# Top Sector
# High Tech Systems & Materials

## Roadmap Mechatronics & Manufacturing

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## 1. Societal and economic relevance

The societal and economic relevance of Mechatronics and Manufacturing (M&M) is established through the various applications within HTSM that are enabled by high tech M&M innovations [ref: http://www.pointone.nl/Innovatieprogramma/Roadmap_2012].

Advancements in M&M are essential to tackle the big challenges our society is facing. Proper design of machines like for example novel robot technologies or energy efficient drive techniques can constructively help to address problems we are facing in Climate change (environmental monitoring), Energy (efficient design of machines), Health (novel diagnostic or robotic intervention), Mobility (coordinated intelligent transportations) and Security (Monitoring and Intelligent prevention or Screening).

*Mechatronics* integrates electrical, precision mechanical, thermodynamic and control engineering and software for the design of products, systems and manufacturing processes. It relates to the multi-physics and multidisciplinary design of systems, devices and products aimed at achieving an optimal balance between all basic disciplines. The application areas include numerous applications, such as mass production equipment, consumer product design, medical equipment, instrumentation, automotive systems, manufacturing methods, computer integration and process and device control. Important area of research is the design of machines, devices and systems possessing a degree of computer based intelligence like in lithographic systems or robotics applications.

*Manufacturing* covers the area of high tech supply chain, fabrication technologies and processes, parts production, assembly and integration of high tech systems or modules. It represents an industry of considerable size that is the foundation under industrial realization ('kunde') of the high tech mechatronic architectures and designs. Key in understanding the relevance of the Manufacturing side of things, is that a society can only make money to pay for its prosperity if they make products, not by selling services.

The combination of mechatronics and manufacturing in the Netherlands constitutes a unique global position and a valuable competitive advantage in various high tech applications and businesses. This insight is not new, and has already been extensively addressed in various roadmap documents within the high tech eco-system. This roadmap gratefully uses (and refers to) these valuable references [ref: http://www.pointone.nl/Innovatieprogramma/Roadmap_2012].

### 1.1. Global market size.

The market size of this sector is considerable; the Netherlands has seen the rapid development of an industry for High Tech Systems in recent decades, with annual turnover totalling over EUR 27 billion. The ambition is to at least double this amount in the next 8 years. This growth is the result of a high rate of innovation of both products and the underlying technology. For the Dutch high tech the market for lithographic machines alone can be estimated currently around 7 Billion Euros a year. Rising fields like robotics are estimated by the Japanese Robotics association to rise above 60 Billion in 2020. Considering the same mechatronic technologies, and other needed and available expertise's Robotics could possibly follow the same success of the lithographic sector which reached undisputed international leadership by Dutch innovation.

### 1.2. Competitive position of the Dutch industry and total R&D investments.

The Dutch industry plays its role well. The products that are being produced within the HTSM area are exported world wide, and in many cases, are among the top 3 in their market segments. Many of these products has been manufactured to a large extend in the Netherlands, and many contain advanced mechatronic designs, which are the result of the 2.1 B€ R&D spending of the industry.

## 2. Application and technology challenges

### *2.1. Application challenges*

Within the HTSM scope, mechatronics and manufacturing is found in various application oriented roadmaps (e.g. Semicon equipment, lighting, printing, solar, healthcare, automotive, aerospace [ref: http://www.pointone.nl/Innovatieprogramma/Roadmap_2012]). Also the application of Mechatronics will increase in the field of agricultural and food equipment. These roadmaps provide application specific background for the M&M technology challenges that are (not so surprisingly) shared to a large extent.

While the other HTSM theme roadmaps are still under development it is not possible to enlist the final M&M challenges as derived from the various applications. In the mean time valuable reference documents are used for relevant input [ref: Point-One Phase 2 roadmap and annual plan 2011, Brainport Industries business plan CFT2.0, RoboNED]. To keep the M&M roadmap compact, a listing of the M&M relevant sections from these reference documents is given in the appendix.

Here, an attempt will be made to summarize the shared equipment/system functions and innovation drivers in the following overview (without claiming to be complete):

| Equipment/System functions | Shared innovation drivers |
|---|---|
| Imaging & patterning or image capture & observation<br>Inspection & metrology<br>Substrate / object positioning<br>Substrate / object handling and manipulation<br>Deposition<br>Component placement<br>Picking objects<br>Packaging<br>Autonomous & intelligent task completion | Performance (accuracy, productivity, bigger substrates, smaller objects)<br>Novel sensor technologies and metrology, vision integration<br>Low cost (equipment + development + manufacturing)<br>Reliability, low maintenance, fast repair<br>Speed (innovation, first-time-right, time-to-market)<br>QLTC and life cycle management, optimized manufacturing and assembly flow<br>Clean and conditioned environment (contamination, particles, radiation, harsh, heat, noise, vibrations, EMC, cryogenic, …)<br>Green: Energy efficiency, low waste, sustainability<br>Intelligence and autonomy, adaptation or robust to varying conditions<br>Human – Technology interaction (safe, haptic, intuitive)<br>Information & data processing and transport, sensor fusion, 3D representation, efficient calibration, |

### *2.2 Scientific challenges*

From technology side the accompanying challenges can be formulated (without claiming to be complete). The line between the description of technology challenges and the formulation of research directions is thin, so there will be some overlap with section 3.

Better mechatronic systems or better manufacturing technologies and infrastructures can be achieved by giving attention to better components and a better integration of those to achieve a complete system (also known as system architectures). The innovation on both the component and integration level is driven by continually increasing computational power, novel micro and nano fabrication technologies and supporting (CAD) tools which speed up the development of complex systems. The Dutch industry has a world class position in mechatronic (precision) design and building of complex machines, but there are a number of technologies developed in academia which have not yet reached industry and a number of technologies which should still be developed and made available to industry.

As components, on the sensing and metrology side, fast and accurate sensing technologies are necessary which can be applied broadly both in manufacturing and processing as well as for (semi)autonomous robotics applications. Considering a growing number of applications outside a well structured environment like it can be the case in many robotics applications, an improvement in precision, reliability, size, costs of sensors, and their fusion for better perception capabilities is mandatory. Beside the perceptual capabilities, navigation and planning are fundamental in both mechatronic and manufacturing applications.

Micro and nano technology can support the development of such sensors as well as new materials, computer power and novel integrations and architectures can allow more robust and reliable applications at lower costs.

There will be a great need for new smart materials, sensors and actuators, which can be cheaply produced, possibly on demand, in different shapes at low scale and costs to be dynamically able to adapt to rapidly changing requests from the market. Novel smart system structures with distributed sensing and actuations will require advance control strategies which are able to cope with this increase of complexity and in case of robotic applications with unpredictable changes with environmental interaction.

An increase of needs for mobile (robotic) applications will necessarily have to go hand by hand with innovations in light, energy efficient, compliant and regenerative actuation systems with intrinsic safety for possible interaction with humans as it is necessary for example in healthcare, manufacturing in environments populated both by humans and machines without strict separation, consumer applications and the like.

An increasing complexity paired with increasing reliability requirements can only be achieved nowadays with well structured, verifiable or automatically generated software, being that the biggest source of downtime for any (computer controlled) machine.

Adaptive and learning systems will also be necessary in all those situations where variability is unavoidable like it can be the case in consumer or care applications.

