications. The most significant market is the mobile phone: with a 1.1 Billion units forecasted in 2009, it represents more than 80 % of the image sensor total available market.

Although originally based upon frame acquisition (image displayed on a screen) CIS (CMOS Image Sensors), the market is now also expected to grow in accordance with new applications that require a large number of dedicated imagers per system. For example, for automotive application, pedestrian detection can be addressed using infrared imaging. The infrared image is then displayed on an LCD display. As a matter of fact the driver can hardly interpret in real time the infrared frame. Thus today, R&D work needs to be performed so as to embed scene analysis software within the camera head system - with the objective only to output the meaningful information in terms of activating the correct warning. This new imager trend is called smart imaging. The ultimate architecture is not yet fixed but a promising approach may be a neural network. This architecture is based upon a frame acquisition that is not displayed but that is analyzed via neural network layers in order to generate useful system commands.

Professional imaging (medical, space, security & defence, industrial inspection) represents also a large turnover even if the total quantities are much smaller. US and Japanese companies are quite strong in this field but European companies still remain competitive and need to develop their R&D in order to remain worldwide players. This activity requires ongoing innovations in order to improve mainly electro-optic performances in the whole spectrum ranging from X-rays, UV, visible IR and now terahertz and also hyperspectral and multispectral imaging.

Applications addressed by image sensors are broad and cover from medical diagnostic imaging (e.g: x-ray imaging for cancer detection), non destructive testing for industrial inspection, multimedia, and ultimately body-worn electronics (firemen, battlefield soldiers…).

For security purposes (chemicals, improvised explosives and concealed weapons), detection over the whole spectrum from x-rays up to terahertz is needed to acquire corroborative information. It is mandatory in this case to make data fusion in order to ensure both fast screening and very low false alarm rates. Good understanding of the data content and efficient software are both still needed.

In addition to computing science, new sensor technologies still need to be developed. For example, terahertz imaging is quite new and the terahertz detectors that already exist require ultra cooling and are still monolithic. A 2D real time room temperature terahertz image sensor is still missing and R&D work still needs to be performed to achieve terahertz imaging and spectroscopy.

For multimedia and domestic applications, cost and compactness are the key drivers. Current pixel sizes can be as small as 1.4 µm x1.4µm. Lowering the pixel size is a cost driver. However, going under 1µmx1µm pixels with current pixel architecture is not compatible with physical limits. It is becoming a real challenge to detect the photons while decreasing the pixel size. The electronic industry needs to perform R&D on new pixels in order to continue decreasing pixel size. The same trend is foreseen for non-visible imaging.

Also the complete technology stack will need to evolve (from polyamide filters that are becoming too thick up to the optic system that will need to allow minimum z dimension while ensuring zoom and autofocus functions). In order to address such challenges, built-in-silicon data processing will also need to be considered. The image sensor needs to be addressed as a whole – smart systems approah including imaging pixel, optic & data processing.

Finally, for all the applications, the imager of the future needs to be very compact, with embedded intelligence, cost effective to manufacture and last but not least very low in power consumption. Finally other topics are emerging as major issues for the future. Brain-Computer Interfaces will revolutionise neuroscience and will impact man machine interactions in many applications ranging from diagnosis, consumer products as well as mobility and ambient intelligence. On a shorter term basis, new generations of Electro Magnetic sensors will be required to monitor power systems and to complete studies on the interaction of EM Waves with living tissues.

As a summary, the EPoSS research priorities can be clustered into: technologies, functionalities and methodologies. Technologies and functionalities need to be combined to build innovative smart systems. Methodologies are the process-oriented dimension which encompass applications as well as technologies and functionalities. The following list identifies selected R&D topics of high relevance for Smart Systems Integration:

Technologies

- Materials (Si, SiC, SiGe, non-Si semiconductors, ceramics, polymer, glass, textiles, etc.)
- Nano-scale devices (surface functionalisation, nano-electromechanical systems e.g. sensors/resonators/arrays, nano-characterization tools and methodologies)
- Technologies for micro/nano-scale inte¬gration (wafer-level packaging, 2,5/3D integration, heterogeneous integration)

Functionalities

- Sensing (nano-sensors and MOS-detection devices, multidimensional sensing technologies like sensor arrays, data-processing including data fusion and model-based techniques, low-power platforms)
- Energy (advanced energy scavenging techniques, energy storage, energy management etc.)
- Communication (Micro- and nano-devices e.g. filters, nano-resonators, RF-MEMS, antennas, EM modelling and simulation, low-power components, wireless networks)
- Human-machine interface and visualization (µ-displays, flexible displays, carbon nanotube displays, large-area display technologies, speech recognition and communication)
- Security (low-power cryptography,
- Privacy

Methodologies

- Design tools and approaches (system-level modeling and design tools, multidisciplinary and multi-scale design tools e.g. from system to IC design and mechanical functions, from large-area to nanoscale through macro-, meso- and micro-scales, knowledge management)
- Manufacturing techniques (reliability, equipment, process management including e.g. data-flow management and manufacturing floor planning)
- Simulation of multi-domain systems and components at all levels of abstraction
- Standards, Robustness, Quality and reliability.

Thematic priorities

The following chapters present an overview on R&D priorities within a technological horizon of ten to fifteen years. These named research topics and areas were defined with the objective of achieving European added value in terms of strengthened economic competitiveness and benefits for European society due to the rationalization and renovation of product portfolios across European industry.

The application fields which are most relevant for smart systems applications in Europe are automotive, aerospace, information and telecommunication, medical technologies, the Internet of Things, Safety & Security. These chapters outline the need for the specific priorities along a timeline including technological requirements to reach the set goal. Where appropriate, a preliminary roadmap is presented.

›› 5. Smart Systems for Automotive Applications

The automotive industry represents 3% of Europe's gross domestic product and 8% of EU government's total revenues. The vehicle and equipment manufacturers provide employment for more than 2 million Europeans and support an additional 10 million indirect jobs in both large companies and SMEs.

The importance of the automotive industry is reflected in a number of high-level policy initiatives, such as the European CARS21 scheme, to which EPOSS relates in accordance with the EUCAR and ERTRAC guidelines on the critical research sectors necessary to sustain this European sector's competitiveness.

The automotive sector is the largest R&D investor in Europe (20% of total manufacturing R&D) and constitutes a major driver for the development and diffusion of new technologies and innovations throughout the economy.

Stronger European partnerships and visions are required to face the challenges raised by a growing dependence on primary energy, primary materials (steel, aluminium), by societal demands, particularly in terms of the environment and road safety, and by design innovation in functionaslity whilst avoiding negative side effects:

Fatalities: Despite the pledge in the 2001 to cut Europe's 57,000 fatalities by 50% before 2010, today more than 40,000 still meet their end on Europe's roads in car accidents every year. Road accidents are the main cause of death in the under-34 age group. Microtechnology has already played a substantial contribute to reduce fatalities from 600 to less than 200 fatalities per million vehicles, but to pursue the long term perspective of zero fatalities new considerable efforts have to be given to develop a higher level of smart sensing and actuating devices that can assist and anticipate the driver's actions in dangerous situations.

Congestion: 1% of Europe's GDP is wasted in congestion.

Total Oil Consumption and Emissions: Transports represents 73% of oil consumption in Europe[5]. The current efforts to improve the efficiency of Internal Combustion Engines are impressive; Europe is at the front-head of all major results in this area with the highest efficiency diesel, gasoline and gas engines.

Transport is responsible for more than 26% of green house gas emissions in the EU. The progressto reduce this has been impressive and with a further EU target of 120 grams per kilometre by 2012 (-25% from the current level), as testimony to this intention. By the middle of the next decade 120 g/km average emissions will be called for, continuing further towards 95 g/km and less in the decade thereafter[6] (Similarly, noxious emissions are expected to decrease by 80% from 1997 to 2010). EPoSS envisions the development of novel smart integrated technologies to enable a radical reduction of critical oil dependence and emissions. In short, by Smart Integrated Systems EPoSS is aiming for continuous prosperity by breaking the link between growth in transport capacity and the increase of hydrocarbon dependence, pollution, congestion and deaths.

Significant efforts will continue to be planned to develop smart systems:

- to enhance traffic safety with a long term vision to achieve zero fatalities on European roads,
- to improve the interaction between driver and vehicle as well as passenger comfort and the driving experience,
- to improve the efficiency of conventional internal combustion engines so that gasoline and natural gas engines could become as efficient as diesel, and diesel as clean as gasoline and natural gas engines.

The focus of EPoSS also addresses the development of smart systems enabling a quicker move to the era of full electrical mobility. Smart Systems are the key enabling technologies to meet and exceed the obligations to make Europe a low carbon economy by 2020: Following Commissioner Janez Potocnik's observation that"..making the European transport industry greener, safer and smarter can actually boost our industrial competitiveness" by reducing Europe's greenhouse emissions by 20%, generating 20% of Europe's final energy use from renewable sources and increasing energy efficiency by 20%[7].

[5] see also: Janez Potočnik, European Commissioner for Science and Research, "Making the European transport industry "greener, safer and smarter" to boost our industrial competitiveness", Transport Research Arena Opening Ceremony, Ljubljana, 21 April 2008 (SPEECH/08/211)

EPoSS is dedicated to deliver all the technologies, processes and components needed for highly innovative smart vehicle systems that can make an advantage out of the current adversity.

Aims

The multidisciplinary integration of technologies and competences addressed by EPoSS call for comprehensive approaches beyond the capabilities of single components –the challenge of Smart Systems Integration.

Figuratively, sensors and actuators are the nerves and arms, and controllers and power semiconductors are the brain and muscles of smart vehicles.

The ever stringent demands on safety and comfort have led historically to a continuous adding-on of new functionalities with an average 15% weight increase of all car segments as well as a growing electrical power demand at an average of 100W/year over the last 17 years. Up to 5 km of wiring, 80 - 100 sensors, 50 - 80 processors, 80-100 actuators are common in cars nowadays.

The application of smart electronic engine control strategies with a processing power approaching one billion instructions per second and microtechnologies for precise multi-step fuel injection and air control has allowed continuous improvements in fuel efficiency of 1% per year over the last 20 years. Thanks to that, and in spite of the increasing energy demand, the goal of emissions reduction below 120g/km before the 2012 has already been met by several EU vehicles.

A comparable rate of growth in processing power is more and more experienced also in the forthcoming real-time integrated multi-spectral and multi-functional vision systems for safety and driver assistance.

In comparison with the consumer and the industrial sectors, the automotive domain has much more stringent specifications which have to be combined with higher demands upon long term supply, integration level, innovation and cost pressures.

Building as it does multi-disciplinary technologies, approaches and specifications demanded, EPoSS automotive is set to be a reference for advanced micro- and nano- technology developments in general. The priorities of R&D in smart systems for automotive applications are clustered into: safety, driver assistance and convenience, smart power trains with a focus on enabling technologies for full electrical vehicles, and cross-over technologies. Rather than continuing the logic of add-on functionalities with add-on components, EPoSS is addressing a pervasive approach aiming at a global resources optimisation and overall system simplification.

Research Priorities

The research priorities are clustered within EPoSS into: technologies, functionalities and methodologies taking up the general challenges formulated by the European automotive industry. Technologies and functionalities need to be combined to build automotive systems. Methodologies are the process-oriented dimension to createapplications as well as technologies and functionalities. The research priorities in the automotive sector can be divided into five areas of particular interest:

safety, driver assis-tance, convenience, smart power train and cross-over topics.

- Safety includes active and passive vehicle systems to protect the driver and the passengers as well as other road users. The major R&D objectives for the next 15 years are:

Driver information on vehicle dynamic limitations (e.g. traction, curve speed, ground clearance); adaptive human machine interface (HMI) systems to interact with the driver based on the specific situation; a personalised safety system adapted to characteristics of the individual (e.g. weight, age, size); driver drowsiness monitoring to sense and predict dangerous driver situations (e.g. sleep recognition); pedestrian protection systems including reacting and avoiding strategies; collision mitigation systems to automatically reduce impact severity; emergency braking systems for unavoidable accidents; vision enhancement systems including night vision and blind spot monitoring, and vehicle interaction systems to allow cooperative driving using car to car and car to infrastructure communication.

- Driver assistance is support to the driver in guiding the vehicle. Consumer demands, technical limits, and legal issues all require the driver to retain full responsibility for the vehicle. Taking account of the human ability to deal with complex situations, a synergetic solution aimed at extending

	Consumer	Industrial	Automotive
Temprange	0°C to 40°C	-10°C to 70°C	-40°C to 80° …150°C
Humidity	Low	Environmental	0% to 100%
Product life time	6 - 18 months	5 to 10 years	Up to 15 years
Tolerated failure rates	Below 5 - 10%	Below 1%	<< 1ppm

Figure 8: Comparison of requirements for consumer, industrial and automotive systems

[6] see above
[7] Proposal for a Regulation of the European Parliament and of the Council: setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles", Com(2007) 856 of Dec. 19, 2007

driver abilities is the midterm perspective for vehicle control. The major R&D objectives here are:

Lateral and longitudinal vehicle guidance systems (including lane-keeping and lane-change support, ACC stop & go, and ACC for urban areas); later, semi-autonomous driving for defined situations (e.g. automated parking, automatic following and guided driving); personalised driving based on individual driving patterns, constitution, and appropriate vehicle adjustments; active load-management systems controlling chassis systems and the suspension based on the weight distribution in the vehicle; adaptive human-machine interfaces for situation specific interaction (using e.g. force feedback, HUD and speech recognition systems), and adaptive light projection systems for a better illumination of the vehicle's forward scene (using, e.g., turning lights, projection, automatic high beam).

The objective is that the adaptive technical systems provide optimal driver support taking account of vehicle and driver capabilities and characteristics. EPoSS will build upon networked functionalities using numerous sensor inputs to collect information, (shared) computational power to analyse and interpret situations and decide on appropriate measures, and a variety of actuators for operations to assist the driver in a smart and situation-specific way.

- Convenience addresses secondary driver and passenger requirements (beyond vehicle guidance). Convenience is one of the major decision factors for vehicle purchase. To feel good in a car, first of all the vehicle has to be safe. Therefore appropriate warnings and automatic interference for safety critical situations is one of the major R&D objectives. Secondly, a car should fulfil the transport requirements – maybe a challenging demand for an increasingly crowded traffic scenario. Individual dynamic routing and supporting overall traffic measures will address this issue.

Automated secondary functionswill include, for example, non-fogging windscreens, anti-dazzle systems and automated light and wipers, user-identification systems, adaptive control elements and human-machine interfaces (including situation specific interaction, scalable and auto-adjusting vehicle control elements), a personalised environment creating a feeling of comfort and convenience (including e.g. audio separation, personalised surfaces, adaptive climate, forming seats and air conditioning), advanced multimedia systems based on wireless communication and digital broadcast technologies.

EPoSS aims follow a user centric approach, it is not the user who will adapt to the car or learn how to operate the systems, instead the vehicle will adapt to the user's needs and capabilities.

In terms of both Safety and Convenience a first example employing the EPoSS approach will be a multi-functional smart system device based on CMOS technology integrating several functionalities such as lane warning, pedestrian detection, and road-sign detection while keeping the ability to detect crossing vehicles, the status of incoming traffic, tunnels, bridges, mist, fog, rain, and ambient light intensity and operates as controller of several actuators.

Networking architectures and related processing with sensors mounted at different locations around the vehicle to detect different areas in a multi-stereo and multispectral approach at both visible and infrared wavelengths could make it possible to reconstruct the road environment and obstacles, thus providing the basis for novel safety, driver assistance and convenience functions. Micro-optics with novel materials, micro-mechanics, microelectronics, advanced packaging, advanced processing (data fusion) and wireless communication links underlay such on-going developments.

- Smart power train addresses the overall objective of a clean and powerful propulsion system. The R&D objectives are: To develop a clean power train by, for example, high pressure direct injection and exhaust after treatment, smart energy strategies (including integrated starter /generator approaches, regenerative braking, and route planning), alternative fuel concepts (based on the use of natural gas, synthetic and bio fuels, hybrid vehicle concepts and hydrogen), adaptive power train solutions (e.g. scalable engines, self calibration and active friction avoidance), comprehensive energy management taking into account all loads, and active wheels (to concentrate different functionalities like drive, braking, steering, suspension and diagnostics in a wheel system).

Especially, the last objective of an active-wheel concept, or the so called "quarter car", demonstrates the power of a smart systems approach – changing the perspective to solve vehicle requirements in a new context by exploiting advanced technologies. The concept is illustrated in the "quarter car" assembly of Figure 9, including suspensions, tires, and the actuating systems for steering and braking functions with related sensors.
The integration of smart actuation and of networked sensing systems will allow the complete control of a vehicle's dynamic behaviour. Electric actuators integrated into the wheel/suspension system will provide efficient and clean traction, completely controllable, with regenerative braking capability in the active wheel. The vehicle control system and the driver will have a real-time detailed awareness of the vehicle status in every driving condition through the distributed sensing network.

