

SHORT DESCRIPTION OF THE NETHERLANDS SPACE OFFICE (NSO) ROADMAPS 2.0 for Roadmap HTSM Space Upstream¹

> High Tech Space Instrumentation

Roadmap 1 Optische Instrumentatie

Ambition: Extend further the world class position of the Dutch instrumentation sector for optical space- instruments

The Netherlands holds a strong position in space-based instruments for scientific research in astronomy and earth- and planetary observation, especially through its role in optical instrumentation and enabling technology on detectors. In addition, there is a strong 'user group' of scientists that are among worlds top-level scientific research groups. Since optical instrumentation is one of the key-features of scientific missions, there is a traditionally strong connection between the technologies developing industry and the scientific world. This remains true for the years ahead, with a number of new space missions on the drawing board. In the near future the European Space Agency will make important decisions on mission proposals and hence on the scientific space research. The ambition of the space sector (users and industry) is to maintain the current pole position in the field and to work towards leading (Principal Investigator)-roles in future instruments. At present the context for this is given by ESA's Cosmic Vision program, ESA's Living Planet Program, ESA/GMES Sentinel program and contributions and sales to programs of space research organisations outside ESA (e.g. NASA, JAXA, China).

The field of the space optical instrumentation is a rich and broad field, ranging from laser technology to X-ray detection. This roadmap is therefore composed of an overview of the markets and the required technology. The Markets Domains as identified in this roadmap are:

- Earth Observations (institutional): Sentinel-4, ~5 and future research missions
- Scientific Missions / Astronomy and planetary research (institutional): Spica/Safari and ECHO, EJSM, Mars missions
- Commercial Earth Observation opportunities, especially for miniaturised instruments: SSTL missions and to be developed commercial missions

The products in Space Market are divided into the following products/technology application:

- Spectrometers and spectropolarimeters (TROPOMI, S4/5, SPEX)
- X-Ray optics (ECHO mission)
- Imagers and hyperspectral imagers
- Active remote sensing instruments, such as LIDAR
- Optical metrology (LISA)
- Optical Sensor systems.

¹ Numbering used in this document, is the numbering used by the Netherlands Space Office (NSO) in its Roadmap 2.0.

These numbers differ from the ones used in the Innovation Contract HTSM Space.

A very rough estimate of the financial needs (i.e. turnover for flight models) is 10-20 M€ per year on average. The actual expenditure profile could vary strongly depending on which missions are realised. A technology development budget should comprise 1-2 M€/yr of which 30-50 % is own investment by participating industry and institutes.

Roadmap 2 Radio Frequency (RF) Technologie

Ambition: Introduction of a Dutch supplier of small sat based SAR observation satellite

The use of Spaceborne SAR observations for scientific and commercial purposes is a well-known and increasingly active field of Earth observation. Over the years, an exponential growth in the demand of SAR data has occurred. Given the technological issues involved with (especially) space-born SAR however, it is not as common as other types of instruments (i.e. Optical / InfraRed).

A SAR mission tailored to a specific application would allow reducing the development burden, and the confinement of the mission to a single function (SAR observation) would result in reduced size and weight of the satellite bus. Recent missions, such as SAR-Lupe (2008 ~770kg) and one of the most advanced specific SAR observation satellites: TECSAR (2008 ~300kg) have shown that a SAR payload can be flown on smaller satellites. However, the hardware for the generation of the high peak power needed for pulsed radar technology has not allowed so far the substantial reduction in size/cost needed to fit a SAR payload onto smaller (100-150 kg class) satellites.

At the same time, recent years have seen a development of light-weight SAR sensors for small airborne platforms such as Unmanned Aerial Vehicles (UAV). Some of these radars are not based on the conventional “Pulsed” radar, but based on Frequency Modulated Continuous Wave (FMCW) technology. Although Pulsed radar technology is currently still the common choice for most SAR systems, FMCW technology has proven to ensure better power efficiency and simpler, smaller, and cheaper radar systems.

In 2011, industry and TNO agreed on close co-operation in the field of FMCW SAR and agreed an exclusive co-operation on the development of a space-born FMCW mini-SAR. This co-operation has also led to a joint project to perform a phase-A alike study into the proposed FMCW SAR concept using micro-satellites. The ambition will be that in the coming years a proof of concept can be given with an in-orbit demonstration. This ambition will cost approx 20 M€ of which 25% will be borne by industry.