In addition to this, scientific research is needed on how the Netherlands, with its high cost labour, can remain competitive and attractive as a manufacturing country. Optimized supply chain control and lean, efficient production technologies are essential. Identifying research topics here can only be generic, as the manufacturing chapter captures nearly all activities within the HTSM area.

Additional text can be found in the appendix and used documents (listed at the end).

## 3 Priorities and Programs

From the roadmap challenges, as listed in section 2, the next step is to formulate innovation priorities and programs that are to deliver the required innovation. This will be set up from a high abstraction level first, with more detailed research and development topics later.

### *3.1 M&M innovation high level overview*

Based on the funneling of M&M challenges and future roadmap demands from various applications, the categorization for M&M innovation is proposed as:

| | High Precision Mechatronics | Robotic Systems | High tech manufacturing |
|---|---|---|---|
| Science & Technology | | | |
| Integrated System Architectures | | | |
| Industrial translation & transfer | | | |

The columns provide a coarse segmentation across main program lines. The rows reflect the segmentation across the well known range from topical scientific research to industrial innovation and implementation. This overview provides challenges for both academia an R&D institutes in a way that short and long term programs are covered, synergy across parties can be obtained, and safeguards that solutions really result in value for the HTSM industry.

### *3.2 Proposed R&D and scientific research directions*

As a first attempt, more elaborated and topical directions for industrial innovation as well as scientific research are listed below.

- Smart Surfaces
  - Micro/Nano manufacturing enables the creation of massive amounts of sensors and actuators on surfaces for reasonable cost. Such surfaces will lead to innovations in many applications where the increase of computing power will be used extensively.

  - For Robotics such surfaces will lead to systems that are responsive to external effects encountered in unstructured environments
- Smart Structures
  - Increased computing power will allow optimization of modules in many ways. The resulting shapes may be quite complex and the combination with additive manufacturing solutions will allow to create novel structures, that, combined with innovations in sensor and actuator disciplines will allow them to be "smart" as they can react to disturbances in an active way
- Smart Control
  - Driven by the availability of massive computing new avenues for control become viable. Systems may possess many sensors and actuators and all information passing through the control can be used to estimate performance and disturbances.
  - Multi Input- Multi Output control and systems that are adapting to disturbance or system variations may become industrially relevant. But also distributed control approaches to deal with the ever increasing complexity of high tech systems and their control architecture.
- Smart metrology / Sensor Fusion
  - With the availability of low cost, large numbers of sensors systems must combine large amounts of information to take the right decisions. Camera systems have millions of pixels, pressure, strain, temperature sensing and many others will add to these numbers.
  - Research into the numerical handling and into wireless transmission of this information will be needed.
  - Smart nodes, 3D algorithms,
  - Methodologies for accuracy improvement through advanced calibration and correction of (repetitive) errors. In general the deviations in machine performance are considered to be of a repeatable nature. Calibration of such deviations can be done and corrections can be implemented. This appears to be a straightforward strategy. In real systems the required metrology systems, mathematics for parameter estimation, implementation of repetitive control and hardware for in-line correction and computation prove to be non-trivial. New research in these directions may lead to improved performance of equipment.
- Distributed Digital Realization
  - Cyber-physical systems is a rapidly rising field of research.
  - Controlling the function of a complex system with one centralized controller does not seem to be the best future solution. Distributed intelligent agents will be used and they must be able to communicate in an intelligent way.
  - Such distributed systems will allow multi-rate control solutions to be designed, lifting some of the limitations in present day equipment
- Smart system architectures
  - The need for ever increasing capabilities for High Tech systems calls for smart system architectures, that exploit the scientific advancements into integrated system architectures.
  - Typical bottlenecks that current architectures are increasingly struggling with, set the targets for next generation mechatronic and robotic architectures. New systems have to be really lightweight, able to cope with deformation (e.g. quasi-static, dynamical, thermal induced), extended actuation and metrology topologies, and operating under extreme conditions (e.g. vacuum, extreme temperatures (cryogenic to extreme heat), sterile, nuclear radiation, particle / molecular contamination, noise, vibration, ..)
  - New systems must be manufacturable at the right quality, cost and lead times. Real industrial innovation should also implement these into system solutions of high quality and reliability in an industrial application setting at acceptable cost and development time. The basis for this is to be secured in the system architecture and concepts. This must be a leading prerequisite in system architecture.
- Smart design and analysis
  - Solving multi-criteria, complex design problems will be the key to really exploiting the potential in novel system architectures. This probably will quickly go beyond human mental capacity. Shape and topology optimization provide a very promising enabler in this respect to find breakthrough solutions.
  - At system level, adequate analysis tools should be available to safeguard system performance through combinations of system designs at component level and various performance aspects.

- Smart manufacturing
    - Product lifecycle management including adequate ICT solutions and tools.
    - Optimization in the supply chain from design to product with regard to lead time, flexibility and reliability, effort, waste, risk, cost, low stock, etc.
    - Production technologies such as joining, glueing, cleaning, free-form, machining, micro-milling, etc.
    - Additive manufacturing for high tech parts is seen as a promising and rapidly progressing field which provides an unsurpassed design freedom, that opens up many favourable possibilities at system architecture level when combined with design optimization. AM will enable the creation of prototypes and small series at little cost. It will also lead to a novel look at "forgotten"production technologies as casting, which become cost effective again. Furthermore, AM will almost completely take away the step of design for manufacturing, and will able to realize complex designs and small series at no extra cost. See also the printing roadmap.

*3.3 Competitors and future outlook.*
The Dutch industry will face competition from other high tech regions as Singapore, South Korea, Japan, USA and several emerging economies. It is generally belief that we have a leading edge, which we will be able to maintain. It is also understood that innovation and manufacturing have to remain closely knit.

*3.4 Envisioned TKI for M&M*
This section sketches the current ideas about the formulation of a possible TKI format for M&M innovation. This is not at all competed and agreed, and not at the level of a detailed implementation plan. So, this reflects the current status and open for discussion and further elaboration.

Along the high level M&M themes as described above, a TKI format for M&M is proposed under the temporary working title: "High Tech Mechatronics and Manufacturing Innovation Center" (HTMMIC), with 3 main innovation themes:
- Mechatronics for high precision systems
- Robotics systems
- High Tech Manufacturing

HTMMIC should bring together:
- Various companies, OEM's , branche organizations, cooperations
- R&D centers for industrial innovation
- Academic research groups for scientific research

Such that a M&M innovation program is implemented under lean governance that covers mid and long term innovation and scientific research.
Elements and intentions for such TKI are already available in the following existing platforms and consortia within the High Tech eco-systems:

- *Brainport Industries initiatives and business plan under the title CFT2.0:* This initiative has originated from suppliers in the High Tech industry and is a rapidly growing cooperation and building collective funding for manufacturing related technology and innovation. The CFT2.0 business plan sketches a governance model that could be useful in setting up a M&M KPI.
- *Point One Mechatronics working group:* This group of university, industry, and R&D institutes/mechatronic development companies that has a long history under the Point One umbrella and has been steering in the definition of several High Tech mechatronics innovation programs.
- *RoboNED:* Since April 2010, RoboNED coordinates the robotics activities in the Netherlands, eith the aim to stimulate synergy between the robotics fields, stimulate the innovation-ecosystem as well as the social acceptance of robotics in the Netherlands
- *High Tech Systems Platform:* This is a cluster of some 20 Dutch high tech systems companies, all of them leaders in their fields in the world market. The objective of the platform is to promote the branch and stimulate collaboration between the companies.