These capabilities, coupled with a network of external sensing and communicating systems will provide a natural integrated platform for the development of personalized, autonomous driving functions, enabling the capability of managing vehicle interaction with the external

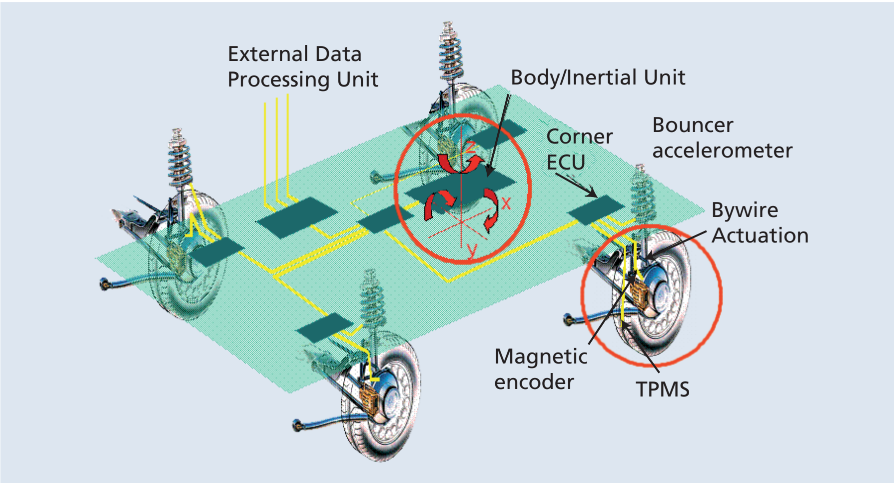


Figure 9: Integrated smart actuators and sensors for the comprehensive "quarter car" control. Essential element to enable Efficient Fully Electrical Power trains as well as advanced safety and convenience concepts.

world, including obstacle and pedestrian avoidance. The quarter car can then be considered an essential element both to enable Efficient Fully Electrical Power Trains as well as advanced safety and convenience concepts.

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Before 2020 a large share of mid and large sized vehicles are very likely to continue to be powered by Internal Combustion Engines "ICEs" for which the current research roadmaps aim at more efficient diesel engines as clean as natural gas or gasoline engines and, vice versa, natural gas or gasoline engines as efficient as diesel engines. ICEs will continue to be a crucial area of competitiveness that will require a higher degree of integrated Sensing, Processing and Actuation. With the number of sensors increasing from today's 12-15 to over 30 in a few years, an integrated approach including wireless and autonomous sensors/actuators will be necessary to handle the complexity.

The focus of EPoSS' SRA is to provide a framework for Smart Integrated Systems enabling efficient Full Electrical Vehicles (EVs). EVs, due to their zero local and potentially minor green house gas emissions, are considered the cleanest option. Of even higher importance are the opportunities that, EVs provide in terms of efficiency and flexibility in the use of energy. Taking into account that in Europe 73% of all oil is consumed by transport, the introduction of EVs should be a first priority for savings of the most critical source of primary energy.

Interestingly, the broad introduction of EVs should not even be an issue for utility providers and grid operators: Estimating the energy consumption of an EV to be about 140Wh/km (e.g. for a mid size vehicle) and taking into account on average 10.000 km travelled per year, it can be stated that 10 million vehicles would require 14 TWh of energy which is just a small fraction of the annual electricity output of an EU member state. The use of on–board solar cells could further reduce this percentage.

Leveraging mass use of EVs however is currently facing several weaknesses amongst which are: limited driving range, high cost and overall limited efficiency. For the most part of these issues, solutions may be found at the level of the subsystems for energy storage, electric power train, and energy management. As demonstrated for the internal combustion engine previously, it can be expected that smart system technologies combining novel microsystems and advanced ICT solutions will be the key enabler for the required gain in performance. The key functional blocks of an Electrical Power Train are shown Figure 10

The energy-power from the accumulators is first DC-DC converted to a higher voltage then by a DC-AC inverter is efficiently coupled to the direct drive motor, which in its most advanced implementation and can integrate a magnetic gear for adaptable torque transmission and be integrated in the wheel. A high degree of system intelligence is required for an efficient bidirectional energy-power flow both from the energy-power sources (accumulators-solar cells-range extender) to the wheels and during braking from the wheels to the accumulators. All elements will need their own process management and connected by a smart sensing network to continuously adapt their operation for maximum efficiency and minimum use of energy.

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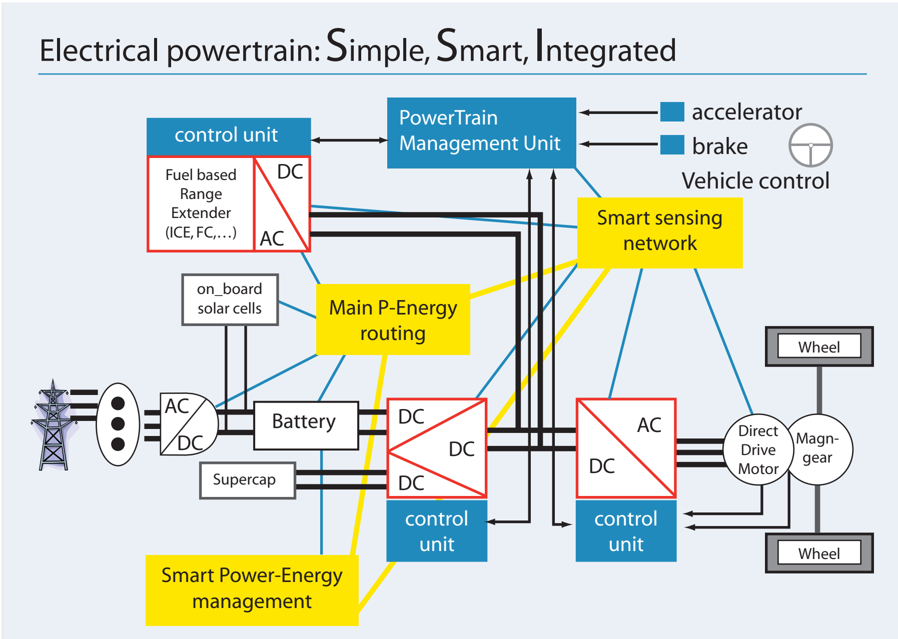

Figure 10: Key elements of the electrical power train including the option of a fuel based range extender and on-board solar cells.

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Smart Systems for the Management of Energy Storage Systems

Beyond the relatively small energy density of the single battery cell, which today is the biggest roadblock for the EV, the integration of cells into a battery pack is an important issue particularly concerning safety, cost, manufacturability, diagnostics, maintenance, repair and recycling. Solutions for these challenges may be found in both passive measures (e.g. pakkaging and thermal management) and active measures for electrical monitoring and adaptive control.

The R&D identified and classified as most urgent is in the domain of energy management system architectures and fast active switching elements, as well as the establishment of evaluation and testing standards.

Continuous Advancement on smart Power/Energy Management Systems of accumulators will be required, integrating functionalities for the determination of the value of the battery, failure diagnosis, cell equilibration and crisis management, thus providing safety for the full life cycle of the battery including the end of life, and advanced functionality such as energy/power routing and ECU communication. Priority R&D needs to be addressed at the earliest possible instance to include the development of an ageing model and measures for the protocol of ageing, as well as for energy deploying circuits. Operating at the global level this would help with the choice of accumulators, or it could be applied to a combination of batteries and supercapacitors, and at the local level of single battery cells the R&D could provide a new way of extending the battery life.

Further key R&D needs are globally the development of charge and discharge algorithms, and locally the application of power electronics for monitoring and switching individual cells.

Intelligent Power Electronic Devices

Power electronic devices of importance for the electric vehicle include DC/DC converters, inverters for the main drive and the auxiliaries as well as battery chargers and vehicle to grid connectors. Development of these devices faces challenges due to the high currents and temperatures which they have to withstand. Intelligent solutions for such issues are a particular property of smart system optimisation.

The most important and most urgent R&D topics include thermal management (i.e. sensing, cooling, the use of thermally stable materials like SiC and/or GaN), pakkaging technology, the development of passive components, and the voltage/current rating of semiconductor devices. Additionally, integration vs. partitioning of modules has to be considered.

Three distinct technologies will continuously evolve to higher and higher degree of smartness: Power Switching Components, Power Electronics with Partitioned Intelligence, and Local Level Power/Energy Routers.

Power Switching Components are characterized by their power loss at a particular frequency. Their critical functionalities include reliability and failure management properties like for example failure prediction, self diagnosis, shut down processes, and self healing capabilities. R&D needs refer to materials, module development, failure prediction, degradation conditions, advanced deterministic concepts, fault-supporting topologies, and design for test.

Power Electronics with Partitioned Intelligence will require balancing between intelligent and deterministic algorithms and thus requires special design approaches. Local Level Power-Energy Routers are characterized currently by the integration of passive and active devices which may lead to a sophisticated and costly interface. R&D requirements include, for example, an intelligent strategy for control at local level.

Active Control Units for Electric Motors & Wheels

Electric motors significantly affect the performance of a vehicle, e.g. regenerative and electric braking, full torque at all vehicle speeds, and the opportunity to distribute the power between several motors, if wheel motors are used. Making use of these properties requires active and adaptive control measures that take into account the driver's intentions, the state of the road and the state of charge of the battery, that is, a full range of functions optimised by smart systems technologies.

The most urgent general R&D needs are related to the weight, torque density and cost efficiency of electric motors and to packaging. A further need is in modelling, which in the midterm may lead to architectural optimization of electric drive trains as well as to new measures for vehicle health monitoring and fault diagnosis.

Smart Traction Control Units for Vehicle Dynamics (as part of the quarter car concept) are very likely to be used in higher performance EVs. Their functionalities include good torque controllability over a wide speed operating range, high torque density, high efficiency and low cost as well as regenerative braking, anti-lock braking/traction control, and fault diagnosis and tolerance. Foremost R&D needs for such smart systems cover the investigation of robust traction control techniques, power quality and stability studies of the vehicle's electrical systems, the analysis of safety critical failure modes and the understanding of their consequences, methods and tools for health monitoring and fault diagnosis as well as measures for compliance with EMI/EMC and power train safety standards.

Smart Integration of Range Extenders

The need for long-haul driving, even though representing just a minor fraction of the standard drive cycle in Europe, is considered a key functionality for user acceptance of alternative drive trains. Given the range restrictions of batteries, advanced electric vehicles will be equipped with a range extender that recharges the battery if needed. Such range extenders may be highly-efficient internal combustion engines or fuel cells possibly assisted by solar panels. Managing the efficient use of the range extender, one has to take into account various parameters including the state of charge of the battery, the driver's intentions, the traffic situation etc. Thus, also calls for smart system solutions.

The most important and urgent R&D needs associated to the integration of range extenders are smart system based solutions for energy storage management and strategies for integration. In view of the two most apparent range extender technologies, R&D related to plug-in batteries and to effective internal combustion engines (taking into account exhaust standards) are required. Generally, the effective use of range extenders requires information exchange on the availability of power. Smart systems that will play a role for the integration of range extenders into the EV are the Energy Management Assistant and an On Board System optimising the generation and accumulation of Solar Energy (smart photovoltaic or simply photovoltaic in motion).

The Energy Management Assistant, aimed at minimizing energy consumption in regular use, should have energy routing capabilities and should be aware of the availability and limitations of power. Other key functionalities span a range from an HMI based trip planner (allowing e.g. the alteration of plans) to thermal control of the internal combustion engine and its after treatment devices. R&D is required particularly in the area of con-

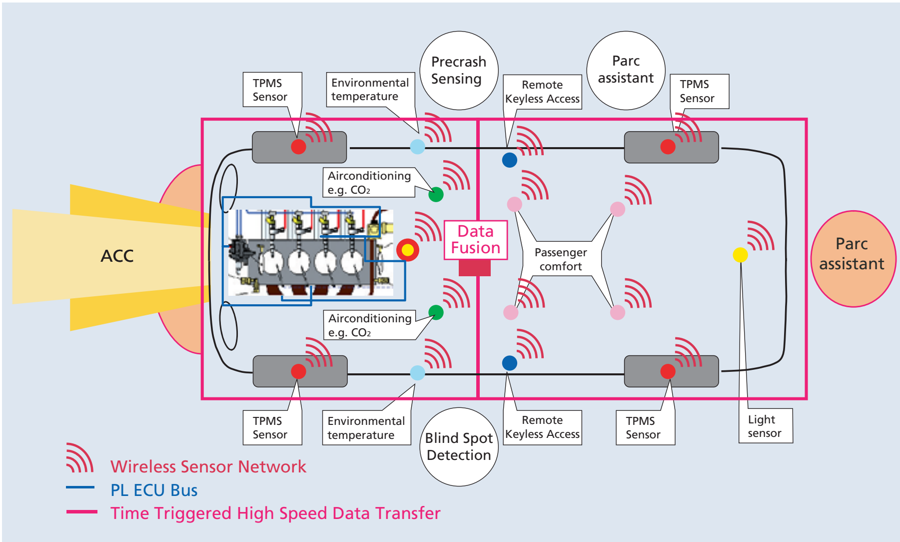

Figure 11: Future applications of smart wireless devices in automotives

troller topologies, interface parameters, data management and the application of advanced control strategies. Furthermore, some research on assessment criteria (NEDC) is needed.

The On Board System optimising the generation and accumulation of Solar Energy is a system that will be called for as soon as solar cells can be used on board the vehicle, i.e. probably in about five years from now for the first significant commercial introduction. An interesting functionality would be a direct link from the solar cells to the grid, and in terms of life cycle considerations, it would be good to match the lifetimes of solar cells with those of the electronics. R&D is required particularly in the domain of non-planar solar cells that can be applied to the car, in the area of electronics integration, and in general strategies for the use of solar power asking for instance. which to charge, the battery or the super capacitors. Research projects on these topics should start as soon as possible.

Advanced Vehicle to Grid Connection Systems

The Vehicle to Grid (V2G) concept adds functionality to the basic charging and metering capabilities of a power plug by allowing bidirectional routing of energy between the battery and the (smart) grid. This way, batteries can be considered part of the grid that in peak times may be available for power regulation. A V2G system has to anticipate and be aware of the user's charging needs and the state of the grid, and thus would be a smart system providing both new functionality and new business opportunities at the interface between the car and the energy supplier.

General R&D needs related to V2G systems cover mainly three areas: the development of basic control algorithms and appropriate hardware, research in user acceptance, and the development of new business models at the interface of vehicle and grid including leasing concepts for batteries and life cycle cost sharing between the EV owner and the utility company. All these topics are considered being of high urgency, and thus have to be considered at the earliest possible instance. Two smart systems for the V2G connection can be envisioned: an On-board and an Off-board Charging and Metering devices.

The On-Board Charging and Metering Device will enable the integration of plug-in hybrid vehicles into the grid. It shall be equipped with navigation aids based on

GPS and with wireless communication connecting the device to the computers of the grid operator. This will enable the device to identify which utility is running the nearest local power plug. In addition, the On-board Charging and Metering Device will combine metering and charging capabilities with safe and trusty operation and simple power grid awareness. R&D needs (to be addressed early on) are identified to be on charger topologies, contactless charging, increased durability and general reduction of cost, weight and size.

The Off-Board Charging and Metering Device will provide full V2G or Vehicle to Home (V2H) functionality and may be supported broadly by the utilities.

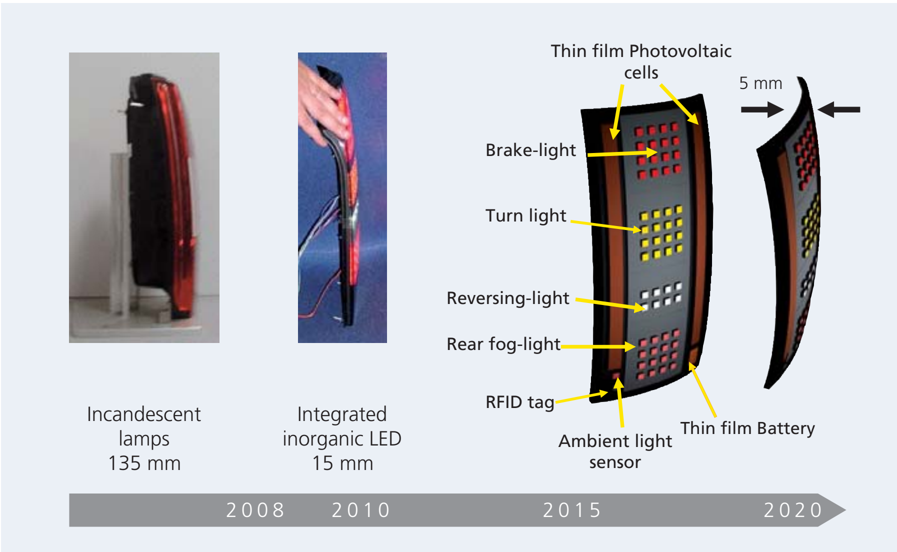

Figure 12: Lighting System Evolution driven by Smart Systems Solutions

Crossover Functionalities

The fifth topic addresses the crossover functionalities and methodologies which find applications in several other non automotive contexts. These include data fusion and management, advanced human machine interface concepts, manufacturing and design methodologies, integration, security, privacy and robustness. Robustness, for example, can no longer be solved at the component level. Especially for safety critical systems a breakdown cannot be tolerated. New measures and comprehensive approaches will ensure functional robustness far beyond today's possibilities.