Roadmap 3 On board software/data systems

Ambition: To become a exclusive supplier for on-board data processing in all major ESA-programs

The technology defined in the On-board Software & Data Systems cluster is in this technology roadmap document referred to as On-board Payload Data Processing (OPDP) technology. This roadmap is supported by relevant ESA technology dossiers, and is in line with the previous NSO roadmap activities. ESA has driven this technology from its technology department TEC-EDP, as a potential candidate for on-board data handling and processing of future advanced payload instruments. Besides ESA, also instrument designers like TNO and SRON and satellite integrators like Astrium and Thales-Alenia emphasize the

need for more payload instrument calculation power, in order to have a more efficient usage of the downlink.

The current status is that this roadmap is on the verge of industrialization and productizing of different OPDP technologies:

- OPDP data processing, mainly based on FFT-processing;
- OPDP data compression, with or without FFT-processing;
- OPDP as payload instrument handling;
- OPDP suitable for small satellites (up to 100 kg).

The ambitions are to contribute these systems to SAR (radar) missions, both institutional and commercial. Examples are the follow-on Sentinel GMES missions, possible Earth Exploration missions like BIOMASS and commercial missions like Terrasar follow-on. In addition, there is a potential in Science missions that is being explored.

Estimated needed external investments 2011-2016 are 1.6 M€ and 950 k€ own investment. The potential turnover is over 10 M€

Roadmap 4 Groundsegment data processing

Ambition: To become a major factor in using satellite data for public use

At present, data from operational and scientific satellites are mainly used institutionally. User friendliness is limited and therefore use is limited to experts and specific teams closely related to specific missions.

We see the following trends with respect to data processing for space-born sensor data:

- The data rate of future sensors will increase dramatically. This will impact the system architecture for the data processors, quality assurance of systems, and data dissemination techniques.
- Future data processing will be much more geared towards the integration of sensor data. For example, the Group on Earth Observation (GEO) is coordinating efforts to create a Global Earth Observation System of Systems (GEOSS) that will require that data from various sensor systems (not only space-born) must be integrated (GEO, 2011).
- Initiatives have been started that require the use of long-term data series, much longer than used in current studies. For example, the various topics as defined in ESA's Climate Change Initiative (CCI) require data series that extend a range of at least 30 years (ESA, 2011b). That is, these climate-monitoring programmes need to incorporate data from ERS-1 to ENVISAT and even future missions. These facts impact the way how data processing centres handle data storage, access, and quality assurance.

These trends in data processing, together with the relative limited usage of space-born data, requires that the Dutch space sector invests in the development of new techniques, architectures, standardization, and working procedures to ensure that the Netherlands remains in its leading role.

Several initiatives in the earth observation and astronomical domain aim to improve the public use of satellite data, for example Global Monitoring for Environment and Security (GMES) for EU and ESA, the Long Term Data Preservation (LTDP) (ESA), the Infrastructure for

Spatial Information in the European Community (INSPIRE) (EU), national initiatives are the Nationaal Modellen- and Data Centrum (NMDC) to stimulate the integral approach of models and data for solving environmental issues (NMDC, 2011), the KNMI Satellite Data Platform - KNMI Data Centre (SDP-KDC) and the NSO Satellietdatabank.

Many of these (inter)national initiatives are build on a chain of services using technologies that are addressed in this roadmap.

The objective of the roadmap data processing is to develop technology that prepares satellite data for public use.

The technological challenges comprise:

- Handling and analysis of large data volumes.
- Combining different databases and infrastructures
- Ensuring the accessibility of historical data series
- Distributed systems and grid computing
- Quality control of datasets
- Data dissemination protocols
- Data mining
- Pattern recognition
- Data processors
- Virtualization
- User tool boxes
- Lineage

Harmonization and data standardization are cross-technology challenges.

Roadmap 5 In Situ Bioanalyse

Ambition: To become both in- and out of Space a major supplier analytical instruments for insitu bioanalyse

This domain concerns the development of technologies and realisation of miniaturized (bio)chemical analytical instruments based on a combination of micro/nano- and biotechnology, suitable for applications in space research in general and human- and robotic exploration in particular. The focus is on the development of instruments that can be used on-site, on-orbit and/or during space travel.

In the Netherlands, planetary research and -science is a fast growing upcoming field with a lot of potential. It is for this reason that the KNAW in her evaluation of priorities for space research in The Netherlands concluded that planetary research should become one of the priorities for space research in the Netherlands and that the planetary community should strive to acquire at least one (co-)PI-role in the years to come. This advice has been endorsed by the Ministry of OCW. For the Netherlands to be able to play such a prominent international role in instrument development for planetary missions, it is essential to create a 'stable environment' which ensures limited but continuous and sustainable funding for planetary scientists and instrument development. The current flagship development Life Marker Chip (LMC) can be seen as an excellent example for this.