With this high level of organization across themes and stakeholders from research, education, industry and society, there is great confidence and an excellent starting position to raise industrial commitment to M&M innovation and efficient collaboration across the knowledge infrastructure.

## 4 Investments

In terms of investments and financial overviews it is requested to present an overview of public-private partnership R&D through budget tables 2012-13 and 2014-16. This should also be considering other innovation instruments (such as IPC, Innovation Funds, SBIR, valorization grants).

### 4.1 Industrial partners

Here a list of industrial companies, who have already indicated their interest in funding the M&M Roadmap or who are expected to join. More will come in the near future.
All MEPP BV, Anopanel, ASML, Assembléon, BKL Engineering, Bakkerfijnmetaal BV, Bomacon, Bosch Rexroth, Bronkhorst High Tech, Buhl Fijnmetaalbewerking, CCM, Ceratec Technical Ceramics B.V., Contour BV, De Rooy Slijpcentrum B.V., Demcon, ERIKS Aandrijftechniek, Euro-Techniek, FEI, Festo B.V., FLOS B.V., FMI, Frencken, Galvano Hengelo, Geton Roestvrijstaalindustrie BV, GL Precision, Green Tech Engineering BV, Halin Group, Heliox, HIT, Hittech, Holland Innovative, Hoogerdijk Technical Rubber, IPS Technology, Jansen Precision, KMWE, Kusters Goumans, Lamers High Tech Systems, Louwers Glass & Ceramic Technologies, Mag45,
Maxon Motor Benelux, MCB International BV, Melis Gieterijen, Mevi FMI B.V., MI-Partners, MTA, Nucletron, Nijdra Groep, Norma, Nossin, NTS-Group, Océ, Panalytical, Pezy Product Innovation, Promexx Technical Automation Roosen Industries, Sioux, SKF B.V. , Smits Machinefabriek, Stetec, Technolution BV, Tegema Group, TMC Group, Van Berlo, TSG Group, Van der Hoorn Buigtechniek, Variass Group, VDL-ETG, VHE Industrial Automation b.v., Via Engineering, Wetering Reinventing Brass, Wijdeven, Wilting Components, Witec Fijnmechanische Techniek BV

### 4.2 Scientific partners

All Technical Universities will be natural partners for all things related to this roadmap. Other Dutch Universities as well as NWO institutes and HBO institutes are of course also potential partners The large GKI's can and will also be involved (TNO, ECN, …)

### 4.3 Investments

At this point a budget estimation can be presented, with the remark that this is very much under development because of active discussions with companies and expected response from broad communication of the roadmap draft within the abovementioned communities and platforms. Numbers, as presented below, should be considered as indicative and not at all committed for now. Given the nature of this roadmap, it is clear that M&M related topics are part of ALL AND ANY development project within the Dutch industry. Double counting is therefor unavoidable.

NOTE [January 2012]: numbers mentioned below originate from the situation half December 2012. The current status of industry commitment to the M&M roadmap as expressed in the signed Letters of Intent, is under processing to provide the correct numbers.

| **2012, M€** Financing<br>↓ Execution | Companies | Government TNO | Government NWO | Government other | Universities (matching) | EC | Other *) |
|---|---|---|---|---|---|---|---|
| Universities TKI | 1 | | 2 | | 5 | | |
| Universities non-TKI | | | 1 | | | | |
| TNO TKI | 2 | 5 | | | | | 0,5 |
| TNO non-TKI | 5 | 15 | | | | | 1 |
| Companies TKI | 4 | | | | | | 1 |
| Companies non-TKI | 8 | | | | | | 2 |
| International R&D consortia | n.m. | | | | | | |
| Total | 21 | | | | | | 5 |

| **2013, M€** Financing<br>↓ Execution | Companies | Government TNO | Government NOW | Government other | Universities (matching) | EC | Other *) |
|---|---|---|---|---|---|---|---|
| Universities TKI | 1.1 | | 2.3 | | 5.5 | | |
| Universities non-TKI | | | 1.1 | | | | |
| TNO TKI | 2.2 | 5.5 | | | | | 0,6 |
| TNO non-TKI | 5.5 | 17 | | | | | 1.1 |
| Companies TKI | 4.4 | | | | | | 1.1 |
| Companies non-TKI | 8.8 | | | | | | 2.2 |
| International R&D consortia | n.m. | | | | | | |
| Total | 23 | | | | | | 5.6 |

| **2012, M€** Financing<br>↓ Execution | Companies | Government TNO | Government NOW | Government other | Universities (matching) | EC | Other *) |
|---|---|---|---|---|---|---|---|
| Universities TKI | 1.5 | | 2,5 | | 6 | | |
| Universities non-TKI | | | 1,5 | | | | |
| TNO TKI | 2.5 | 6 | | | | | 0,5 |
| TNO non-TKI | 6 | 20 | | | | | 1,3 |
| Companies TKI | 5 | | | | | | 1,3 |
| Companies non-TKI | 10 | | | | | | 3 |
| International R&D consortia | n.m. | | | | | | |
| Total | 26 | | | | | | 6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Topteam advies 2015 totaal | 120 | | 30 | | 6 | | 12,5 |

The above is a very rough estimate, based on the fact that 1% of the industries total R&D funds will be spend to this roadmap, leading to 20 M€ cash commitment. The amounts are excluding in kind contributions from participating companies. The column "other" represents contributions we expect from participants in Belgium and Germany, who join the Brainport Industries community.

Based on the roadmap and innovation program, it will be intended to raise commitments as much as possible and as fast as possible at the level of Letters of Intent (LOI). The LOI's should reflect serious intentions to the innovation agenda in terms of cash and in kind contributions.

## 5 Used documents (references)

The information shown in this roadmap is based on various contacts and meetings with professionals in the M&M domain and on publications like roadmaps and other written information. A selection of these documents is given below:


- *Other HTSM roadmaps: http://www.pointone.nl/Innovatieprogramma/Roadmap_2012*
- *Point-One Phase 2 roadmap & annual plan 2011: http://www.pointone.nl/Innovatieprogramma-*/Roadmap_2012/Point-One_Phase2_Roadmap_Annual_Plan_2011
- *Brainport Industries*: http://www.brainportindustries.com/
- Holland High Tech: http://www.rijksoverheid.nl/bestanden/documenten-en-publicaties/-rapporten/2011/06/17/holland-high-tech/rapport-topsector-high-tech.pdf

- *Programme for High Tech Systems*
- *Roboned:* http://www.roboned.nl/IIP-RN-kanaal/IIP_RoboNED.html
    - http://www.roboned.nl/iiprn/RoboNEDRoadmapPart2.pdf
    - http://www.roboned.nl/iiprn/RoboNEDRoadmapPart1.pdf
- *Berenschot studies*:
    - roadmap uit 2004 (Berenschot): http://dl.dropbox.com/u/22938964/Roadmapdefinitief.pdf
    - update van de roadmap in 2008: http://dl.dropbox.com/u/22938964/Precisiebewerken.doc
    - voorstel voor hightech equipment programme / instituut: http://dl.dropbox.com/u/22938964/High%20Tech%20Systems%20-%20Roland%20Berger%20projectvoorstel%2012-1-2006.pdf

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## 7 Appendix

For the sake of a compact roadmap size, a considerable amount of valuable material could not be integrally incorporated in the main text. For further reading and more in-depth background for the short version, this material has been redirected to the appendix.