R&D topics to reach this objective include: a better understanding of failure scenarios and mechanisms, improved ageing and lifetime test procedures, failure tolerant components and systems, lifetime monitoring and failure prediction, advanced and robust networks, shared resources and flexible hardware and software architectures together with robust component solutions and manufacturing technologies.Some very promising but also challenging technologies are: torque measurement, camera technologies, integration of antennas, energy scavenging, image and speech recognition, and 3D packaging and integration. Rather than single tech-

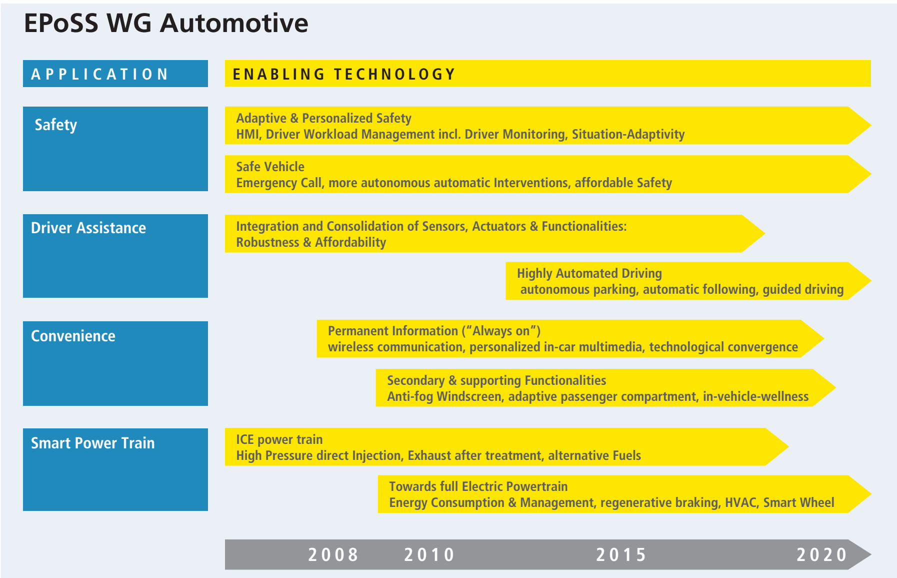

Figure 13: Research priorities for automotive technologies

nologies and functionalities, a collection of specific solutions is needed to build the required advanced applications.

Scavenging-harvesting of solar, vibration and heat energy could provide primary power to sensors and actuators thereby reducing complexity, (i.e. a scavenger provides the possibility to either avoid or reduce the use of connectors and cables and allow wireless connection) and also yield primary power to the electrical power train.

Further research development is envisaged by EPoSS in wireless technologies to reduce both system complexity and cabling which accounts for of about 25 kg in mid sized cars up to above 100kg of copper wires in luxurycars. Autonomous wireless technologies are envisioned for most non safety-critical inter-vehicle sensor networks including for instance smart sensor networks for battery monitoring and low power actuators. Future applications of smart wireless devices are expected in

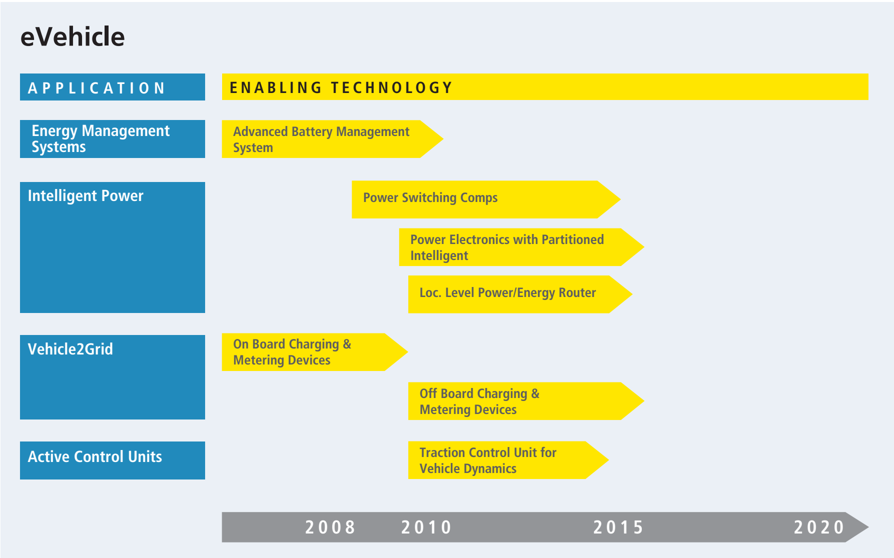

Figure 14: Specific research priorities for Electrical Vehicles

car-to-car as well as car-to-environment communication. (Figure 11).

Another example of a multidisciplinary approach leading to a higher level of both smartness and system integration is the lighting system shown in Figure 15. When compared with a conventional LED tail-light, the result of a first level of integration can be summarized as follows: thickness reduction (factor of 10), increased efficiency/power reduction (-70%), weight reduction (-50%), for-life operation, simplified installation, cost reduction. The research in this direction needs further support to allow the EPoSS approach envisaging the development of fully autonomous lighting systems adaptable to different conditions of visibility, integrating both solar energy converters and energy storage, combining hybrid inorganic and organic materials with sensors and wireless communication links all integrated into a single flexible printed-electronic multilayered foil.

Demonstrated in Figure 15 conventional taillights (left), a first level of system integration (centre) with solid state emitting sources, novel nanoscaled high efficiency phosphors and planar micro optics integrated directly on the external polymeric cover, and (right) expression of the EPoSS concepts of a fully autonomous system integrating in a multilayered foil planar light sources, solar cells, thin film battery, processing unit, ambient sensors and an RF communication link.

Research Strategy 2020 and Beyond

Once a principle or idea has been created, more than a decade of development is usually necessary before it can be exploited in the automotive sector. The design of a new vehicle spans three to seven years depending on the availability of appropriate solutions and on the complexity and degree of innovation in the vehicle. The period in which the vehicle will be produced ranges again between three and seven years, which limits the scope for introducing new future technologies. The average age a vehicle reaches is about 10 years, which translates into a slow market penetration for newly introduced solutions, even if a 100% equipment rate is assumed. In sum, innovations in automotive technology are rather long-term.

The short and midterm automotive R&D perspective (up to 2015) is driven by customer, legislative and competitive requirements. The four (out of five) chosen application clusters: safety, driver assistance, convenience and smart power train reflect these needs. To improve safety, three major approaches will be followed: a better understanding of the situation based on sensors to collect information about the environment; the merging of passive and active safety towards personalised and situation-specific accident mitigation measures, and the active interaction of road users towards a collaborative traffic approach. The underlying technologies are sensors to characterize the situation completely (traffic, vehicle and driver), computational networks to analyse and obtain decisions, communication protocols and infrastructure for interaction, and smart actuators and human-machine interfaces which act appropriately.

Driver assistance calls for comparable measures. Based on a comprehensive understanding of the traffic, vehicle and driver situations, appropriate supporting measures are chosen. Subsequently, the human-machine interface becomes of prime importance, aiming for an adaptive and personalised system. In parallel, convenience aspects will gain further in importance. The objective is to develop personalised vehicles – adapted to the driver and changing their attributes to personal and situation-specific needs. Finally, yet importantly, smart power train applications are a major R&D focus in order to respond to the challenges of lower fuel consumption and fewer emissions. High-pressure injection systems and exhaust after-treatment are short term perspectives; R&D of ICEs will continue in all directions in that it will be crucial to enhance the efficiency and emission control of the conventional power train as well as that of full parallel hybrids and of the range extender approach required by full electrical vehicles.

To meet short-term requirements the development of auxiliary systems is an appropriate approach. This does not require changes to established systems, while still promising potential benefits of high relevance. The second, more mid-term approach is optimisation of the original system, perhaps also including additional auxiliary systems. The EPoSS approach is to seek to solve problems and challenges at a specific level, ideally exploiting the systems potential of the whole vehicle. Thus the midterm R&D solutions which EPoSS focuses on are a combination of emerging technologies and the optimisation of existing functions.

One example of a visionary mid-term perspective for an efficient small sized Electrical Vehicle is that the average daily energy generated by on-board smart solar cells, based on the 2008 photovoltaic technologies, is sufficient to drive the vehicle 15km in central Europe and up to 25 km in southern Europe. On a world basis the largest request is for urban mobility where 80% of the Europeans travel less than 20 km per day.

As a consequence, photovoltaic technologies are expected to be more and more counted amongst the research priorities for the automotive environment.
To provide a long-term R&D perspective (up to 2050) two inputs are taken into account: first, the mid term R&D perspective visualised in Figures 5-6 and, second, anticipated major societal trends. These trends are mega-cities with more than 10 million inhabitants, pollution, ageing and fuel/energy shortage.
Scenarios of never-ending traffic jams, unacceptable pollution in the cities and further accelerating global warming, isolated individuals in societies with an average age of 50 years, all leading to restricted personal mobility, are to be avoided.

Possible solutions include:

- full penetration of zero-emission propulsion systems based on regenerative energies;
- communicating vehicles with electronic safety regions surrounding them and safety systems to avoid fatalities and to mitigate accidents;
- cooperative driving, reducing the number of dangerous situations and using the existing infrastructure as well as possible, including intermodal transport, and
- adaptive vehicles with advanced human-machine interface concepts including the ability for autonomous driving on demand to allow everybody to stay mobile.

It is evident that such solutions can no longer be based on single functions but need complex and interacting system solutions. EPoSS will, together with adjoining technology platforms, prepare and investigate such solutions for our future.

To summarise, EPoSS focuses on Smart Systems Integration starting from application requirements and exploring all possible scales and potential technologies. The technology platforms ENIAC (nano-electronics), ARTEMIS (embedded systems), Photonics21, ERTRAC (transport technologies and approaches) and EPoSS - as the linking element on the way to future products and features - will provide the required solutions for sophisticated European vehicles. The linkage between the platforms will be ensured by individual stakeholder's commitments in the various platforms, by co-ordinated activities through organisations like ACEA/EUCAR and CLEPA as well as by commonly supported activities among the European Technology Platforms.

›› 6. Smart Systems for Medical Applications

Smart systems are critical in driving innovations in the field of medical technology, as they provide the basis for information-based care and cure which will contribute to solutions addressing the increasing challenges in healthcare. Non-limiting examples will be given of applications which will come into reach once the EPoSS research priorities are introduced into the practice of cure and care.
The integration of microsensors and micro-actuators in products for cure and care will provide the healthcare professional with more advanced and improved options to treat and take care of patients and will enable patients to attain a better quality of life, even when suffering from chronic diseases. The seamless linking of such microsystems to a telemetric and telediagnostic infrastructure will significantly reduce response time, and simultaneously contribute to containing cost of the public healthcare system.

To make sure that the innovations in technology can be implemented in a clinical setting, it is important to focus on aspects related to their application. Therefore, apart from the three areas in which technological breakthroughs are expected, separate attention will be paid to the embedding of smart-system enabled technological approaches into integrated healthcare solutions.

Smart miniaturized devices

Biochemical sensors or, in short, biosensors, that detect specific molecular markers in minute amounts of body fluids or body tissue have the potential to revolutionize medical healthcare and, more specifically, medical diagnostics. Molecular biology and medical sciences are advancing to a point that human health and disease can be traced to the molecular level. New biosensor and lab-on-a-chip technologies are expected to dramatically change future medical workflow, paving the way for "personalized" medicine.

Developments in integrated biosensors can lead to new opportunities in settings where an extensive laboratory is not available or is not reliable (e.g., in the case of point-of-care testing), or in applications where rapid information on disease characteristics is essential (e.g., information on cardiac enzymes in acute cardiovascular disease). Important parameters for modern bio-analytical technologies are sensitivity, speed, low sample volume, ease-of-use, reliability, and low cost.

Smart, miniaturized devices are essential building blocks for the creation of new biosensing technologies for sensitive and rapid biological detection in complex samples such as blood, saliva, urine, etc.

Three critical phases need to be addressed in biosensor research:

- Modules: biosensor modules with cutting-edge performance for sample pretreatment, detection, multiplexing, etc.;

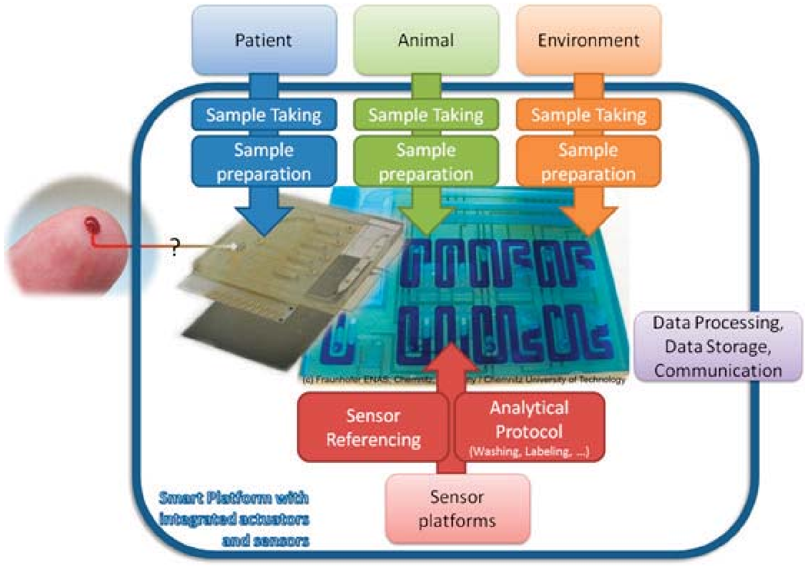

Figure 15: Smart Systems for Molecular Diagnostics in Point-of-Need Applications: Integrated platforms that provide the entire sample processing chain from Sample Taking and Preparation to Data Processing, Storage and Communication. (Source: Fraunhofer ENAS)

- Integration: integration of different modules into a system that displays adequate bio-analytical performance (biological sensitivity, specificity, speed, multiplexing) whilst maintaining ease-of-use and cost efficiency;

- Optimization, operation and validation of an integrated biosensing system in actual application cases based upon patients and a control population, as well as by making use of established biobanks.

New biosensor technologies are needed which – in addition to being sensitive, specific and rapid – are able to cope with variations in environmental conditions, can deal with variability in biological samples and are reliable in the hands of unskilled users. Clearly, the performance of a biosensor is not only determined by its sensitivity and speed of operation, but also depends on correct sampling and sample pre-treatment and the interpretation of the measured data (Figure 15). These steps are essential for the commercial success of these platforms. System integration is therefore a key factor in the success of point-of-need diagnostic biosensors, thereby motivating the development of smart miniaturized devices with a high degree of integration. Such integrated devices consist of actuators and sensors, and have to combine properties like "ease of use" and "high accuracy" at the same time.

Fully integrated systems must include functionalities such as sample taking, sample preparation and sample pre-treatment, with sample and liquid transport abilities and sensing functionalities. Furthermore, data processing and data storage are important elements of such systems.

The integration of complex sensors into small or even implantable smart systems will permit robust functionality and ubiquitous availability of relevant biochemical data, which provides the basis for evidence-based medicine and may save lives in critical situations.

Future developments in system integration will be based on novel reagent storage and release concepts. In order to bridge the gap between academic lab-on-chip demonstrators and near-product prototypes, special attention has to be given to the development of low-cost production technologies, for the production of devices and consumables. Hybrid, multimaterial solutions provide the basis for such Lab-on-Chip platforms, incorporating low-cost manufacturing routes for "active cartridges", but also for precise and robust sensor solutions (e.g., integrated sensors based on magnetic particles, electrochemical sensors, CMOS sensors, SPR or other evanescent-field based optical sensors) (Figure 16).

Another important future focus will be the validation of Lab-on-Chip systems in clinical settings. Therefore pilot-scale production lines operating within the rigorous QA/QC framework needed for regulatory approval have to be established in order to produce a sufficient number of qualified Lab-on-a-Chip cartridges.

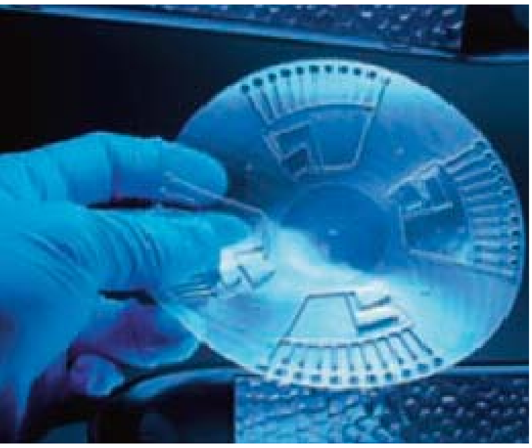

Figure 16: Low-cost approach to mass production of Labs-on-Chip: microfluidic integration of a diagnostic assay in a thermoformed foil cartridge (Source: HSG-IMIT/IMTEK)

Finally, in addition to biosensors and Lab-on-Chip systems there are opportunities for a manifold of miniaturized devices to be used as front-end for system integration. Examples are implantable systems which can be reabsorbed by the body after use (e.g. wireless temperature sensors), non-invasive sensors based on trans-dermal principles, devices for responsive administration of medication (e.g. Parkinson patch controlled by inertial sensors).