### *7.1 Mechatronic sections from Point-One Phase 2 roadmap and annual plan 2011*

This section presents almost integrally the relevant passages from the Point-One roadmap and plan. For readability, minor text changes have been made.

#### 7.1.1 Mechatronics Priority themes

Distributed actuation, identification and control

This includes high tech systems with high numbers of carefully selected distributed sensors and specially designed electromechanical actuators, with both continuous and discrete dynamics, and with systems and control technology that is able to handle this high level of complexity. Increasing interaction with humans adds the requirement of intrinsic safety and energy usage. Massively Parallel systems constitute a future trend with hundreds or thousands of sensors and actuators are working together to perform a function exploiting advances in Micro/Nano System technology. Examples are found in the deformable mirrors, lithographic imaging or illumination, and in Industrial Printing.

High Volume and Precision manufacturing systems

Design of high-end mechatronic systems with extreme performance demands, with use of innovative design, over-actuating, reconfigurable structures, transient performance, dynamic stress, sensing and intelligent (learning) data- and model-based control principles, thermal aspects, in order to achieve high-acceleration and high-accuracy (in nanometer range) precision systems, including concepts for metrology (also vision) and power electronic issues for production, manufacturing and instruments, eventually in a vacuum environment. Robust solutions for wireless machines, both for data and for power transmission, eliminating the parasitic influences of cabling.

Technologies for mass reduction and increased speed of operation, while maintaining accuracy

Higher speeds and accelerations are demanded to increase productivity, leading to large driving forces introducing more disturbances and heat loads. Innovations towards significant mass reduction are to be found in over-sensing and over-actuation, integrated sensing and control into "smart actuators", high force-density actuation, advanced drive electronics, spatial and deformation metrology, advanced materials with favorable properties, dynamically optimized lightweight design and multi-disciplinary system architectures.

Multi-physics modeling for integrated design and optimization

Modeling of multi-domain systems are needed to derive new concepts to exploit the combination to the full benefit of the system performance. A similar aspect is found in the integral optimization of mechanical design, topology, disturbances and controller solutions for high performance systems. In such cases developments of novel mathematic approaches or complete new paradigms will be needed.

Autonomous or tele-manipulated Systems in close cooperation with humans

To develop robots / intelligent machines for the execution of servicing as well as industrial tasks, in high-level autonomous operation, with capabilities to effectively communicate with, physically interact and adapt to its, often unstructured, environment, and to operate and coordinate in teams. This includes the integration of technology; applications of multitudes of sensors, machine/robot vision for 2D and 3D scanning and recognition, including learning, haptics (force sensing and feedback), adaptive/learning systems, and the control of interacting/cooperating systems

Methodologies advanced calibration and correction of repetitive errors.

Calibration of repeating deviations can be done and corrections lead to significant performance improvements. Although conceptually relatively simple, the industrial implementation often proves non-trivial due to practical issues related to metrology systems, mathematics for parameter estimation, hardware platform implementation and computational aspects.

Industrial mathematics and systems and control

Industrial mathematics is capable of enabling solutions to highly complex problems by reducing complexities. In this field, areas such as modeling, optimization, advanced numerical methods, planning and data analysis are directly relevant.

The field of systems and control is a strong enabling technology that ensures robustness to uncertainty of many feedback control systems in high tech systems applications.

Also model reduction for multi-physics systems and hybrid system theory are relevant topics. The systems approach has generated effective and generic tools for modeling interconnections of multi-domain (physical /chemical mechanical) dynamical systems in one and the same framework, analysis of its stability and performance, and ensuring robustness with respect to uncertainties.

Another way of utilizing mathematical frameworks is in the optimization of shapes or topologies of the mechanical system in such a way that the performance of the controlled system is optimized.

### 7.2.2 Mechatronics topics derived from specific applications

While the application oriented roadmaps are currently still under development with the HTSM innovation contract preparations, the mechatronics topics derived from these roadmaps will be subject to changes for the coming weeks. Keep this in mind while reading the paragraphs below. The most recent versions of the roadmaps can be obtained from the HTSM roadmap 2012 internet site (see references via http://www.pointone.nl/Innovatieprogramma/Roadmap_2012).

Healthcare & Wellbeing

New mechatronics and robotics devices and technologies specially designed for medical applications are important to healthcare both in clinical and home environment. The research challenges range from medical robotics and haptic surgical tools to medical implants and assisted life technologies requiring the design of novel types of distributed actuators such that specifications with respect to safety, mobility, flexibility, low power consumption, etc. are met. Improvements are needed in automating routine jobs for cost reduction, more ergonomics for care providers, higher quality of interventions, less dependencies between care receivers and care providers, through e.g. domestic monitoring. Keeping care for chronic patients in their home environment as long as possible calls for remote monitoring of their condition, assistance in daily living like fetching objects, opening/closing doors and drawers, operating switches, etc. The technical challenges to be solved are quite broad: autonomous navigation in robotics (e.g., fusion, simultaneous localization and mapping), safe and adaptable (mechanical) human-robots interaction.

Lifestyle and Leisure

M&M relevant application challenges are found in *:*

*Sensor and actuator data fusion*: a network of sensors and actuators that are easily fused to obtain meaningful information for use in different applications and appliances,

*Domotics:* supporting tele-working and automating recurring tasks for elderly and disabled, using using advances in robotics (low cost building blocks, intelligent algorithms, manipulation of house hold objects),

*Mechatronics:* Aiding systems for getting in and out of bed or bath, as through exo-skeletons, washing or brushing, autonomous helpers (floor, window, bathroom cleaners).

Main directions for innovation *are Robots for cure and care* and *Human Machine mechanisms.* In terms of technology, this will require advances in vision, control and navigation, mapping, sustainability, high-tech production for new materials, and the interaction between devices and body.

Energy and Power

M&M relevant application challenges are found in:

*Energy generation*: wind energy : far offshore installation and maintenance : advanced robotics systems for inspection of infrastructure.

*High tech decentralized micro CHP systems:* cost effective and reliable micro CHP products need to be developed in the 2 – 5 kWe power range, enabling optimal usage of smart grids, local charging of Electrical Vehicles, grid stability

*Nuclear energy*: ITER nuclear fusion: remote handling and vision robotics for maintenance and object manipulation.

*Solar energy*: cost effective solar cell production equipment. In addition to batch-wise panel production, also equipment for roll-to-roll, including continuous printing and ALD is needed.

*Energy distribution*: Smart Grids: sensor technology, intelligent information and control.

*Energy usage*: intelligent Lighting Systems including sensors and actuators to bring the right light at the right place.

*Energy efficiency in buildings*: Energy-efficient building cooling, heating and lighting control using low costs micro- and nanotechnology-based autonomous sensors and control systems with local intelligence.

New mechatronic designs for *'green' drives of industrial equipment* (motion) and transportation vehicles (moving). Aiming at light weight design principles for motion/moving systems including simulation and control models striving for energy efficient controller and trajectory parameters.

Transport, Logistic, and Security

M&M relevant application challenges in the area of automotive:

- *Active safety systems*; car-2-car systems, noise & vibration control; active headlights; intelligent lighting and optical systems, hybrid and electrical driving:
- *Design for low weight*
- *Drive-by-wire* solutions
- *Real-time imaging*, 3D vision systems, data fusion

ICT Equipment and components

M&M relevant application challenges are found in:

Semiconductor front-end: Main processes involved in this sector are substrate patterning, material deposition and treatment as well as metrology & inspection. See the Semiconductor equipment roadmap within HTSM for more elaborate descriptions, in view of space only the topics themselves will be mentioned without further explanation):

Application challenges *Lithography equipment* are related to: Immersion, double patterning, EUVL, nano-imprint, direct write, holistic, substrates. The technology challenges that can be derived from these converge to desired increase of positioning accuracy and stability, while also increasing productivity and more aggressive motion patterns, with possibly the challenge to serve bigger substrates (450 mm wafers). As a consequence, there are solutions to be found for equipment architectures that provide a clean and extremely conditioned environment, such that all kinds of disturbances are not harming performance or availability. This boils down to the integral need for improved Mechatronic system architectures to meet all conflicting requirements in one system design concept. It is widely accepted that a stage mass and power explosion must be avoided, through innovative lightweight design, precise and highly efficient actuators and drives, advanced thermal and dynamic concepts, better position sensor and metrology solutions, advanced control techniques, data processing and transport platforms. In addition, this must be solved with Cost of Ownership (CoO), uptime, serviceability, etc. in mind.

*Metrology*: To improve the Front End processes, inspection tool accuracy, resolution and metrology tool speed/throughput must be improved. Inspection techniques range from scatterometry and Scanning Electron Microscopes (SEM) to E-beam inspection and maybe even nano-probes. Rapidly increasing challenges need to be tackled with respect to data transport and processing, as well as improving the accuracy of production equipment by minimizing thermal, dynamical, etc. effects

Semiconductor Back-end

Handling and bonding ultra-thin wafers and dies : The trend to thinner dies down to 30 μm or below poses challenges for handling equipment within tool and from tool to tool, when shipping from facility to facility, pick-and place before bonding and in die separation without breakage.

Dicing and singulation equipment : The new packaging technologies impose new challenges on dicing equipment: debris-free sawing processes, low mechanical stress. Laser dicing is the obvious way to go. Ceramics, CSP and WLP singulation will challenge the process capabilities on productivity and quality of singulation processes, as these materials require higher equipment performances in accuracy and stability.

Improved pick-and-place tools: Discriminative in this market is intrinsic high quality and accuracy at low cost. The current state of art provides either very fast, low accuracy, or very slow solutions with high accuracy. For future equipment the, e.g. for 3D-stacking with TSVs, simultaneous improvement of placement accuracies, productivity, and cost-effectiveness must be found. Machine modularity and scalability in combination with extremely high availability and reliability requirements pose an additional challenge. Attention to sustainability and energy consumption is growing, leading to the need for really light weight equipment designs, smart motion mechanisms, 'green' motion trajectories, and energy buffering.

Encapsulation equipment : For 3D integrations with MEMS and/or photonic functions new encapsulation techniques, materials, and equipment are needed.

Industrial Printing

M&M relelvant application challenges are found in:

*Graphics printing*: For graphical applications increasing speed and reliability at a cost effective level are main technology challenges for printing equipment, especially for increasing wide format sizes.

*Printed electronics:* The difference between PCBs and large area electronics might be the ultimate drive to high-speed roll-to-roll printing, which requires the availability of high tech equipment.

*Other applications*: Food and nutrition / High Tech Textiles / Biomedical / Creative etc. will bring forward the need for new to be developed equipment architectures with probably special attention to handling of objects or substrates, and specific climate or process (clinical) conditions, etc.

*Rapid manufacturing:* Complex 2D patterns and 3D structures can be produced from mixed materials using ink jet and other techniques, allowing for high tech component manufacturing. Innovations towards smaller drops, higher accuracy, new materials for new applications, tuning of final droplet shapes after jetting and drying/fixation on the substrate.

*New generations of print heads* need to be developed, enabling smaller feature sizes, higher jet frequencies), wider range of fluids to be jetted, higher integration densities (more nozzles per mm2), added sensors, intelligence and control principles to increase reliability, accuracy and lifetime.

*Mechatronics and embedded control:* New mechatronic machine platforms and modules are needed which are faster, more accurate, more reliable, use less energy to operate (green machine), having wireless (remote) control, use less and environmental friendly material and that should be easier to configure, install, operate and maintain. Embedded system design will need to focus at smart system integration of print heads and scalable print-head arrays, substrate handling and flexible engine architectures with added intelligence, flexibility, real time feedback control loops based on vision and acoustic sensing principles, image quality optimization, automated operation, remote monitoring and self-diagnostics.

Cross-business challenges

M&M relevant application challenges are found in:

Image capture: Machine Vision and Industrial Robotics Industry: For high-end vision applications the trends point towards higher resolutions and pixel rates, costs reduction, feature detection and (geometric, 3D) measurement . Related technical challenges lie in the area of *Optics*(higher dynamic range, wide gamut and new applications like 3D and multi sensor), *Imaging sensors* (higher resolutions and pixel rates, integration of processing on chip, 3D and region of interest (ROI) detection), *Real-time* (image/video/data processing: algorithms for better image quality, 3D), *Feed-back signals* (sensor data fusion, high bandwidth multi sensor control).

Human Interaction: important in human-technology interaction are interfacing, graphics and supervision. Especially for interaction between non-trained non-professional users and robotic systems, intrinsic safety, ergonomy are essential. Furthermore, intelligence, haptic feedback (for example assisting delicate work like surgery or fine mechanics involving skilled human manipulation) will enable increasing human acceptance technical assistance through high tech robotic systems.

*Sensors and Actuators:* Sensors and actuators extend safety, security, mobility, health and enhance comfort and lifestyle. More accurate, and reliable, safer and faster systems are possible which are taking over or supporting more and more human actions. Also a combination of several sensors integrated with complex logic will enable new functionalities.

As sensors continue to become *smaller* in size (e.g. to chip level), they become *mass producible* and *cheaper*, requiring *minimal power*, new possibilities are opened such as large sensor networks enabling the monitoring of large and complex infrastructures .

In mechatronic machines and equipment, numerous sensors and actuators are incorporated to give feedback, enhance accuracy, speed, reliability etc. With smaller and cheaper sensors and actuators, more monitoring and control functions can be incorporated in the mechatronic designs of high tech equipment. This will boost the performance, reduce maintenance requirements or allow remote monitoring and adjustments through internet, reducing energy usage etc.

Sensors are crucial for robots to react on their environment. They rely on vision, touch, sound, conductivity, and many other sensing techniques. In addition to more generic needs such as cost reduction, innovation is needed to enhance robustness, functionality and performance, to improve the state-of-the-art in sensing, intelligent interpretation of sensor data, perception and sensor fusion.