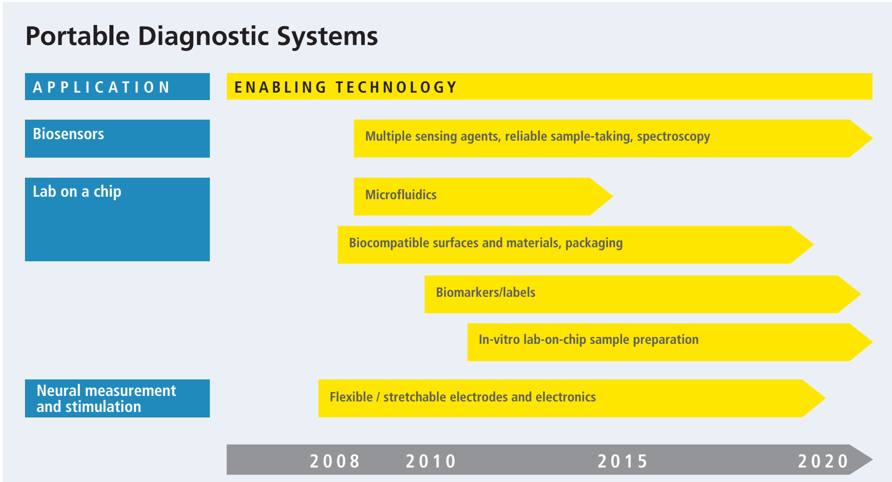

Figure 17: Smart Systems for Portable Diagnostics - Roadmap

Autonomously operating networked devices

A key element in health management is the assessment of the actual health status of a person. For that purpose smart sensor systems have to be developed that can be either worn on the body or integrated into the home environment. The sensors will not only give information on the vital body signs of a person, but also on his/her activities and other contextual information. All this information can be used to diagnose diseases at a very early stage. Algorithms for the diagnosis of the health status are amongst the most important elements of the system. In addition, the data will serve as input for therapy or lifestyle recommendations. Lifestyle and therapy recommendations will be given by a healthcare professional in person, or in an automated way by means of a user interaction device. User interaction and motivational schemes are required in order to actually invoke a behavior change of the user. On the professional side, i.e. in the hospital or the primary care facility, the physicians and nurses need support in order to deal with the large amount of data that such systems will generate. Decision support engines and care plan automation are examples of the research that is required in this field (Figure 18).

As an example, a significant number of patients with stroke or trauma related disabilities need to re-learn everyday behaviors. Sensors and electronic systems enabling closed loop feedback will provide significantly faster recovery, in some settings giving access to unique rehabilitation possibilities. Haptic feedback as well as behavioral monitoring and multi-sensory feedback to the patient provide an improved acceptance of the therapy as well as a steeper recovery curve.

Networked devices are eminently suited in relation to chronic diseases, which typically are under-diagnosed and under-treated. The goal of the EPoSS research priority is to introduce a systematic approach to improve health care particularly for people with chronic disease, delivering care more effectively and efficiently by enabling an active, participatory, role of patients in their own care, and supporting care providers with the means to better assist their patients in managing their illness. Technologies that enable care providers to diagnose better and to organize the self-care and professional care more effectively, will have substantial impact on both the social and economic burdens of the ageing society.

Figure 18: Smart sensors systems for vital information

A key technological enabler for a true autonomously operating networked device comprises a system architecture that enables autonomous operation of its various generic building blocks. These blocks typically comprise sensors and sensor interfaces, signal processing and storage, communication, and power modules. A fully integrated (CMOS-based) programmable platform is desired to achieve cost efficient and ultra-low-power (ULP) devices. A secondary aim is to increase reliability and robustness. At present, wireless sensor devices are heavily resource constrained and typically lack ULP processing resources to perform data analysis locally. Current devices typically send raw data for remote analysis, thus consuming the majority of their power budget on radio communication. To minimize radio traffic (beneficial for device power and network scalability) and to raise the level of device autonomy, there is a clear need to introduce ULP local processing resources unlikely to be provided by existing (RISC and DSP) processor solutions. In addition, there is a strong need to further innovate (BAN and PAN) short range radios and wake-up mechanisms. This includes not only optimizing radio and network protocols towards lower average and peak power, but also improving antenna design for on- and off-body communication. Active energy management of wireless sensor nodes and networks is another must that should enable a (dynamic) trade-off between ULP behavior and actual conditions. Solutions for resource-efficient network security and data access control are essential for the deployment of sensor devices collecting highly-personal information.

Another key technological enabler in autonomous sensor platforms is the availability of suitable power systems which comprise an energy source or buffer, power conversion module, and means of (re)charge. These systems should not only be designed towards technical requirements (e.g. energy budget), but also to personal requirements, such as unobtrusiveness. For small and integrated sensor nodes in the home environment solid-state thin-film power sources (and capacitors) can be effectively utilized, while for larger on-body sensor platforms shapeable and/or flexible batteries can be employed that can enable the systems to be body-conformal. To reduce user interference and maintain unobtrusiveness, integrated wireless (inductive) charging and energy harvesting will also be amongst topics of interest.

Applications as shown in Figure 18 will become possible, which can be worn on the body, give information on the vital body signs of a person, but also on his/her activities and other contextual information (left). All information can be recorded at home or mobile, in a remote setting, and communicated to a service centre, where data is integrated and interpreted, and decisions can be taken by professionals to provide advice to the individual person, or to take immediate action, when necessary.

Robust and adaptive systems

Robust and adaptive integrated systems will deliver new functionalities that can be used to sustain patients with chronic disease or may provide assistance during therapy. They will open up novel possibilities of treatment, also at remote locations, enabling independent living, and for monitoring and optimization of medical treatment. A number of application areas can be envisaged in a clinical and hospital setting, but with significant potential for application at home and away.

In a clinical setting one may think of systems for innovative and minimally invasive surgery. Use of navigation technologies and advanced multi-modal imaging technologies will improve accuracy and outcome of therapy. Sensors, for example integrated in catheters, will provide data to surgeons to guide interventional procedures with increased safety, less radiation and improved patient outcome.

Novel, miniaturized and cost-effective high performance and extremely reliable ultrasound transducers offer new opportunities for intra-operative imaging. Due to their fast response times they may be used in conjunction with slower, more information-rich imaging modalities to provide real-time input to guide therapy. Attractive concepts for ultrasound transducers are micro-machined devices. They will enable large bandwidth and thus a high depth resolution in addition to operation at high frequencies, e.g. in the 10-20 MHz range. Devices processed on silicon enable integration with electronics, and offer low-cost products in mass pro-

Figure 19: Revolution in drug delivery with potential future application of implantable devices mastering chronic diseases

duction. Examples are, amongst others, piezoelectric micro-machined ultrasound transducers.

Implantable devices are examples of smart systems which may be increasingly applied home and away, offering assistance to failing heart function, and in the future also providing support to neural functions and potentially to other bodily functions. Other examples are devices for application of drugs on demand, and for pain therapy and management, offering options to master chronic illness. Such medical devices at present are mainly used on the body, but will be increasingly internalized. Miniaturization is essential to minimize their invasiveness. In-vivo diagnostic devices, such as diagnostic pills or miniaturized sensors, may be integrated in closed loop systems, together with internal and autonomous devices for drug delivery. Autonomous power, self-diagnosis, remote control and external transmission of data are important technological challenges to be considered in the development of these smart systems (Figure 19). The example shown here is the intelligent pill, targeted at assisting drug development and enabling new therapies for debilitating and life-threatening digestive tract disorders such as Crohn's disease, colitis and colon cancer.

Just as miniaturization is paramount in the development of autonomous implanted devices, it is essential that the design of the whole system is optimized to a geometry best suited to a particular sensing (i.e. monitoring) or treatment application. This will imply, amongst other things, organ conformal devices that thus consist of flexible electronic systems. Key enablers are the use of flexible silicon platforms in which all functionality is embedded, manufactured utilizing substrate transfer processing.

Additionally, devices can be processed onto non-rigid or polymer substrates. As these diagnostic devices are also to be used in-vivo, biocompatibility of substrates and, more importantly, packaging needs to be checked and further developed.

Moreover, the use of these new carriers will undoubtedly require a re-analysis of current processing routes for integrated devices. Just as with on-body counterparts, in-vivo sensor platforms require integrated sensor, signal processing, communication and power modules. However, the emphasis will be, even more strongly, on miniaturization and reducing power consumption. Enablers herein are CMOS-compatible building-blocks that

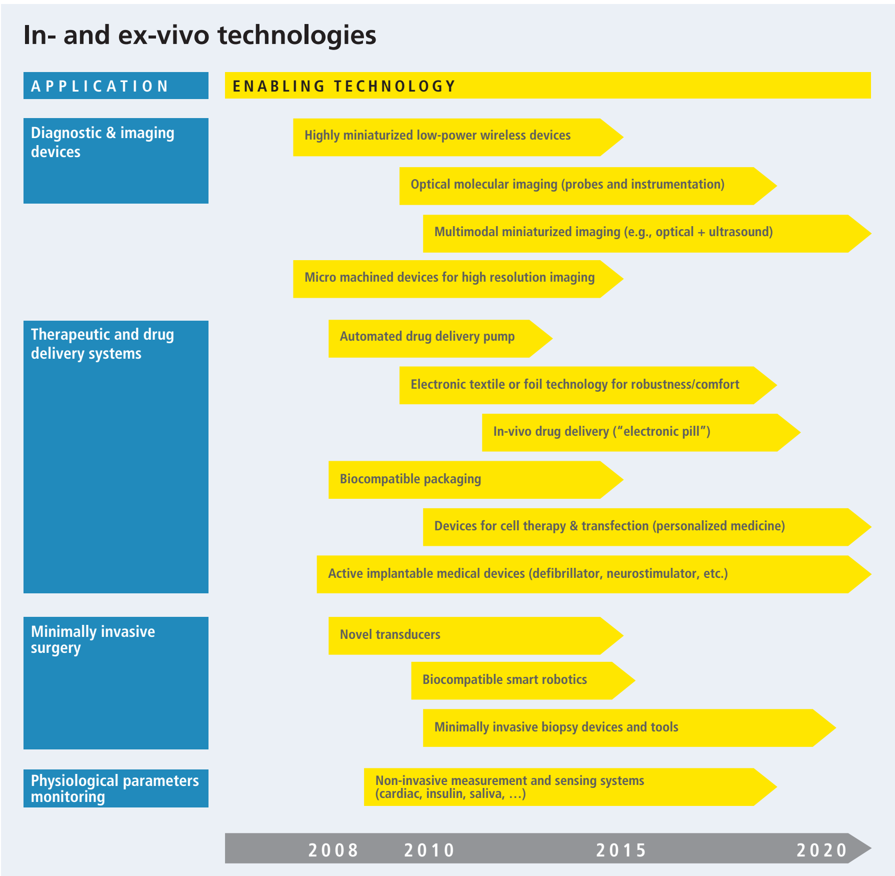

Figure 20: Roadmap of Smart Systems for in- and ex-vivo applications

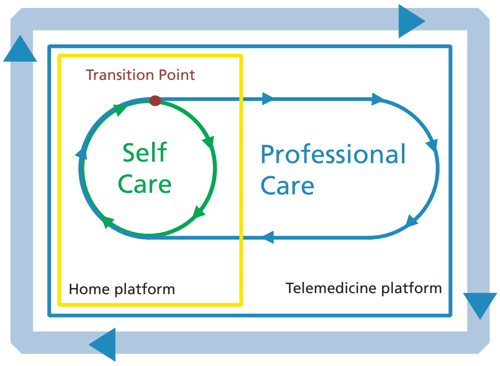

Figure 21: Closing the loop in integrated disease management, bridging professional care settings and the home

can be combined using, for example a System in Package (SiP) approach, such as solid-state thin-film power sources that can be recharged using non-contact charging or in-body scavenging (i.e. by reduction of bio-fuels).

Integrated healthcare solutions

The innovations in medical technology enabled by the introduction of smart systems need to be implemented in cure and care in order to take effect. In this section attention will be paid to integrated healthcare solutions, introducing a holistic view to cure and care, such as represented by the 'Care Cycle' approach, providing the holistic approach to healthcare schematically depicted in Figure 21. Implementation of the opportunities offered by innovations in medical technology require consideration of the total healthcare architecture required for their introduction into a clinical setting, but increasingly also in distributed settings, ultimately at home.

The integration of technology-enabled information-based healthcare solutions needs to be considered for major care settings, which have a major influence on workflow and accessibility aspects. As health-economic evidence is required to gain public endorsement and re-imbursement for technology-innovation in healthcare, significant clinical studies need to be part of the research programme in order to test new systems in the field.

While most of today's healthcare is focused on the treatment of already present conditions, prevention has been identified as a very successful tool to minimize the impact of risk factors on the health situation of the patient-to-be. Unobtrusive sensors for certain conditions (e.g. monitoring movement, critical load conditions to bone, stress monitoring) can provide an early feedback to patients with an identified risk condition, minimizing the impact or even preventing the occurrence of a clinical condition. Such a scenario will connect the sensors to a telemetric network with adequate access rights granted by either the patient him/herself or a trustee to allow risk assessment and taking preventive action, if the risk level is increased (e.g. high blood pressure in a stressful environment).

Examples of major care settings which will be significantly influenced by the introduction of smart systems are:

- **Digital Hospital:** Patient-centric care in the digital hospital supporting multiple multi-disciplinary care teams in all phases: diagnosis, treatment and nursing.
- **Time is Muscle:** Acute care models covering all the phases from the event at an emergency location, diagnosis and treatment in a hospital, concentrating on shortening the time between event discovery and start of treatment.
- **Hospital at Home:** Inter-mural care covering the post-intervention phases from discharge at the hospital, care at home and rehabilitation.
- **Home and out-door models**
  - **Continuous Care:** Inter-mural care related to managing chronic disease models by multi-disciplinary care teams (e.g. clinician, GP, home care nurse, physiotherapist …), concentrating on preventing re-hospitalisation by early detection of degeneration of the health status of the patient.

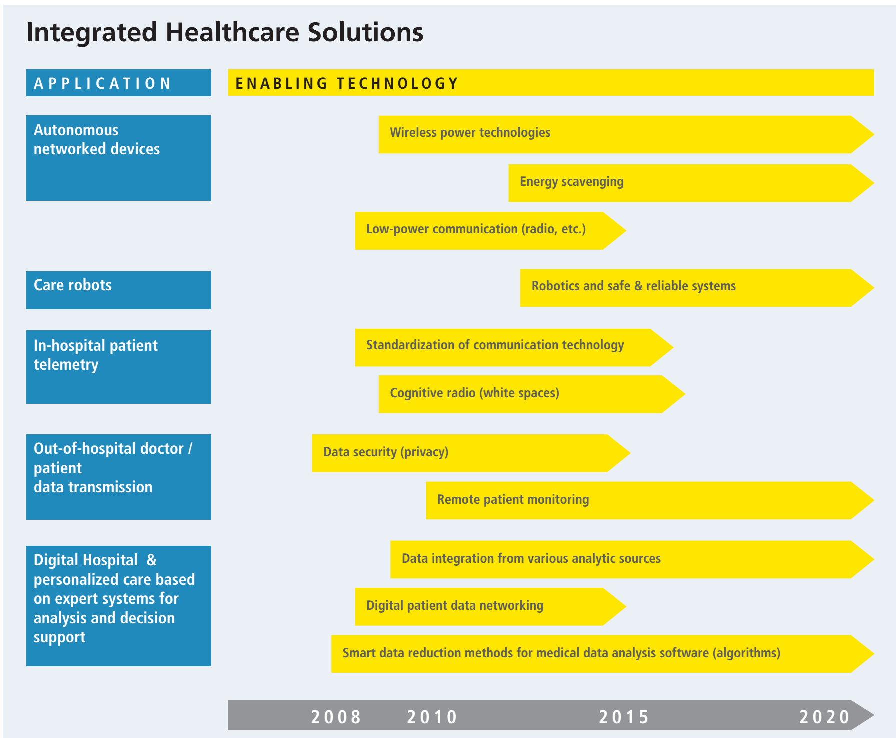

Figure 23: Roadmap of Smart Systems for Integrated Healthcare Applications

	Digital Hospital	Time is Muscle	Hospital at Home	Home and out
Collect new types of patient data	Physiological biological, genetic, …		Physiological biological, …	Physiological biological, …
Collect relevant non-medical data				Activity, movement, weight, location
Collect patient data in new ways		In-body, on-body	In-body, on-body unobtrusive	In-body, on-body, unobtrusive
Data collection at patient location	Room in clinic, bed-side	Ambulance	At home	At home, on the move
Process raw data to information	Back-end server	Back-end server	Back-end server	Back-end server, local
Information processing to support decision making	Back-end server CDSS	Back-end server for CDSS	Back-end server for CDSS	Back-end server for CDSS
Data access by relevant care givers	Clinicians, nurses	Paramedics, clinicians	Clinicians, GPs, pharmacists, home care nurses	Clinicians, GPs, pharmacists, home care nurses, physiotherapists, dieticians, …
Data access to relevant data by patients	Bed-side		At home	At home, on the move
Present aggregated data at relevant locations	Anywhere, any time	Ambulance, emergency room, intervention room	Anywhere, any time	Anywhere, any time
Support multi-disciplinary teams, workflow, task oriented dashboards, electronic communication	Clinicians, nurses, pharmacists,	Paramedics, clinicians	Clinicians, GPs, pharmacists, home care nurses	Clinicians, GPs, home care nurses, pharmacists, physiotherapists, dieticians, …
Support electronic communication between patient to caregiver	Clinicians		Clinicians, GPs, home care nurses	Clinicians, GPs, home care nurses
Integration of services in context of care delivery organisations			Home care organisations	Home care organisations
Integration of services in context of non care organizations (AAL)			Home care organisations	Home care organizations, AAL services
Early detection	Targeted therapy			Relapses
Prevention				Enforce or adjust treatment regime, lifestyle advice
New treatment technologies	Guided, minimal invasive surgery	Portable treatment devices defibrillator, heart massage	Remote actuators	Guided rehabilitation exercises, behavior management
Treatment at patient location	Room in clinic, bed-side	Ambulance	At home	At home, on the move
Treatment compliance by care givers	Treatment protocols related to evidence based medicine	Treatment protocols related to evidence based medicine	Treatment protocols related to evidence based medicine	Treatment protocols related to evidence based medicine
Treatment compliance by patients			Monitoring, medica-tion management, behavior management	Monitoring, medication management, behavior management
Direct feed back and intervention				Local analysis and feedback

Figure 22: Functions for the integrated care models

- **Care integrated in Ambient Assisted Living:** Embedding an extra-mural care for chronic diseases in the Assisted Living approach.
- **Holistic Health Management:** managing the state of complete physical, mental and social well-being, not merely the diagnosis and treatment of disease or infirmity, for persons in their whole life, from conception to grave in a cross domain context.