*Electronics and drives:* For many high tech systems, the electronics platform, architecture, components, etc. are crucial elements in obtaining the ultimate performance at acceptable cost. Continuous improvements and innovation s are required in this area:

Frontiers in Power Electronics: disruptive component technologies (GaN, SiC, LED material science, OLEDs, phosphor coating), increased energy density and improved (low noise, wide-bandgap switch technology, multi-level, and interleaving power converters technologies), application of state-of-the-art control technology in a power electronics, realize extreme size and form-factor restrictions - piezo technology, flat magnetics, distributed magnetic structures, EMC optimized air core PCB transformers, embedded magnetic structures (in-PCB layer based), contactless energy transfer over 5mm/5cm/5m distance, minimum component switched networks, reliable and robust topologies (reconfigurable converters, inherently safe topologies), fault diagnosis in combination with robustness/reconfigurability, magnetic and electric structures to contactless transfer both power and information, high current PCB technology, reliable and robust piezo structures to transfer energy acoustically, replacement of passive components in power circuits by adding extra semiconductor switches operating at high frequency with advanced control, high-precision and high-power switching (PWM) amplifiers, optimization of (automotive) power trains (batteries, power electronics, motor, cooling)

Multiport converters: multiport converters are alternative energy systems. The use of a single power processing stage to interface and control multiple power ports opens the door for centralized and integrated power conversion from a variety of independently maintained power sources (e.g. EV batteries, solar panels, microturbines, etc.).

Circuit technology: Passive components are still not in proportion with the dimensions of semiconductor switches. Therefore, minimization of the passives should receive attention. Also the (semi)automatic production and placement of passive components should be taken as start conditions of design procedures. From this point of view, high power circuits should be divided in low-power modules, with the possibilities given by new topologies and control techniques.

### *7.2 Manufacturing*

Manufacturing is a very large industrial field, that covers the realization of designs into products or systems in many different industries. Here, the focus will be on manufacturing for High Tech Systems.

#### 7.2.1 Manufacturing for High Tech Systems

Suppliers in high tech are increasingly responsible for engineering, fabrication, and assembly, and integration of high tech systems. Knowledge and skills of specialized production technologies have proven to be of crucial importance for the position of the high tech industry today. Among the high tech suppliers community there is rising ambition and commitment to maintain and develop further this position to be able to meet the increasing demand of high tech OEM's and safeguard a healthy future for manufacturing industry in western Europe.

International competition in High Tech manufacturing is rising. The available knowledge infrastructure is a major asset, certainly against the trend of increasing technical complexity of high tech systems and the growing capital intensity involved in manufacturing those. OEM tend to focus more on their core application and increasingly outsource development and realization of equipment modules, thus shifting responsibilities more and more to the manufacturing supply chain.

The scope for manufacturing within high tech is very wide. Within HTSM, the scope will be initially restricted to industrial research and development for High Mix Low Volume High Complexity (HMLVHC) supply chains. Obviously, studies and innovations on productivity and yield improvements in high tech production and assembly flows, including the human factor in productivity, are also very important.

#### 7.2.2 Manufacturing challenges

Typical manufacturing phases can be listed as:

- Engineering
- Fabrication / machining
- Assembly
- (qualification, integration and test)

Associated challenges:

- Manufacturing flow and organization optimization
- Further development of production technologies
- Increasing demands on cleanliness, conditioned environment
- Increasing quality requirements on manufactured parts.
- Increasing complexity of designs to be manufactured
- New materials
- First time right, low NRE proto parts and initial series production
- Sustainability / Green manufacturing
- QLTC compliance to OEM requirements

These challenges are amplified by the demand of *Higher level of integration* by various OEM's. This trend forces suppliers to deliver at a higher integration level, for instance from parts level to subassemblies or even completely integrated and tested sub-modules. This poses a serious challenge to suppliers to gear up with this higher level. Moreover this also implies that maintenance and further development of associated production technologies, knowledge, and skills will become a responsibility of the high tech supply chain.

An efficient way to deal with shared challenges and ambitions along the large number of suppliers with different size and financial means, is to join forces, formulate a collective manufacturing roadmap, and share research and development initiatives to obtain maximum efficiency for all.
An example in this contact is the BrainPort Industries initiative that is rapidly gaining momentum.

*7.3 Actuation and electronic drive challenges*
Actuators with multiple degrees-of-freedom In most mechatronic system every motion axis or degree-of-freedom is driven by a separate linear or rotary motor, which results in large and heavy systems. Integration of degrees-of-freedom to planar, helical or spherical drives can cause significant mass reduction and accuracy improvement. Magnetic bearings can be integrated as well and enable very smooth and accurate operation and very high rotational speeds. To design such actuator system, fast three-dimensional electromagnetic modeling tools and design methods are required.

7.3.1 Over-actuated systems
Mechancial over-actuation is a promising technique for constructing light-weight systems with a high accuracy. Ultimately, the moving part can be a membrane type surface. Support of plate or such a membrane require a distributed actuator system in which can support the membrane on a large amount of points. Such a system requires strong multi-disciplinary research into mechanics, electromechanics and control technology.

7.3.2 Other actuation principles
In high-precision systems very predictable Lorentz type or voice coil actuators are usually applied. However, this technology has a limited force density. Reluctance and hybrid actuators can have a 10-50 times higher force density, but the behavior is time dependent due to hysteresis and eddy current phenomena inside the actuators. In order to design and control reluctance actuators with sub-nanometer accuracy, transient models in combination with advanced measurement techniques are required which can predict the fields inside the non-linear anisotropic magnetic materials. Based on the exact distribution of the fields, the force distribution can be predicted.
Materials
The energy density of electromechanical systems is limited by material properties and cooling systems. New materials such as high-temperature superconductors, magnetically loaded composites, nano wires etc can enable higher force densities and more compact systems.

7.3.3 Frontier in Power Electronics
- Channeling disruptive component technologies - GaN, SiC, LED material science, OLEDs, phosphor coating.
- Increased energy density and improved reliability is key for photolithography and medical applications. This means that research into wide-bandgap switch technology, multi-level, and interleaving power converters technologies must be intensified. Precision low-noise switching techniques are amongst the most promising directions in this area.
- Application of state-of-the-art control technology in a power electronics environment - use of all available computing power, exchange hardware + sensors for software + models
- Realize extreme size and form-factor restrictions - piezo technology, flat magnetics, distributed magnetic structures, EMC optimized air core PCB transformers, embedded magnetic structures (in-PCB layer based)
- Contactless energy transfer over > 5 mm / 5 cm / 5 m distance (large area sensor networks)
- Minimum component switched networks providing multiple outputs with extreme specifications (w.r.t. power level and stability)
- Research into reliable [>10 years] and robust topologies (reconfigurable converters, inherently safe topologies). This is important for e.g. lighting (10 years), solar (20 – 30 years), and medical applications (20 years). Fault diagnoses in combination with robustness/reconfigurability.

- Magnetic and electric structures to contactless transfer both power and information.
- High current PCB technology.
- Reliable and robust piezo structures to transfer energy acoustically (prevent material fatigue). This of interest not only in gasses (air), but also in fluids (e.g. salt water). Important future medical applications could be drug dosage by temperature control (pinpoint heating), and CT-scanner aided microsurgery.
- Replacement of passive components in power circuits (less volume and weight) by adding extra semiconductor switches operating at high frequency with advanced control. Otherwise stated, more Si/SiC/GaN and less Cu/Fe/Al.
- High-precision and high-power switching (PWM) amplifiers with analogue performance (bandwidth, noise, accuracy). Accurate gate drivers and sensors should also be developed.
- Optimization of (automotive) power trains (batteries, power electronics, motor, cooling), aiming at maximum overall efficiency, action radius minimum overall weight and fault tolerant operation (limp home).