Considerations and changes in integral care and cure are summarized in the table below.

Conclusion

Smart systems are key components serving medical technologies, which are at the basis of innovative breakthroughs in healthcare and cure: providing the input for evidence-based and pre-emptive medicine, and enabling longer independent living with a better quality of life. Breakthrough technologies are discussed within the framework of the three EPoSS priorities, focusing on potential implementations in different major care settings of the future: the Digital Hospital, 'Time is Muscle' (rapid response), Hospital at Home, and several Home and Out-door models of integrated and holistic approaches to cure and care. Turning the opportunities offered by the EPoSS technologies into clinical practice forms the main objective of the application field Medical Technology – providing meaningful innovations in cure and care.

›› 7. Smart Systems for the Internet of Things

Vision

Smart Systems open the way towards multi dimensional, context-aware, and smart environments that can bridge the real, virtual and digital worlds by using wireless connectivity for energy efficient and environmentally friendly applications and services.

The Internet of the Future, or as it is commonly called, the "Future Internet", will result from a synergic merge of today's computer networks with the Internet of Media (IoM), the Internet of Services (IoS) and Internet of Things (IoT) into a common global IT platform.

Among those components, our Working Group has its main focus on the "Internet of Things". There is no standard definition for the IoT; often, it is defined as "the network formed by things/objects having identities and virtual personalities, operating in smart spaces using intelligent interfaces to connect and communicate with users, social and environmental contexts". Semantically, the "Internet of Things" could be defined as "a world-wide network of uniquely addressable interconnected objects, based on standard communication". Using this network, smart wireless identifiable devices will be able to seamlessly interact and communicate with the environment, thereby helping to make our society more efficient, secure and inclusive.

While the current Internet is a collection of rather uniform devices, heterogeneous in some capabilities and very similar in terms of purpose and properties, the future IoT will exhibit a much higher level of heterogeneity, as totally different objects, in terms of functionality, technology and application fields will belong to a common communication environment.

Under this vision, objects will be able to transport themselves, implementing fully automated processes and thus optimising logistics; they will be able to harvest the energy they need; they will configure themselves when exposed to a new environment, show an "intelligent" behaviour when faced with other objects, deal seamlessly with unforeseen circumstances; and, finally, they will self dispose, helping to preserve the environment, at the end of their lifecycle.

In this context smart wireless identifiable devices (EMID-Electro Magnetic ID: USID-Ultra Sound ID, RFID-Radio Frequency ID, MMID-Millimetre waves ID, etc,) will form the backbone of an "Internet of Things" infrastructure allowing new services and enabling new applications.

These smart wireless identifiable devices will provide the means for the fusion of the real, virtual and digital worlds, creating a map of the physical world within the virtual space by using a high temporal and spatial resolution and combining the characteristics of ubiquitous sensor networks and other wireless identifiable devices, whilst reacting autonomously to the real world and influencing it by running processes that trigger actions, without direct human intervention.

Technology

From the Technological point of view, in order to realise the vision of the IoT, several advances must be carried out by the research community:

Energy
Energy in all its phases of harvesting, conservation and consumption is a key issue for the future. There is a need to research and develop solutions in this area, having as an ultimate objective a level of entropy

Figure 24: Smart RFID System on Alu strap

as close as possible to zero. Current technology development is inadequate in this respect, and existing processing power and energy capacity is too low to cope with future needs. The development of new and more efficient and compact energy storage sources such as batteries, fuel cells, and printed/polymer batteries etc; as well as new energy generation devices coupling energy transmission methods or energy harvesting using energy conversion, will be the key factors for the roll out of autonomous wireless smart systems.

Intelligence

The Intelligence of devices, in particular as regards context awareness and inter-machine communication, is considered a high priority for the IoT. This context awareness will be strongly related to information received via sensors, corresponding sensor networks and the capabilities of localisation, as well as the possibilities to influence via according actuators. Besides this, environmental context identification can also be user related or social. Communication capabilities will have to include multi-standard as well as multi-protocol compatibility.

Furthermore, the development of ultra low power designs for mobile IoT devices and a new class of simple and affordable IoT-centric smart systems will be an enabling factor. In that context the terminology of ultra low power design is a broad one - from high efficiency front-ends, ultra low power processors/microcontrollers cores, ultra low power signal processing capabilities, ultra low power sensors to low power base stations (see also Chapter telecommunication).

However the intelligence of local IoT nodes will be heavily restricted by size, cost and the need to mass-produce in high speed, roll-to-roll manufacturing processes, thus keeping the distributed intelligence on a rather low level and accordingly quite specific. Processing of accumulated information will take place separately.

Communication

Communication, in terms of physical wave transmission and protocols, will be the cornerstone of the novel IoT architecture. Machine-to-Machine technologies will be central: context-awareness and situation-specific behaviours will shape the interaction between objects. In the future, application- specific antennas will need to be developed in order to allow the smooth functioning of applications and services; these antennas will eventually evolve into smart devices themselves, able to reconfigure themselves, and to adapt to the specific application needs and to their surrounding environment.

Integration

The integration of chips and antennas into non-standard substrates like textiles and paper, even metal laminates and new substrates with conducting paths and bonding materials adapted to harsh environments and for environmentally friendly disposal, will become mainstream technologies. RFID inlays with a strap coupling structure will be used to connect the integrated circuit chip and antenna in order to produce a variety of shapes and sizes of labels, instead of direct mounting. Inductive or capacitive coupling of specifically designed strap-like antennas will avoid galvanic interconnection and thus increase reliability and allow even faster production processes. The target must be to physically integrate the RFID structure with the material of the object to be identified, in such a way as to enable the object to physically act as the antenna.

This will require ultra-thin structures (< 10 µm), as well as printed electronics, which are both robust and flexible.

Interoperability

It is a common experience that two different devices might not be interoperable, even if they are using the same standard. Future tags must reliably integrate different communication standards and protocols that operate at different frequencies and allow different architectures, centralised or distributed, and be able to communicate with other networks unless and until global, well defined standards emerge.

Figure 25: Polymer Strap on aluminium substrate with slot antenna

Trust and Security

There is a vital need to have a technically sound solution to guarantee privacy and the security of the customers in order to have a widespread adoption of any object identification system. While in many cases the security has been done as an add-on feature, it is likely that public acceptance for the IoT will happen only when strong security solutions are in place. Long term security protection is a necessity, one which takes into account the product lifecycle.

Applications

Under the current vision, the IoT will have an even more fundamental impact on our society than has the Internet & mobile technologies or even today's acclaimed "Information Era". The future ubiquitous IoT will make it possible for virtually any object around us to exchange information and work in synergy with each other in order to dramatically increase the quality of our lives.

We will be wearing smart clothes, made of smart fabrics, which will interact with the Climate Control of our cars and homes, selecting the most suitable temperature and humidity levels for the person concerned; smart books of the future will interact with the entertainment system, such as a multi-dimensional, multi-media Hypertext bringing up on the TV screen additional information on the topic we are reading in real time; and so on.

Many application areas are foreseen for the future IoT embracing automatic meter reading, home automation, industrial monitoring, military, automotive, aeronautics, consumers (Personal Area Networks), retail, logistics (shipping tracking storing, managing the supply chain), food traceability, agriculture, environmental and energy monitoring, healthcare, pharmaceuticals, and public and private safety and security.

Initially, RFID technology, which is the foundation of the IoT, was studied in order to replace the bar code in retail applications. Whilst currently being tested in a variety of pilot projects, and showing multiple benefits over the older systems, the adoption of RFID has been slowed down by several factors, such as the much higher cost of an RFID tag over bar code labels, necessary technological improvements within the transmission of metals and liquid items, and privacy concerns.

In the future though, IoT technology will not be limited only to identification, but, using the autonomous routing of data packets in today's internet as a model, the next evolution step will be the integrated automation and individualization of material flows. For that purpose, logistics objects will be equipped with RFID tags which contain not only identification attributes but also information regarding the destination, routing, priority, and processing steps of the object.

Today, wireless sensors are already part of current home applications, in systems like air-conditioning or security. They cooperate in a strictly defined system to fulfil a precisely defined task. Normally, those systems are closed and cannot exchange any other kind of information. The future IoT will create a continuum of objects, and will change radically environments like our homes.

We can just imagine a few of the applications that will be possible through the development of the IoT. Some of those applications are described in specific sections in this SRA, such as medical, automotive and aerospace.

Research Priorities

The roadmap for the realisation of the IoT is, as we can expect, long and strewn with obstacles. The research priorities are built on the five pillars that will form the basis for developing smart wireless identifiable systems:

- **Multidisciplinary:** different disciplines are involved spanning from micro/nano to communication protocols and integration
- **Convergence:** the convergence of different technologies like nano/micro, sensor, flat batteries/printed, printed antennas, silicon/polymer,
- **Heterogeneity:** heterogeneous communication protocol, sensor technologies, and the combination of different antennas, batteries, power generation and displays.
- **Multifunctionality:** multi functional miniaturised and smart RFID devices and readers operating at different frequencies and protocols, that have improved quality, performance and cost effectiveness, that are security/privacy friendly, and are world wide compatible and transparent for the user. Flexible and adaptable RFID devices (passive/active) that incorporate sensing and actuating devices in a wide range of materials depending on the application requirements.
- **Integration:** very high levels of miniaturization and integration, small size, low power and low cost requirements that imply high integration using a combination of system on chip (SoC) and system in package (SiP) implementation

The key research priorities for the next years are the following:

Intelligent systems
A clear research priority focuses on system intelligence. Context-awareness and inter-machine information exchange will be central to the IoT. In the coming period, there is therefore the need to study a global architecture for the IoT, where peer-to-peer communication models, the shift of already existing bio-inspired approaches from a centric view to a distributed one, in which intelligence is pushed towards the edge of the system, and the development of autonomous devices able to generate automatic code and behaviours, will play a central role.

The research priorities will focus on increasing and adapting the intelligence at the device level by the integration of sensors and actuators, new power efficient hardware/software security architectures, highly efficient, multistandard and adaptive communication sub-systems, adaptable antennas (smart beam steerable phased array antennas, multi frequency band antennas, on chip antennas (OCA), coil on chip, printed antennas, embedded antennas and multiple antennas using different substrates and 3D structures), and miniaturised smart RFID readers supporting multi standards to be used with mobile devices for different applications.

Energy sustainability
A strong emphasis will be put on energy efficient and self-sustainable systems. Novel ways to harvest energy from the environment must be explored and developed, in order to create systems that require little external energy, if any. Efficiency in processing and in communication must also be achieved through novel programming paradigms and the further development of energy efficient protocols and smart antennas.

Research efforts will focus on multimodal identifiable sensing systems enabling complex applications such as implants monitoring vital signs inside the body and drug delivery using RFID, whilst harvesting energy from different sources.

Research on printed batteries manufactured with sensor, thin film solar (thermal) cells for energy harvesting, vibration and piezoceramic devices for energy harvesting, (or even micro fuel cells for long term power generation) wireless power supply to sensors and thin batteries with lifetimes of 10 years. Hybrid energy generation, storage and transmission based upon a combination of RF, piezoelectric and battery power generation.

Privacy and Security
Many of today's concerns about the wide adoption of the IoT lie in the popular belief that both privacy and security will be compromised. In order to reverse this belief, sound technological solutions must be developed, together with legislators at national and supra-national level. Extensive dissemination of the results of these discussions must also be undertaken by all IoT actors.

The research will focus on RFID with privacy control and energy efficient cryptography algorithms and the use of non-linkable digital transfers for disguising digital transactions, e.g. a combination of different identification technologies to increase the security and privacy by using private, revocable ID enabling users to be the sole owners of the object's identity.

Harsh Environments and Integration into Materials
Current trends show that the research process from application specific antenna designs to smart antennas, suitable for different applications and materials, will finally lead to the integration of devices into non standard substrates. These substrates, and their operational fields, might have very specific requirements, and the resilience of these smart electronic components must therefore be extremely high.

Research will focus on RFID devices with sensing capabilities that are embedded in composite parts, by using antennas, integrated electronics, micro sensors, materials and special assembly techniques for operation in harsh environments (large temperature, pressure variations, etc.) or, if implanted, requiring biocompatible functionality.

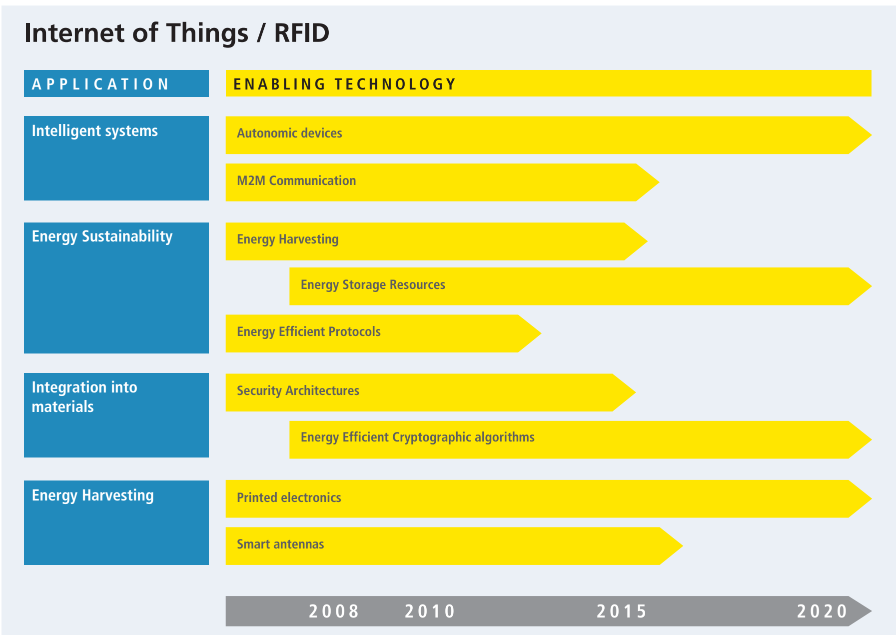

Figure 26: Roadmap Smart Systems for Internet of Things

8. Smart Systems for Information and Telecommunication

Vision

Smart Systems will create

- a single personal multifunctional gateway to connect the individual with the machine world.
- an invisible, zero-carbon-footprint communications infrastructure
- miniaturized, long-life devices for "one-touch installable", smart, scalable machine-to-machine networks

The story of smart systems, and the new hardware technologies that they require, is closely entwined with that of communications. Miniaturized, autonomous smart systems will unlock key bottlenecks in the expansion of existing personal communication services. They will also enable new applications that require extensive machine-to-machine communications.

Any future vision of personal communications must consider both the end-to-end system and components, both hardware and software, both user devices and infrastructure.

Personal connectivity: How smart systems enable ubiquitous high-speed connectivity

The communications needs of end users are becoming ever more complex, interacting with an ever-wider range of remotely controlled products and services and interacting with other users with ever-richer modes of communications. The challenge is therefore to create a single multifunctional personal gateway device to interface the individual with a multi-faceted machine world and to connect the individual with others. This device must be tailored to the needs of the individual and be easy to use. It must be permanently connected with low-cost, high-performance network access and have a high degree of energy self-sufficiency

The other key component of personal communications is that of the wireless access infrastructure with which the users' devices communicate. The infrastructure of the future will be low in cost, visually unobtrusive and energy efficient, all while delivering ever increasing bandwidths.