#### 7.3.4 Multiport converters

Multiport converters are a promising concept for alternative energy systems. The use of a single power processing stage to interface and control multiple power ports opens the door for centralized and integrated power conversion from a variety of independently maintained power sources (e.g. EV batteries, solar panels, microturbines, etc.).

#### 7.3.5 Circuit technology

The passive components are still not in proportion with the dimensions of the semiconductor switches. Therefore, minimization of the passives should receive attention. Also the (semi)automatic production and placement of passive components should be taken as start conditions of design procedures. From this point of view, high power circuits should be divided in low-power modules, with the possibilities given by new topologies and control techniques.

### *7.4 Cross-Sectional Robotic fields [ref: RoboNED]*

#### 7.4.1 Navigation and Motion planning

Mobile robots need to move in 2D and 3D through known and unknown, static and dynamic, structured and unstructured environments. Besides, they have to be able to deal with unfavorable conditions for sensing, mobility and manipulation, like varying light conditions, water, dust, mud, etc. This relies on the robots' observation of the world through its sensors and data acquisition through other robots and systems, such as surveillance cameras. They need to localize themselves, navigate to target destinations, while avoiding obstacles in a safe and efficient way.

#### 7.4.2 Sensing and Perception

Sensors are very important for robots to react on their environment. They rely on vision, touch, sound, conductivity, and many other sensing techniques. Often, these sensor lack in robustness, functionality and performance, and are very expensive. Combining the needs of multiple application domains can enable the required innovation to improve the state-of-the-art in sensing. Moreover, the intelligent interpretation of sensor data, perception and sensor fusion of different sensing principles is very important to achieve the goals.

#### 7.4.3 Human-Robot Interaction and Haptics

Interaction between users and robots is getting increasingly important. Robots are getting more complex, more divers, and need to be controlled by non-trained non-professional users. One natural way for a human to control a robot is by feeling counteracting force on the master that the user is using to control a robot. Other aspects important in human-robot interaction are interfacing, graphics and supervision.

#### 7.4.4 Learning and adaptive systems

A robot needs to be able to adjust itself to changing environments and changing tasks to work efficiently (in a factory, at home, or in e.g. in professional service). Creating flexible and intelligent robots that are able to use and update databases and knowledge about the environment requires special R&D effort on many areas, in hardware, as well as in the control software, both on a high and low level. This cannot rely on the continuous effort of programmers, for an application to pay-off. Robots need to be able to learn from humans, their environment and from other robots. Especially robots working on repetitive tasks, which is often the case, can benefit a lot from learning, while optimizing their performance.

#### 7.4.5 Software Engineering for Robotics & Automation

Construction of the software for integration and control of machine controller software is often time-consuming and expensive. Considering robots alone, the costs of integration are three to five times the cost of the robot hardware alone. The reuse of robotic software artifacts is a key issue in decreasing the integration costs. It can be promoted by domain engineering, components, frameworks and architectural styles. Besides, the interoperability of hardware and software components for robotics is important in forcing a breakthrough in the development of robots.

#### 7.4.6 Safety for service robots

Robots and robotic devices in personal care applications require close human-robot interaction and collaborations as well as physical human-robot contact. Providing for a safe service robot system requires the cooperation of a variety of "stakeholders" – those corporate entities that share a responsibility for ensuring the safety of the overall robot system. This is one of the reasons that developing safe service robots is a non-trivial job. Fortunately, a new ISO standard is being developed that deals with personal care robots in nonmedical applications.

#### 7.4.7 Education

The education cluster will make an inventory of the education in bachelor and master tracks. We will start in the technology education area but preferably we will also make an overview of the education in application of robotics in areas such as agiculture, cure and care . This inventory will give an overview which can be compared with the technology needs as defined in the roadmaps of the agriculture, manufacturing, cure, care and household Roboned clusters. Thus an advice can be derived for further improvement of robotics education in the near future.

#### 7.4.8 ELS (Ethical, Legal and Social)

Business and consumer interests and technological advancements will lead to the wide diffusion of robotic technology into our everyday lives, from collaboration in manufacturing to services in private homes, from autonomous transportation to environmental monitoring. Building an early awareness of the resulting ethical, legal, and societal (ELS) issues will allow timely legislative action and societal interaction, which will in turn support the development of new markets. ('Robotic Visions to 2020 and beyond - Strategic Research Agenda for robotics in Europe, 07/2009')

### 7.5 Metrology in HTSM [input by VSL (The Dutch National Metrology Institute)]

For technological innovation a far-reaching knowledge of **metrology** is often required. **Metrology** includes accurate and absolute reliable measurements, measurement set-ups and measurement methods, even when the measurement range and uncertainty is at the edge of the possible. **Metrology** includes at least the traceability of measurement results to the highest measurement standards to make comparable measurements possible and to guarantee reliability (and thereby internationally acceptance). Application examples are listed below (scoped over the whole HTSM Top Sector):

#### 7.5.1 Space instrumentation:

Absolute accurate calibration of instruments, which for space instrumentation is a requirement. This concerns the calibration of instruments for light measurement over a wide wavelength range from UV to IR (radiometry), but also advanced interferometry and stability measurements of materials and structures for use in satellites with sub-nm accuracy. There is therefore great interest to join the initiatives 'upstream space' and the TKI 'High Tech Space Instrumentation'

#### 7.5.2 Healthcare:

Accurate determination of radiation dose to cancer patients, the diagnosis of diseases by means of reliable breath analyses, the accurate dosing (nano-flow) of drugs and measurement of particle size of biomarkers in blood.

7.5.3 Photonics:
Accurate and reliable measurements **of** light (photometry and radiometry) and measurements **with** light (such as interferometry, ellipsometry and radiation thermometry).

7.5.4 Semiconductor Equipment:
Special metrological atomic force microscope (AFM) for traceable measurement of semiconductor structures at the nanometer level in 3D. Through special reference standards traceability will be supplied for e.g. critical dimension (CD) measurements in the semicon industry. Furthermore the measured 3D geometries are used as input for the further development for scatterometry and SEM for the industry. Besides these activities VSL supports the Dutch semicon equipment industry with research in the area of stability measurements at the sub-nm level (picodrift) and high accuracy calibration of displacement sensors and interferometric systems.

7.5.5 Solar:
Solar cell development and production, including reliable measurement of light (radiometry), including UV radiation and sunlight, the measurement of thin films, with solar cell production as an important application.

7.5.6 Nanotechnology:
Measurement solutions to provide traceable dimensional/length measurement in the nanometer range, for example by means of Fabry-Perot interferometry and Atomic Force Microscopy (AFM). With these measurement solutions the measurement systems of for example advanced (electron) microscopy systems can be calibrated. Furthermore reference samples of nano-materials can be calibrated.