European industry has played a leading role in the roll-out of second- and third-generation cellular communications, with European system suppliers and components punching well above their weight in world markets. Maintaining that position depends on Europe addressing two key developments: affordable, ubiquitous access to high-bandwidth wireless infrastructure with low-carbon footprint and the continuing downward pressure on component costs. Smart systems are the solution for both.[8/9]

In the fourth quarter of '07

EU-headquartered equipment providers accounted for 49% of mobile handsets shipped globally

30% of radio accessed network equipment sales worldwide by one important European manufacturer

Other European manufacturers hold the 2nd, 3rd, and 4th positions in worldwide RAN revenue share.

Ubiquitous high-speed wireless connectivity with low-carbon footprint

The last link of personal communications is fast becoming the sole preserve of wireless communications. But applications are ever increasing in their demand for affordable bandwidth and the demand of bandwidth per user will increase too.

Forward-looking standardisation efforts such as ITU-ADV are considering the supply of 100Mb/s and more of data to end-users over long ranges. Such advances will open up new applications with positive impact on society, such as remote video streaming in disaster scenarios, ubiquitous connectivity for health monitors in body area networks, and wireless broadband for rural areas.

Secure communications are also a concern of end users. In the meantime, operators are looking beyond the capital expenditure costs of running networks to minimising operational costs such as power consumption and site costs.

In each case, smart RF system hardware solutions are the key enablers:

- To address spectrum scarcity, frequency agile and multiband RF transceiver solutions will provide the required bandwidth to deliver data rates in excess of 100Mbit/s. Advances in filtering, matching, and analog RF processing technologies, along with their heterogeneous integration, will be needed for tuneable and switchable multi-band operation.
- To more efficiently use existing spectrum, active antenna arrays will trigger the widespread adoption of MIMO and beam steering.

[9] IDC, 2008
[8] Infonetics Research, 2007

- To minimise handset size, ultra-compact passive subsystems combined with radio processing (e.g. mixing, passive and active filters) will be achieved through advances in SiP (system-in-pakkage) integration of heterogeneous technologies such as MEMS, active and passive electronics, acoustic-wave filters, and bio-electronics.

- To minimise power consumption in basestations, highly efficient switched-mode power amplifier modules will improve power efficiency, while innovative thermal management subsystems such as smart fan trays will minimise the energy cost of waste heat removal.

- To minimise basestation site costs, miniaturisation in high-power RF subsystems will be used in low-profile smart remote radio heads.

Hardware solutions for transceivers form the necessary "layer 0" in the communications protocol stack. Hence, the above solutions require more than just software or new algorithms or innovative architectures: advances in heterogeneous hardware solutions, at the core of smart system solutions, are the only way to see real improvements. Achieving hardware which is adaptable and provides high performance requires a close integration in the one package of micro-scale mechanical, digital and active plus passive RF technologies.

Competitive pressures in component manufacture

Smart systems technology will help European component manufacturers to maintain and increase market share and profit margins in the face of increasing competition from low-cost regions of the world. Increasing the intelligence and autonomous adaptability of previously "dumb" subsystems will enable the European RF and mixed-signal component industry to move up the supply chain, capturing more of the value of the end products.

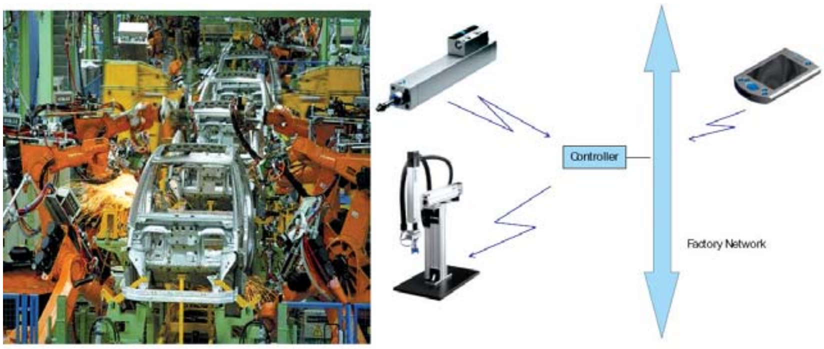

Figure 27: Wireless network of sensors for use in industrial processes

Further strengthening the ecosystem of component suppliers within Europe will help the large European handset manufacturers and system integration companies to retain their R&D operations within Europe.

Machine-to-machine connectivity: How effective communications solutions enable smart systems

Machine-to-machine and sensor network communications are the next big opportunity for the communications industry. Large financial and societal benefits will arise from the invention and realization of miniaturized, long-life devices connected using machine-to-machine and sensor networks. These networks must be "one-touch installable", dynamic in operation, and scalable up to millions of devices.

In a wide range of smart systems, such as medical and lifestyle devices for assisted living, in-vehicle diagnostics, environment monitoring systems, etc., connectivity between smart devices is a critical facility needed to achieve the desired ends. This is because

- Smart devices often have limited local information and cognitive capabilities. Networking the devices results in a better informed, more intelligent overall system.

- Most smart systems have some level of human and/or central supervision and control. Connectivity is therefore required to gather information and to distribute commands.

Thus machine-to-machine (and in the case of body-area networks, man-to-machine) connectivity is a necessary underlying component of many smart systems.

Delivering that connectivity in an affordable, effective manner requires major improvements in many dimensions:

- Advances in RF antenna and filter design, packaging and module integration will enable miniaturisation of transceiver solutions. Particularly critical are novel radio solutions for the low-GHz (less than 2GHz) bands.

- New circuit design techniques and micro- generation techniques for power will extend the operational life of remote devices.

- Integration of NEMS, MEMS, BAW and SAW devices, and classical integrated circuitry, both active and passive, will also drive down the size of transceivers.

- Co-simulation of the various technical domains, electrical, mechanical, and acoustic, will be required for optimised solutions and low time-to-market.

- New scalable architectures designed specifically for the machine-to-machine communications will allow for networks of millions of devices.

- Improvements in techniques for secure and reliable machine-to-machine communications will enable mission-critical applications for sensor networks.

Successful development of the required "layer 0" hardware technologies will place European industry at the forefront of opening up huge new markets in sensor networks, command and control, critical safety networks, body-area networks, vehicle-to-vehicle/vehicle-to-infrastructure communications and machine-to-machine communications generally.

> "… if 'things' become active internet users on behalf of humans, then the number of active [internet] connections could be measured in terms of tens or hundreds of billions."
>
> ITU "Ubiquity: Here, There and Everywhere", 2007

The impact will be seen at several levels:

- There is the potential for EU industry to replicate the success of second- and third-generation cellular technologies – one could envisage European system integrators taking a leading role in the equivalent of GSM for wide-area sensor networks.
- The business models for smart system networks are sufficiently different to that of personal communications – thus there will be new service and system providers to service the communication demands of potentially tens of billions of devices.
- Smart devices enhanced with inter-device communication will result in smart systems with a much higher degree of intelligence and autonomy. This will enable the more rapid deployment of smart systems discussed elsewhere in this Strategic Research Agenda, with all the benefits accruing to European society as listed. For example, vehicle-to-vehicle and vehicle-to-infrastructure communications will significantly advance Intelligent Transportation Systems (ITS) applications such as vehicle safety services and traffic management.
- Unobtrusive man-to-machine communication will be instrumental for enabling the wide deployment of policies such as e-Health, e-Inclusion and e-Accessibility, helping ageing society with assistant devices, improving the participation of people with disabilities in the Information Society, and generally aiding natural, intuitive interfaces to information technology.

Technical objectives and their impact

Personal connectivity

This section specifically addresses the needs of smart systems that enable ubiquitous high-speed connectivity. There are two main drivers. One is the ongoing demand for shrinking size and reducing cost. A key challenge with respect to form factor reduction is to find new approaches to overcome the large physical dimensions dictated by the long wavelengths at frequencies below 1 GHz. From a communications perspective, frequencies below 1 GHz have the greatest range and coverage and hence continue to attract much business interest, despite the lower capacities achievable.

In addition, there is a need for new functionality and new subsystem architectural approaches that are not feasible today. Integration of heterogeneous technologies (a core objective of EPoSS) plays a key role here as it enables new architectures.

Technological advances are needed at both component and subsystem/module levels, to facilitate the new functionality at a smaller size and at lower cost.

Component level
High-linearity, low-loss, tuneable components: New high-performance variable components with low loss, high linearity, and large tuning ranges are needed. Applications would include sub-circuits like tuneable matching networks with low loss to match power amplifiers and antennas over a wide frequency range. Useful component technologies include ferroelectric varactors (variable capacitances) made from barium strontium titanate and variometers (variable inductances), from tunable magnetic materials (e.g. ferromagnetics or multiferroics). Further flexible components are of the MEMS (micro electromechanical systems) type. These are components that are heterogeneous in themselves, with moving mechanical parts at a microscopic scale altering electrical properties.

High-power RF handling: For some specific applications such as high RF power transmitters, components have to withstand large RF voltages and currents. Research is needed to reduce losses in linearity at high RF power levels, when often component properties become a function of the applied signal. New design tools are needed where electromagnetic properties are analyzed in conjunction with thermal distributions and mechanical stress conditions. The challenge is to have an integrated simulation tool, spanning both component and circuit levels and covering electromagnetic, thermal, acoustical and mechanical properties in one environment.

Artificial materials for tunability and miniaturization: New RF artificial materials are expected to deliver solutions to shrink the size and increase tunability, while maintaining performance. One example here would be metamaterials created out of periodic structures comprising switches, varactors and variometers. Besides such materials created out of passive structures, one can conceive of artificial materials incorporating active non-linear devices. Artificial materials provide a large degree of freedom in shaping frequency characteristics and are expected to open a wide new range of applications such as compact flexible filters and antennas and components like phase shifters and couplers with wide frequency agility. Other concepts such as defected ground and defected microstrip structures with high slow wave factor will shrink the size of line transformations.

Integrated MEMS circuits: To achieve the desired flexibility in functionality without compromising on performance, integration of MEMS devices with other MEMS devices (often using different processes) and the integration of MEMS with RFICs is needed. Advances are needed in hybrid integration through system-in-package (SIP) technology to avoid losses in performance arising from leading signals on and off chips. However the package might lead to Q-factor degradations or unwanted couplings which have to be properly controlled. The challenge for the future will be to find a platform technology for SiP that allows for the most flexible combination of devices of different type without degrading performance. Hence, SiP technology will be the key to enable new functionality. Besides performance gain and form-factor improvements, there are also cost advantages and higher system reliability from a shared package.

Module/subsystem level
Increased integration, improved packaging and new compact architectures to reduce size and increase reliability: Increased integration delivers smaller form factors (important for multifunction handsets and for reducing base station physical footprint) and higher reliability. At the module level, there is a need for new techniques for the integration and packaging of a bewildering array of technologies: high-speed digital FPGAs, GaN and GaAs MMICs, LTCC, CMOS RFICs, YIG isolators, acoustic filters (SAW, BAW), high-Q discrete passives, LTCC, multilayer laminates, etc. Critical in this will be the development of a new generation of SAW and BAW filters with respect to substrate materials and packaging, e.g. GBAW filters and band VII duplexers. More broadly, the challenge for research is to satisfy the requirements of different domains simultaneously, e.g. the heat transfer must be managed without sacrificing RF performance; mounting techniques of MMICs should not introduce massive RF parasitics, and so on.

At an architectural level, smart integration will provide more flexibility in partitioning functionality between the enclosed subsystems. This will allow the exploitation of new technologies for low-cost, miniaturized RF systems. One example is the use of metalized plastic component in active antenna arrays – this enables architectures which are cost effective where multiple transmit chains are needed, e.g. for beam-steering and MIMO.

Smart/flexible RF modules with digital control: From a system architecture perspective, a further big challenge is that of frequency agility. As the frequency spectrum for wireless communication becomes more and more fragmented, flexibility at subsystem level must be increased to take maximum benefit from the scattered spectrum resources available. In wireless transceivers, frequency agility has to be implemented throughout the whole RF chain, from antennas to filters to power amplifiers to radios, where their flexibility is obtained from using tuneable components in conjunction with RF detectors.

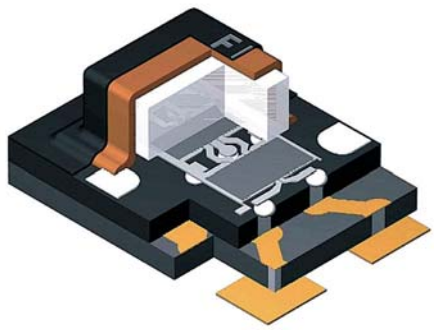

Figure 28: Miniaturized SAW filter in a CSSPlus package (Source: EPCOS)

In this context, bridging circuits between the control chips and the components to be controlled are also needed. In digital control, there is a trend towards lower voltages (e.g. 2.7V), whereas at the component level there is a trend towards higher tuning voltages (e.g. 150V), as this brings higher component linearity. Novel integrated solutions for charge pumps incorporating digital-to-analog converters are needed for turning digital control words at low voltages into high tuning voltages. At a higher level, new concepts for controlling these new flexible RF subsystems are needed to address built-in self-test, health monitoring, and, critically, built-in self-calibration.

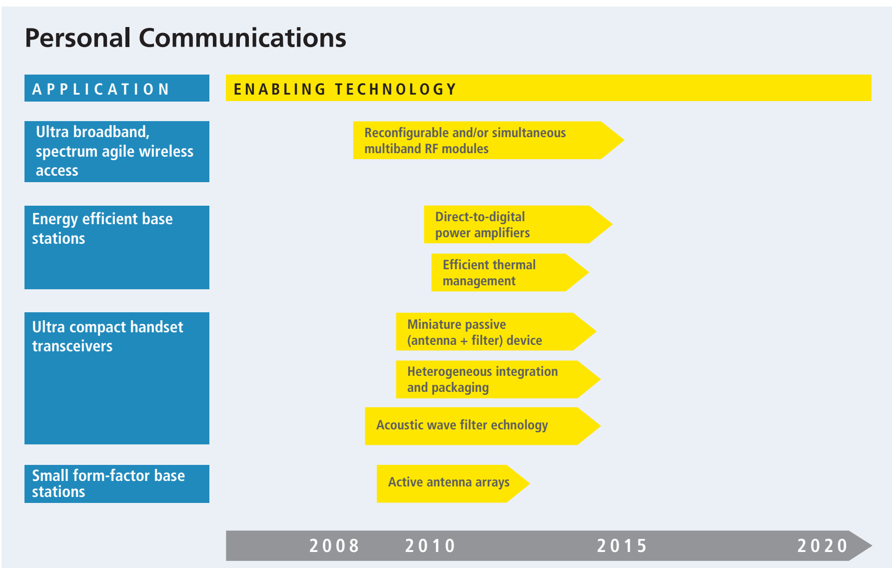

Figure 29: Roadmap Smart Systems for Personal Communications

Smart subsystems for the RF transceivers of the future will rely on adaptable components to give flexibility in functionality and on intelligent control to steer those components in a coordinated fashion.

Technologies for lower carbon footprint: In radio access systems the great consumer of power is the RF transmit chain. Therefore reducing the carbon footprint of radio networks requires improvements in the efficiency of RF transmit power amplifier solutions. One promising research direction is to revisiting the analog-digital divide with direct-to-RF DACs and RF switched-mode power amplifiers.

Finding efficient solutions for removing or scavenging the waste heat generated is also critically important. Smart fan trays can bring additional power reductions (and improved reliability) for communications systems with forced-air cooling, through the deployment of smart algorithms to optimise the air flow. Improvements in heat sink and heat pipe technology will benefit smaller systems such as femtocell basestations, access points, and the larger handsets.

Machine-to-machine connectivity

The ability to communicate with either other nodes or the main network infrastructure is an essential characteristic shared by many smart systems. This holds across a wide range of applications, from health monitoring to remote water quality sensors, from automobile corner control units to smart utility meters. The requirements on the communications transceivers needed are similar across a wide range of smart system applications:

- A high degree of miniaturization
- Extreme power efficiency
- High spectral efficiency
- Secure communications
- Low cost
- A high degree of scalability across aggregations of very large numbers of devices

These requirements are different from those of personal communications transceivers – the power efficiency requirements are more demanding, the need for high data rates is lower, etc. Thus existing technology will not fully unlock the potential of smart systems – further advances are needed for feasible machine-to-machine communications.

Research is needed in the following technology areas:

Hardware level
Advances in RF antenna and filter design for miniature, low-power designs: Applications such as body area network nodes and "smart dust" sensor networks for structural integrity monitoring call for unobtrusive antenna and radio solutions that fit within ultra small volumes (mm3 level) and consume ultra-low power (mW level) for frequencies up to 11GHz. Today, antenna and radio technologies are developed separately, leading to non-optimal solutions in terms of size, power and performance.

Furthermore, the physics of ultra-small antennas make them suffer from impedance shifts, selectivity artefacts and gain losses which impact the communication link negatively. Therefore research should address the integrated radio hardware as a single antenna-radio microsystem, rather than as separate components. The approaches used to achieve this would be antenna and radio IC co-design, research into smart adaptive matching schemes, and the development of intelligent close-loop antenna and radio configuration algorithms. Research is also needed for miniaturised beam-steering antennas arrays implemented using MEMS/CMOS technologies, for improving range and reducing required RF power levels.

Advances in low-GHz radio IC technology: The low-GHz (300MHz-2GHz range) presents significant advantages for applications such as body-area-networks, man-to-machine and machine-to-machine applications. Firstly, the propagation characteristics have much lower attenuation than with multi-GHz (5GHz – tens of GHz) bands, resulting in longer ranges. Secondly, unlike multi-GHz radios, low-GHz radios can have low-current operation (mA-level) at low voltages (1V level). The challenge is to achieve miniaturization of low-GHz radio technology. The approaches to reach this would include research on low-frequency, 1V RF MEMS technologies, on ultra-low power design in ultra deep-submicron RF CMOS technology, and on high-efficiency DC-DC power-management solution.

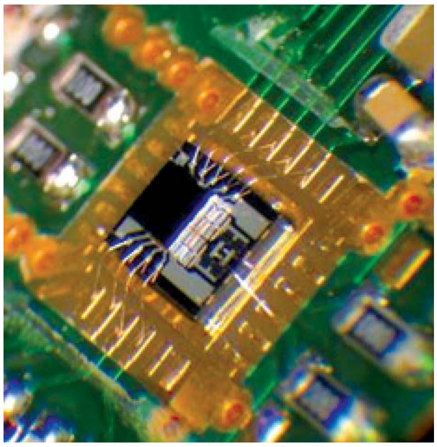

Figure 30: Picture of a 2.4GHz RF front-end co-assembled with BAW RF-MEMS resonators (Source: CSEM)

Advances in packaging and module integration for miniature, low-power designs: To meet performance, cost and reliability requirements while achieving dramatic size and height reductions, new packaging approaches involving high-Q integrated passives, baluns, microacoustic filters, switches, power amplifiers etc. are required. Critical in this will be the development of a new generation of SAW and BAW filters with respect to substrate materials and packaging, e.g. GBAW filters and band VII duplexers. Also required is the realisation of MEMS and IC and SiP platforms for miniature radio modules. Overall, the challenge will be to realise ultra-small (mm3-level), ultra-slim (few 100 m) and flexible (wearable/stretchable) RF micro-systems.

Integration of NEMS, MEMS, and classical Bipolar/CMOS/SOI integrated circuitry:
High-performance integrated radio technology is moving towards embedding a variety of HF-, IF- and LF-MEMS technology to enhance the radio performance while reducing the volume and cost. Simultaneously, ultra deep-submicron CMOS provides massive digital processing capability at low cost and power consumption, which will enable software-defined and cognitive radio paradigms. Merging both paths together could draw on the strengths of both, compensating for the NEMS/MEMS drawbacks (e.g. process/fabrication variations and tolerances, mismatch, temperature dependence, etc.) in the digital domain. Research should address calibration, compensation, and on-chip test schemes for NEMS/MEMS-based radios, methodology and algorithms for designing NEMS/MEMS radio architectures, and the characterization and modelling of RF NEMS/MEMS.

New circuit design techniques and micro-generation techniques:
Power supply and power management are critical components of the transceiver solutions for any smart system. This is particularly the case for widely deployed aggregations of wireless sensor nodes with a high degree of autonomous operation and ultra-small physical form factors. Radio circuits and architectures must be developed with low-power standby solutions and with minimum energy per transmitted bit as a key design metric.
Research is also needed into exploiting point-of-use renewable power sources for the transceiver section.

Figure 31: MEMS-based device for energy harvesting (Source: SINTEF))

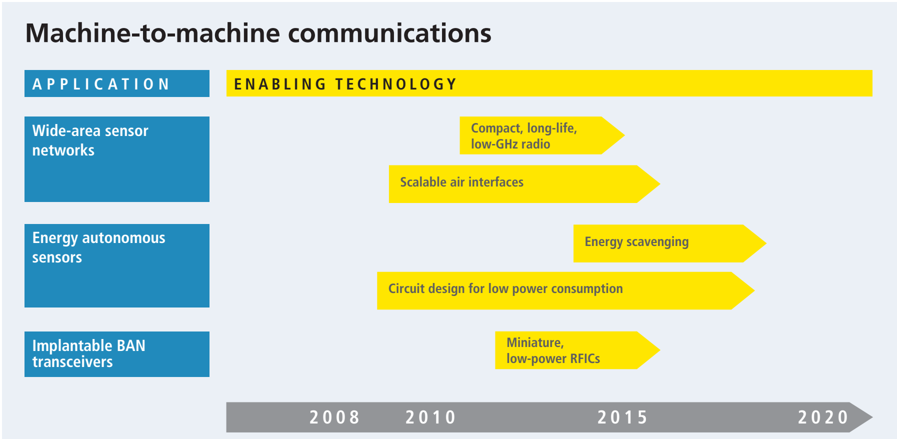

Figure 32: Roadmap Smart Systems for M2M Communications

For more complex systems, it is critical that there is research into modelling, simulation and prediction of energy use for improved energy efficiency and automatic configuration algorithms for optimization.

Coupled EM-thermal-acoustic-mechanical simulation and modelling methods:
Much has been achieved in recent years in design tools for individual technology domains such as low-power digital processing, analog and RF integrated circuits, MEMS and NEMS systems. However, successful low-cost, high-performance, miniature radio transceiver systems require the simultaneous exploitation of multiple such domains in the same chip or package.

For example, for acoustic wave devices, parasitic acoustical resonance phenomena also map into parasitic electrical properties. Simulation environments and modelling tools need to reflect the reality of the heterogeneous implementation environment. Research is needed into simulation packages and design tools which have close coupling of the underlying physical phenomena: electromagnetic propagation, circuit-level behaviour, and acoustics, mechanical and thermal properties.

System level

New scalable architectures for the machine-to-machine communications:
ll of the existing solutions for machine-to-machine communications are severely limited in their scalability. Cellular systems have good coverage and range, but have high transceiver costs and power requirements. Other solutions, such as Zigbee, lack in capacity and coverage. Research is required for communication architectures and protocols which smoothly scale over a variety of data rates, communication duty cycles, power availability, and allowable transceiver form factors. The goal would be solutions that can address a multiplicity of applications and connect the estimated tens of billions of smart systems that require (mostly wireless) connectivity. Approaches would include long-range, cellular-like systems, hierarchical approaches and flat-architecture mesh-based solutions, using a range of frequency bands up to 11 GHz.

Resilient network design and robust smart systems in the face of failure:
Many smart systems are deployed in safety-critical environments such as cars, aircraft, and medical environments. Hence the communications require (a) an assured level of internal reliability in harsh environments, (b) reliability in external connectivity in the presence of interfe-

rence and finally (c) fault tolerance in the event of failure. Solutions will emerge from the creation of proper safety assurance and graceful degradation methods. Multilevel approaches will be needed, addressing the challenges at the hardware, radio-interface, and networking levels. This will include the design and invention of new error detection and correction methods suitable for the low duty cycles and stringent power requirements of many smart systems. Also, in order to create fault tolerant smart systems, advances in data fusion will be needed, with data streams coming from multiple networks including wireless communication, localisation and sensor networks.

Secure communications methods for machine-to-machine and man-to-machine connectivity:
Just as in personal communications, data in many smart systems will need to be private and secure from deliberate interference, e.g. communications for some smart card applications and for health monitoring platforms built on body area networks. Existing methods for RLC/MAC encryption, protocol and interface security from personal wireless networks are inadequate for the requirements of machine-to-machine communications.

›› 9. Smart Systems for Safety and Security

Vision

Statistics show that we live in a much safer world, yet there is still a constant demand for increased safety and security in virtually every aspect of our lives, driven by the principle that 'one death is one death too many'. It reflects itself in public demand for personal emergency and home security systems, and government-led protection from crime and terrorism. However, this is always accompanied by the need for personal protection without restriction of liberty or limitation of privacy, which means that safety and security systems need not only to be reliable and easy to use, but also capable of safeguarding the privacy of end users. It is in this area that the ability of ambient intelligence to recognize individuals and be responsive to their individual needs will be highly valuable.

Smart systems can provide the necessary sensors, computing power and reliability at cost levels that allow safety and security to be built into the fabric of our environment. Safety and security systems can be divided into two groups:

Firstly, low-cost personal smart secure portable objects and home protection systems which are affordable for consumers.: As a result of semiconductor integration, these types of devices are reaching simultaneously very low cost and ease-of-use, reaching towards mass markets and every-day accessibility. This has been the case for cryptographic devices, transformed into smart cards in the early 90s and thus paving the way for e-payment, and later, as SIM modules, contributing to the wide success of GSM standard for mobile communications. These security/privacy items are involved also with electronic commerce, automatic identification and security, e-health, e-governmental and institutional, and within home and transportation applications. Key consumer markets where European companies can play a leading role include smart cards (#1 position for European players), mobile chipset platforms, trusted personal devices, payTV, e-banking and digital ID.

Secondly, high-performance high-efficiency systems for applications such as public transportation, stadiums, business and banking centres, administrative offices, public IT infrastructures, border security, water and energy distribution, telecommunications and other safety critical systems. Together, the systems in this second group outline the rapidly growing e-Government market and the demands for homeland and public security.

New threats have arisen and attacks even with limited resources could have a major impact on these vital infrastructures. The new secure solutions need to increase people's security without restricting their freedoms and their mobility. The 2009 budget requested by the US Department of Homeland Security is US$50.5 billion. Europe has launched a Security research program in this domain.

The safety and security equipment market can be estimated at approximately 25Bn€, of which 5Bn€ relates to electronics devices, with and expected growth rate of 7%. The European market is more than 1/3 of world market in this domain (approx. 10Bn€).

Rationale and Objectives

It is clear that safety and security not only constitute a major market in themselves, they bring protection mechanisms and are the generic enablers for many other applications and support-related services. To make these systems trusted enough so that we do not end up resenting them, they must be also be small, robust, and easy to use. This puts high demands on smart integration within the final product. Yet their requirement to be highly trustworthy also means that they must be complex and multi-functional, so that they make decisions based not on a single parameter but on combinations of parameters (e.g. image recognition, fingerprint, voice, iris pattern). These secure smart systems will involve the integration of a wide range of sensors, MEMS and opto-electronic devices. Such devices will also need to communicate reliably by wired and wireless networks, and they must be made tamper proof and able to withstand environmental conditions that might affect their performance (e.g. radiation, chemical corrosion, shock).
The following considerations are based on strategic objectives defined by the European Security Research Agenda for the homeland security segment and by the core group for the Information Technology security segment.
A range of technologies have to be combined to optimize solutions and allow innovative smart systems integrated product generations. These incorporate:

- Heterogeneous Materials
- Sensor and actuator technologies
- Computing and connectivity components
- Smart packaging
- Combined integration and processing

The outstanding capabilities of smart system devices will be exploited in safety and security applications for detection, identification & authentication, secure transactions, storage & communications, anti-tampering, positioning & localising, detection of abnormal behaviour, detection of hidden dangerous objects/substances, for non cooperative, mobile individual or target recognition, the detection of ill and/or infectious people and warnings associated with with real-time data transmission.

For these applications, market opportunitiesexist in terms of Smart Cards, TPD devices, electronic tagging, component and equipments, e.g. autonomous smart sensors/smart dust, imaging devices (IR, Ultra Sound, µXray, THz), NRBC sensors, biosensors, biometric scanners and sensors as well as smart clothes.

Ensuring safety and security in society and vital operations has become a considerable challenge in Europe. Technology itself cannot guarantee security but security without the support of technology is impossible, so there is huge development potential in this area. Important application areas for technologies that ensure safety and security are energy distribution grids, telecommunication infrastructure, water treatment and supply as well as sewerage systems, traffic and transportation, the safeguarding of people, safety in industry and service operations, real estate and office safety, and information security. To satisfy these needs, a broad spectrum of applications is apparent:

- Secure checks via ID and detection devices providing secure access within transportation, sensitive location entrances, borders and e-government services
- End to end interoperable secure communication and IT infrastructures
- Secure home and personal assistance
- The identification, localisation and tracking of platforms, goods, containers, people, emergency services and inventories.
- Personal protection and equipment for first responders and population in incident crises. Mobile laboratories for deployment in areas contaminated by nuclear, biological or chemical agents

Successful solutions must be sought at the system level spanning materials, components, miniaturisation and the integration of converging technologies.

Research Priorities

Safety and security will be increasingly dependent on how technology can be made to serve the needs of a complex society. Several new applications have already been developed and proved for increasing safety and security, for example the prevention of biohazards or pandemics. In the future the security of citizens, security of critical infrastructure, as well as industrial activities, information security and the technologies and services of the security industry will be key issues for research and development.

IT Security

This involves the founding of the smart systems related technologies needed to meet Information Technology security challenges:

- trusted personal devices,
- personal emergency and home security systems
- security of Information Technologies within infrastructure

Secure Personal Devices
Several form factors of TPD Trusted Personal devices exist: smart cards, memory sticks, RFID, RF key-sticks, terminals.

Secure IT Technology for Infrastructure

Information and communication systems have come to play a crucial role in every walk of life. But certain types of organisation are more vulnerable than others to the consequences of a data security breach. Governments and institutions are good examples, as are financial institutions and operators of critical infrastructure.

Smart and secure device packaging

Materials used for packaging are the first barrier against attack. Three solutions exist today to remove packaging material in order to access the target module or IC: dry and wet chemistry, mechanical tools, laser assisted package de-processing. In case of attacks, access to the die is performed by using one or a combination of these methods. However, new materials based on nanotechnology as well as new 3D integration techniques could make access to the die impossible. Ink projection techniques will allow the provision of non visible conductive contacts.

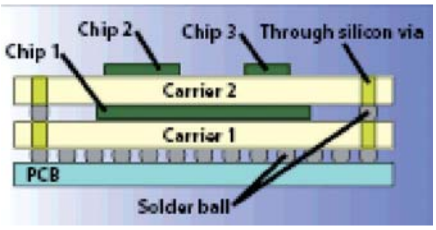

Figure 33: New materials for secure device packages

Another approach to tamper proof packaging is the application of new materials and structures to inhibit the analysis of the circuitry by destructive and non-destructive methods, like X-ray and Ultrasound. Figure 33 by example of assembly using Through Silicon via technology. The access to Chip 1 is impossible using conventional methods.

Integrated µsensors

Sensitive micro-device modules to embed inside device packages will allow the detection of any physical intrusion, piercing of the envelope or any visual intrusion like laser, UV or backward X-ray observation. Movement or pressure sensors can detect tamper actions upon coatings. Embedded micro-batteries will allow monitoring of the behaviour of the overall system and can be activated such as to erase secret and personal data in case of violation. All these sensors need be highly miniaturised and proof against false alarms.

Obstruction techniques

Burying devices into mainstream PCB or electronic substrates will defeat cursory analysis. New changing resins will allow unique identifications for devices. More generally Physical Uncloneable Functions (PUF) could be developed. These are functions that are realized by a physical system in such way that the function is easy to evaluate but the physical system is hard to characterize, it is a cost-effective way of generating secure keys for cryptographic purposes.

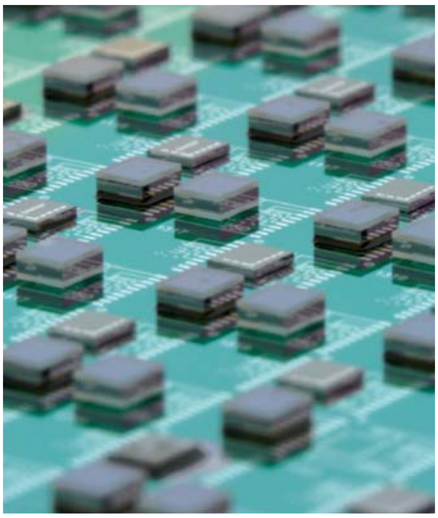

Figure 34: 3D integrated dummy MEMS devices with TSVs mounted on a test substrate (Source: SINTEF)

3D packaging

The 3D integration of sensors and electronics is expected to be an enabling factor for miniaturized and autonomous sensor nodes in the future. The footprint of sensor nodes can be reduced when chips are stacked. Stacking can be especially favourable for any kind of pixel based sensor where TSVs (Through Silicon Vias) down to an underlying electronics chip can both increase the fill factor of the sensor and shorten the routing distance from the pixel to the read-out circuit. Miniaturization by stacking enables combinations of multiple sensors like accelerometers, gyros, pressure sensors etc. into one sensor node even when the individual sensor devices have been manufactured separately.

3D integration of heterogeneous systems with sensors and electronics can be more complicated than 3D integration of more homogenous systems like for example stacks of memory chips. Sensor chips or wafers are normally thicker and more fragile than regular electronics wafers demanding deeper TSVs and more careful process integration. TSVs and interconnect technologies for the 3D integration of sensors and electronics are emerging gradually in ongoing research programs, but still no standards have been established. Existing TSV and interconnect technologies must be adapted from the electronics industry, modified and combined with special technologies developed solely for sensors.