7.5.7 Mechatronics&Manufacturing:
- Calibration and characterization of individual displacement sensors
- Calibration and characterization of complete 3D stages and metrology platforms, both for measurement and production, including analysis through modeling and simulation of the task-specific metrological performance.
- Stability measurements at the sub-nm level of constructions, connections (i.e. glued) and materials.
- Calibration of contactless measurement systems for fast in-line inspection
- Highly accurate tactile measurement systems for 3D measurements of precision components.
- Highly accurate measurements of aspheres and free-forms, both tactile and contactless (cooperation with TNO)
- Calibration of dedicated calibration standards

7.6 Recent input / suggestions from Point One Mechatronics working group (25 november 2011)

Smart Surfaces:
- Piezo active or sensing surfaces, for example with new developed piezo composites for easy production

Smart structures:
- All actuators with feed back
- High dynamic force sensors ((range from mN to N)
- Smart frames (temperature active feed-back controlled)
- Active feedback temperature control for processes (fast response)
- Development of real 3D metrology of large scale complex free form objects with optical quality and/or superimposed structured surfaces with nanometre resolution in full 3 dimensions.
- Balancing as fundampental design principle. This is already present in decoupling within motion stages, eliminating interference between different actuators, or making robotic manipulators fast and accurate.

Smart Control
- Adaptive trajectory generation (Adapt trajectory parameters, not only displacement)
- Calibration
    - Automatic
    - Error proof
    - Simple (operator proof)
    - Robust
- Trajectory generation (higher order trajectories)
- Increase in sample frequency/decrease in loop delay to achieve higher control bandwidths

- Controls for non-linear elements (e.g. reluctance actuators)
- Non-linear control algorithms
- Diagnostic tooling
- piezo layers
- advanced thermal control
- anti-noise to achieve performance insensitive for surroundings
- man-machine interfaces

Sensor Fusion
- 3D reconstruction (μm resolution)
- real time data computation with function approximator "Key Sample Machine" , energy harvesting to provide local power supply to sensors

Distributed Digital Realization
- Reduncancy → fail safe
- Time synchronization / Reaction time
- Multi agent control in combination with Orocos
- Controls in netwerken (cloud)
- Multi core
- Wireless communication/energy transfer
- Cyber Physical systems

Manufacturing
- SMART manufacturing ALD

## 7.7 manufacturing operations

### 7.7.1 Background

Fast and flexible manufacturing operations are critical to modern industry. Increase of flexibility and productivity for manufacturing operations is still a challenge in the European industry.
One aspect of flexibility concerns the growing level of customization and shorter product lifecycle resulting in smaller batch sizes and more variety in products. In order to produce small batch sizes of varying products, both the supply chain and manufacturing companies and their production systems must be both flexible and efficient.
Another aspect of flexibility deals with unpredictable fluctuations in volume demand throughout the year(s). Many companies are exposed to (short) periods of times, where volume demands are elevated. Especially flexibility and lead times in the whole supply chain play an essential role
To improve flexibility there is an increasing awareness of the role and reliability of operators. The adaptability of human workers makes them a flexible part of the production system. Robotics and hard automation are still assisted by complementary manual handling of workers managing and controlling production processes.
Despite the well-known advances which have occurred over the last 30 years in the areas of robotic automation, most companies are today finding that the greatest challenge in the current international market place is that of optimising the manufacturing process from a technological, organisational and human factors point of view as early as possible in the design phase.

### 7.7.2 Challlenges

*Process flow in manufacturing and supply chain*
- Optimization of the supply chain with regard to lead time, flexibility and reliability
- Design of flexible and re-configurable processes and production systems and stations, designed during and in interaction with the product design phase.
- These in turn require the definition of new geometric layouts, new manufacturing equipment, and new protocols for the manufacturing operations.
- New technology and (ICT, Virtual and Augmented Reality) tools are needed to support during the design phase (of products and manufacturing processes) and during operations .

*Reliability and Human Performance*
- The inclusion of human factors in an early stage of the design process of the products and manufacturing processes. Early attention for human factors will lower the costs compared to retrofitting changes for human factors reasons at a later stage.
- Intelligent work assistant devices (IWADs) based on mechatronic technology are one of the most promising methods of improving the flexibility and cost effectiveness of manual production stations, particularly of flexible production stations. These devices, which operate in the gray area between traditional manual workstations and fully automated/robotized workstations, are based on the concept of cooperation between human workers and machine workers.

## 7.8 COFHI proposal Cross link “Hightech systemen en materialen” [input Marel]

A large innovation programme under coordination by Marel is being proposed under the name COFHI. This project has a scope ranging over the following Top Sectors: Agro&Food, Life Sciences, and High Tech Systems & Materials. This paragraph lists some of the cross links of COFHI with HTSM, and in particular the roadmap for Mechatronics and Manufacturing. The mentioned M&M cross link topics are listed in more general terms in the main text. But in view of the size of the overall COFHI scope, these topics deserve explicit attention in the appendix to secure that there will be no topics left behind in between the 3 Top Sector innovation contracts.

These topics are involved:
- Vision, high speed camera’s in tracking complex motion at high velocities;
- Food inspection with multiple sensors using computer vision with a matrix of foto-sensitive sensors such that a high level of accuracy and larger range is obtained.;
- Multi-spectral cameras and 3 CCD camera’s for machine vision, food processing, temperature measurements as well as quality, hygiene and veterenary purposes.
- Image recognition techniques to determine product features like color, shape, defects, etc.;
- Scanning techniques to determine the segmentation structure (skin, bones, fat distribution, muscle, intestines, etc. using X-ray, CT, MRI etc.;
- Lasertechnology to detect contaminants, freshness and safety of food. Also as an alternative for currently applied cutting and water jet systems;
- Determination of internal temperaturs of food products in general using contact-less measurement techniques.;
- Sensors to determine taste, smell, tenderness of meat, etc.;
- Robotics solutions with assistance from CT and high frequent vision camera systems to replace complex and labour intensive actions like deboning, combined with high frequent repeating actions such as preparing for presentation of food products.;
- Reduction of the fat content in food, by applying jet, electrostatic or aerate techniques;
- Introduction of health increasing ingredients in meat like: pro-biotics, pre-biotics, etc. via nanotechnology or other innovative injection methods;
- Develop new efficient open innovation methods, which are more effective than current campus and incubator structures;
- Developing high value remote service techniques;Forward and backward tracking & tracing.

## 7.9 Agriculture challenges

Providing sufficient food will be a global challenge that will require high tech solutions on short notice to balance and optimize all kinds of resources such as labour, fertilization, energy, water, etc. It is acknowledged that Agro & Food is a separate Top Sector. However, for the HTSM Top Sector, and more specifically the M&M roadmap, relevant challenges are found in various robotic assistance in agricultural applications (for example picking fruits, harvesting, etc.). With the aid of mechatronics advancements, especially sensor technology and process control the agriculture innovation can be brought a step further. This should be carefully considered in the M&M innovation programs such that an efficient connection with the agricultural applications is made.

## 7.10 Expertise center HTSM-East

As the result of a joint initiative from Saxion and Windesheim, a scenario has been drafted for an ‘Expertise Center HTSM-East’ aiming at linking knowledge and application relevant for HTSM in the eastern region in the Netherlands. Various knowledge centers like UTwente, ROC Twente, ROC Deltion, regional open innovation centers, and industrial parties are involved.
This initiative is under development, and raising industrial commitment will be key. At this stage, it is worthwile mentioning in the M&M roadmap and should be involved in the definition of M&M innovation programs, based on the available LOI’s.