EDA flow towards security by design

Although a lot of countermeasures against intrusive and side channel attacks have been proposed and used today to get access to the secret keys and other cryptographic data, none of the countermeasures provide absolute resistance and generally are broken after a certain time. Very few criteria exist today to assert the efficiency of given countermeasures regarding smart systems. New classes of attacks will need a methodological approach to the development of countermeasures and their related assessment.

Also new failure analysis approaches need to be clustered at European level such as to understand forthcoming attacks and to propose solutions to the design community.

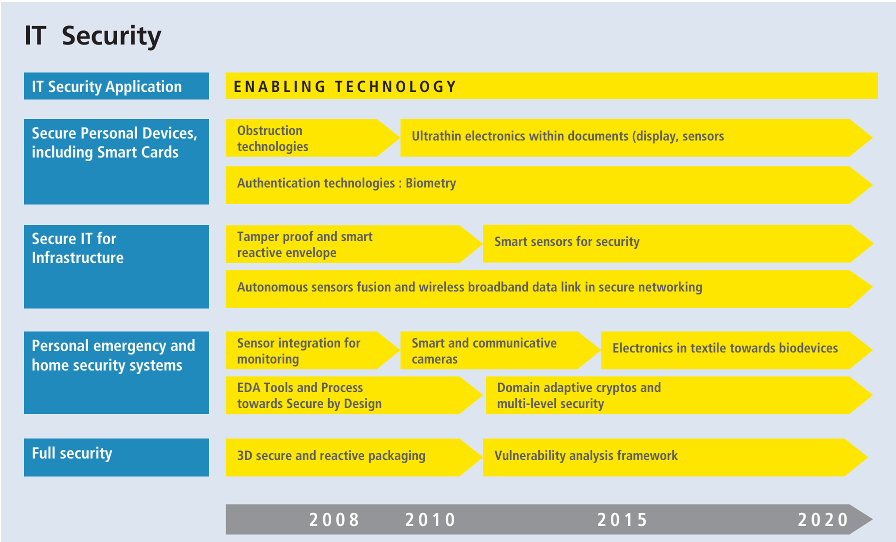

Figure 35: Smart Systems for IT Security - Roadmap

Smart Systems Research Challenges for IT Security

The research priorities address the following areas:

- Smart secured devices, requiring new technical nanoelectronic techniques from systems aspects like embedded sensors, separation of concerns, … to hardware technologies like buried components in substrates, sensors and cryptographic engines, miniaturization and low power consumption, resistance to side-channel attacks.

- Packaging and technology against counterfeit and security threats to the device. Anti-tampering coating and encapsulation. New materials to counter invasive and non invasive attacks. Embedded microsensors and reactive devices.

- Smart Systems in 3D packaging offering high performing signal processing, flexible interconnect and communications capabilities

- Vulnerability analysis to counter new hackers and attacks (physical analysis + reverse engineering, …). Failure analysis capabilities. Design methodology. Security Insurance and related capabilities

Several technologies apply both to IT and Homeland security, namely biometrics, sensor integration, the fusion of autonomous sensors. The related research will be introduced in the homeland security chapter.

Homeland Security

The following focuses on the foundation of smart systems related technologies needed to meet the homeland security challenges:

- identification, sensors and surveillance namely for border security, persons identification and authentification, detection of abnormal crowd or individual behaviour, detection of dangerous goods (such as CBRN, drugs, explosives), tracing dangerous products,

- protecting vital infrastructure such as critical sites, the utilities and food supply chain, the IT and communication infrastructure and the transportation infrastructure.

Detection, authentication and surveillance

Biometrics are one approach to allow authentication or identification of persons to access their private and personal devices, but also to improve access control at border checkpoints, within countries and at critical infrastructures. The technique should increase the efficiency of security checks while giving comfort to the end user. Data related to individuals needs to be preserved so secured. Current concerns are aimed towards improving fingerprint sensors in speed and to allow easier positioning of the finger, to bring multi-modal biometry (fingerprint, face, iris, retina recognition, signature …), to minimise the reject ratio and false acceptations, and to generate cryptographic keys from personal ID data. Multi-modal technologies need also to be technically adapted to the target applications: home comfort appliances, secured transactions, border access, e-governmental applications.

Figure 36: Example of smart detection and ID

Spectroscopy can be used to detect trace gases and chemical agents from explosives and toxic gases prior to an incident. These kinds of sensors currently show limited usability due to the lack of selectivity and sensitivity. Photo acoustic detection combined with optical readout and quantum cascade lasers makes it possible to detect such gases at very low concentrations, and the detection limits can be further increased by the same up-concentration means as used by GCMS. This is possible due to the very low volumes required by a photo acoustic detection cell, which also means that this technology is well suited for miniaturisation. The sensitivity will be in the parts per trillion ranges, and will open for several applications within homeland securities as well as other demanding applications. Optical spectroscopy may also be used to reduce the impact of an incident by monitoring the level of toxic gases, i.e. detection of CO, both for toxicity from a fire as well as early warning of fire to prevent loss of lives. Spectroscopy can also be used to detect gas leaks and make an image of them.

THz techniques in security systems
THz radiation bridges the gap between mm-waves and mid/far IR. Until rather recently this spectral range has received limited attention only due to the lack of efficient and low/moderate cost THz sources and detectors. On the other hand, there are a number of promising applications such as THz imaging (concealed weapon and explosive detection) and THz spectroscopy (pharmaceutical, biomedical, and materials inspection applications). One prerequisite for the successful exploitation of the potential of THz technology is the availability of low cost, versatile, powerful THz emitters and highly sensitive, uncooled, small size detectors which lend themselves to the fabrication of detector arrays (1D or 2D).

THz can be used in the imaging of concealed weapons under clothes for local or stand-off detection in security applications. The priority for components to be developed is related to the need of THz stand-off imaging in terms of more compact systems which can be achieved while increasing frequency. These systems will need to use improved performance components such as higher power and more compact sources as well as higher sensitivity more compact real time 2D array detectors in order to optimize the trade-off between higher resolution requirements together with higher detection range.

The availability of several frequencies for sources and detectors will be useful for multi spectral imaging in THz for the identification of chemical or explosive materials.

Figure 37: Example of THz imaging (Source: QinetiQ)

THz can be used also in mapping of biological materials. THz sensing phenomenology in DNA and related biological materials has been used to produce credible experimental evidence for the existence of species-specific resonance features that arise from phonon mode activity at the molecular level. These demonstrations validate earlier theoretical predictions of a link between THz resonances and internal structure (e.g., dependent on hydrogen bonds of the double-helix base-pairs and therefore defined a new spectroscopic approach for interrogating microscopic information (e.g., genetic information encoded in the variety and arrangement of DNA nucleotides) that could be useful for bio-agent detection and analysis.

IED
Major technical challenges exist relating to the detection of improvised explosive devices (IED), explosive vapours and chemical agents. Microsystems technologies have the potential to considerably enhance the detection limits, speed of detection and the realisation of man-portable detection systems for such threats. Some of the major Microsystems technology challenges that must be addressed are sample pre-concentration of both, vapours and liquids, extremely small sample volume pre-treatment and manipulation, the integration of miniaturised fluidic and optical detection systems and the development of monolithically integrated sensor suites. In addition to the development of the sub system components, considerable challenges have to be overcome in 3D integration to develop 'Lab on Chip' systems that are low cost and all pervasive.

Critical Infrastructure Protection

Data fusion for intelligent sensors
For critical infrastructure protection, the focus is on combining data from a large number of dispersed cameras and sensors. Future applications will have to consider above 20 sensor types and above 40 simultaneous feeds. Future generation enhancements to be developed will include: Localisation of targets from triangulation across multiple sensors, auto target-following for pan-tilt-zoom assets, wireless networking and communication between dispersed sensors to provide an integrated surveillance system, wake-up and actuation to conserve power, energy harvesting and low power consumption. Related middleware is necessary to explicitly ease the process of migrating algorithms into real-time implementations (e.g. on embedded platforms). General purpose tools for data fusion include trakking toolkit (easy to deploy implementations of both established and novel tracking algorithms), a Bayesian modelling Tool-kit (implementing state-of-the-art Bayesian modelling algorithms) , neural network approaches (a self-organising neural network approach) and video analytics

Integrated sensors
The surveillance and control of environments often requires rugged and compact systems with sensing functionality. Wire

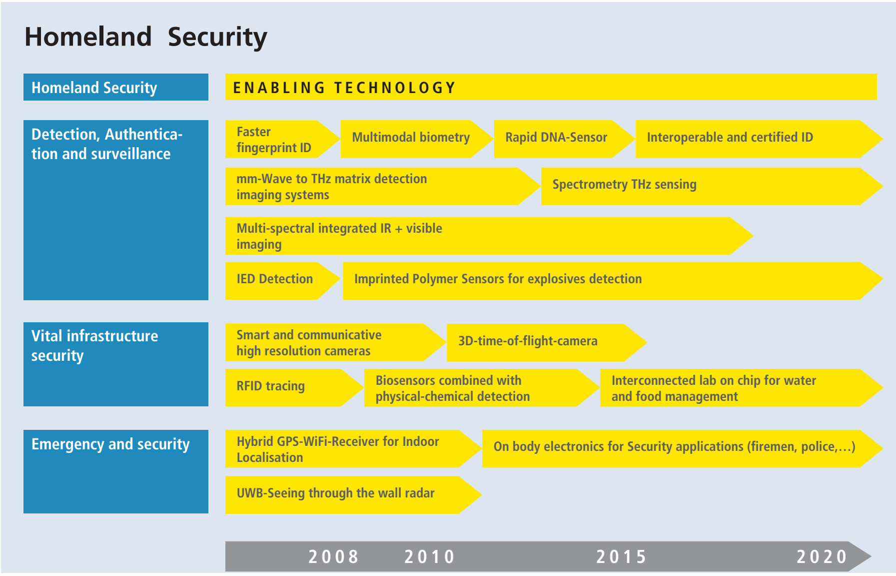

Figure 38: Smart Systems for Homeland Security - Roadmap

less sensor networks are very well suited for these environments, since wired sensors can be either too complicated or too costly to install. Wireless sensor networks demand energy efficient miniaturized sensor nodes, which again demand advanced packaging technologies for sensors and electronics.

Active and passive systems for mobile vehicles protection VIP aircraft and vehicles are a specific case of critical infrastructure of exceptional vulnerability and prone to direct attack. Their protection is extremely difficult due to the diversity of possible threat scenarios. This creates a challenge, which requires the employment of highly efficient smart systems and systems integration. The issues of great importance are: detecting threats, identifying threat zones and applying active and passive systems (including the integration of systems) on different platforms.

Securing the supply chain
The secure production and transport of goods and guaranteed integrity of goods are vital to society and business. Terrorist attacks can affect the system in many places. Counterfeiting of products may bring security vulnerability and at least disrupt European commercial leadership.

Smart Systems Research Challenges for Homeland Security

The research priorities address the following areas:

- Biometrics (facial, fingerprint, iris, retina recognition)
- mm-wave to THz imaging systems, enabling hidden objects detection at low cost and without the risks associated to the current solutions based on X-ray imaging
- Spectrometry sensors, that can detect gases and chemical agents prior to accidents
- High resolution / large number of pixels cameras, enabling precise identification by large field of view cameras
- Fast, high sensitivity IR sensors, for global scene analysis without light-dependent artefacts
- All weather day/night imaging sensors, avoiding collisions and/or enhancing site protections
- Active and passive systems for individual protection
- Mobile scanning devices for container screening
- RFID tags, for tracking of identified of authorized objects
- Sensor fusion, as precise detection or identification without unacceptable false alarm rate will generally be obtained only by cross-checking information coming from different type of sensors
- Localisation technologies

Research Strategy 2005 to 2015 and beyond

The roadmaps show estimated timelines of development activities for the visions of IT security and homeland security as described above.

Smart Secure packaging

- Development of new shielding encapsulation based on ink or nanomaterials
- Development of micro-sensors and micro-batteries for smart embedded security in device packaging to counter different forms of attacks.

All-in-one cameras
The development of smart compact imagers able to operate in a broad range of situations (day, night, bad weather conditions, on fly detection and identification …) exploiting visible/NIR low light level sensors and embedded real time processing.

Spectrometry sensors
The development of compact infrared laser sources and smart imagers able to visualize gas leaks in a broad range of situations. The combination of microsystems technology with wireless communication to miniaturize spectrometry sensor systems and enable deployment on a larger scale.

Fast high sensitivity IR sensors
The development of high resolution, high

sensitivity, fast IR sensors to enable complex global scene analysis and real time operation.

THz-Applications
The development of compact broadband high average power THz sources, especially for spectroscopic measurement based sensors.

The development of efficient THz matrix detectors with both high detection sensitivity and transportability, especially for imaging applications.

Underlying technologies
The technologies developed for 3D integration of heterogeneous systems with sensors and electronics have potential for a continuously reduced form factor. These technologies should be implemented into demonstrators and go through test programs to ensure the required reliability for typical applications.

›› 10. Road towards the EPoSS JTI

Rational and Objectives

To pool all possible resources new forms of cooperation are needed combining the best private and public efforts. Research support mechanisms currently applied at European level are not able to fully succeed in doing this, as the direct involvement of industry into the process of priority setting on content, structure, and instruments of collaborative R&D is still not sufficiently developed. Aligning existing industry technology roadmaps with those pursued by public authorities in research funding programmes is major challenge for future European research policies. Thus, if the definition of research priorities is to be strongly governed by industry players and closely linked to their roadmaps, the only existing mechanism currently available to address this problem at larger scale is the newly introduced – at least in some technology sectors - model of the “Joint Technology Initiative” (JTI).

Accordingly, the EPoSS stakeholders intend to set-up a European Technology Initiative based on industry priorities. Its primary objective consists in strengthening the technological competitiveness of national and European industry in the Smart Systems sector. As this sector is characterised by a strong presence of small and medium sized companies at all levels, one of the major objectives will be to achieve their sustainable integration into the Smart Systems value chain.

The EPoSS JTI will help to overcome the deficits of the existing fragmented landscape of public support in Europe at the various administrative levels and provide a coherent European R&D approach as outlined in the EPoSS Strategic Research Agenda. In this context influences on national policy orientation will be a further positive effect and the first steps towards “Joint Programming” may be induced.

Further to the implementation of a concerted strategy and the pooling of existing budgets from different sources (MS, COM, and regions), it is also intended to increase the volume of financial efforts of all interested parties related to Smart Systems technologies and consequently to achieve the necessary critical mass and to contribute by that to realise the 3% Lisbon objective.

The financial stability and the multiannual work plan (for up to 7 years) shall contribute to the credibility of such a programme amongst the stakeholders and will offer a major planning consistency compared with other existing support models. A well governed approach to drive migration of research results into products will then raise benefits for the industry players as well as for the competitiveness of Europe in general.

By setting-up the EPoSS JTI it is expected to realise a flexible instrument able to take into account economic requirements and technological changes. At the same time - once the initiative has been established - bureaucratic burdens will be reduced for all parties involved. The expected achievements will consist also of a higher impact and leverage of the European Commission’s and of national member states’ financial input. Positive influences on public support priorities at member state level will be a further result.

The Smart Systems sector, beyond every other technology sector, shows a broad variety of companies – particularly SMEs - over virtually all European member states. Consequently, the EPoSS JTI will guarantee the broadest involvement of European companies and a high impact across Europe and its value chains. Therefore, the EPoSS JTI will offer a European dimension as no other initiative can do.

European industry in particular will directly benefit from the JTI by closing the gap of R&D support by means of a new model for implementing large self-determined collaborative R&D, ensuring a precedence of industry interests. Furthermore an increase of public budget volume for Smart Systems research will provide means of funding which currently are not available. Last, but not least, participating companies will benefit from a lower failure rate in acceding to public funding and gain a pay-back guarantee for their investments.

Implementation

The format of the EPoSS JTI will be a programme comparable to existing R&D support programmes. The JTI will be based on financial input from industry, the European Commission and the highest possible number of EU member states. The content and mechanisms of the programme will be determined by European industry within the regulations that the European Union has set for this instrument. The format of the projects to be carried out will be characterised by the following aspects: The projects will be collaborative European projects guided by larger European companies including also SMEs and public research organisations. Precedence will be given to larger projects focusing on strategic industry R&D priorities and addressing major economic and societal problems and global megatrends and which will lead to breakthroughs in terms of product development through focussing on industrial R&D.

It will be worthwhile to follow the path of the already established JTIs as Artemis and Eniac. Furthermore, by comparing the applied models for these joint initiatives with models of other public private partnerships (Clean Sky, AAL) further positive aspects shall be identified and integrated into the EPoSS JTI approach. In particular the idea of implementing a kind of guarantee for a return on investment for the industry involved into the set up of the initiative is anticipated..

The time horizon for the implementation of the EPoSS JTI will follow the common budget planning procedures within the European Commission and shall thus be realised in the FP7 WP 2011-2013. The first call could then be launched at the earliest in the end of the year 2010 to allow for first projects to be funded in early 2011. However, for this to become reality, actions are required today to start the official process.

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EPoSS

European Technology Platform
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