The domain of in situ bioanalysis combines the Dutch technological strengths in the areas of micro- and nanotechnology, biotechnology and genomics in order to build up a renowned position in bio-analysis in space as well as terrestrial applications. Dutch entities involved in this in-situ bioanalysis cluster are characterized by activities in both the space- but moreover in the non-space domains. This cluster and its activities is known for its high degree of spin-in and spin-off when it comes to space- and earth applications. This fits very well in the new thematic approach for Dutch innovation processes, especially in light of the potential of nanotechnology for the Dutch economy.

Ambitions of this cluster are quite significant, both for the space- as in the non-space domains. First indications and projections by the sector regarding ambitions versus required funding show that for the coming years this cluster requires / targets roughly 9,3M€ for technology development, from which roughly 5,4M€ should come from space-related funding sources (ESA TRP en GSTP, NSO PEP, NWO). The remaining part, 3,9M€, should come from other non-space funding sources (EU FP7 and New Horizon 2020, NanoNextNL). In addition to the targeted 9,3M€ required external funding, the sector foresees roughly 3,6M€ (= 39%) of additional own investments.

> *High Tech Space Systems and Components*

Roadmap 10 Thermal management and cooling systems (instruments)

Ambition: To be a world class player in developing, produce and integrate components and sub-systems for thermal management and cooling to most of the Primes of space industry

This first roadmap is a part of both the instrumentation (see above) as the components and (sub)systems part of the Innovation Contract for HTSM/Space.

This domain concerns the technology development and space qualification for (low-)temperature thermal control and cooling systems for a wide variety of space applications, ranging (not exclusive) from the thermal management of optics and detectors in instruments to components and subsystems in front-end electronics and telecommunication payloads. Many of these applications require very precise localized and often miniaturized cooling devices to improve performance and/or life time of space infrastructure. Dutch entities have acquired substantial and globally recognized heritage and credibility in this domain. Next to excellent manufacturing capabilities which are present in Dutch industry and institutes, there are also competence centres and universities which are known for their unique technologies, R&D and expertise in these fields.

To categorize the wide variety and scope of thermal management and cooling systems in which the Dutch entities are active, the related technology and product developments are categorized in the domains of 1) “Recurring thermal control subsystems and components” and 2) “Instruments and payload elements thermal control”. The first domain can be subdivided into 1) small cooling loops and components for cooling systems, high thermally conductive CFRP structures and components, and development of deployable and standardized radiators. The second domain can be subdivided into Sorption-based cooler technology, Microthermal management technology, and Stirling & Pulse tube coolers and associated drive electronics.

The scope of- and variety within the domain of thermal management and cooling systems is very broad which results in the fact that the products and technologies developed within this domain can be used for a wide variety of applications. Most of the work is targeted at development and eventual space qualification of various thermal systems. Next to current and foreseen institutional-based work like applications in science and earth observation missions and technology development (ESA- and nationally funded), even a bigger part of foreseen turnover will come from the ‘commercial market’ (mainly telecom), ESA ‘recurring’ work, and spin-off applications (estimated at 26,4M€ for period 2011-2016). First indications and projections by the sector regarding ambitions versus required funding show that for the coming years (2011-2016) this cluster targets roughly 18,8M€ (national and ESA) for technology development. Next to the external funding sources, the sector foresees an additional 6,2M€(=33%) of own investments.

Roadmap 8 Structures

Ambition: To be and stay the Engine Trust Frame manufacturer for European launch vehicles.

- Metal technology

The current Dutch contribution to Ariane 5 launchers consists of full metal engine trust frames. Further development to achieve cost reduction or mass saving is mainly in the details of connection technology or production process improvements. Implementation of such improvements should be justified by the savings itself. No major technology development investments are expected in this area.

In terms of investment in this part it is foreseen that in the coming 3 years a budget of a little less than 16 M€ should come available. Industry will contribute 2 M€ to these activities.

- Composite technology

The market demands a significant mass reduction for the upper stage of the Ariane 5 Midlife Evolution models. Future launchers will even be more demanding for the whole launcher design. Similar needs exist for spacecraft platform structures.

The only technical solution is to move from all metal designs to composite technology. The development path of composite designs comprises material selection, design methodology, production process technology development, development of inspection techniques, verification and qualification approaches, dedicated modification and repair philosophy and techniques. The most appropriate way to introduce composite technology is a stepwise approach, in which the Ariane 5 ME cryogenic upper stage is the first opportunity.

R&D expenditure is foreseen of some 7 M€ of which industry will contribute about 3 M€.

Roadmap 9 Solar Arrays

Ambition: To achieve within 4 years a position in the market of solar arrays and mechanisms for telecommunication satellites with breakthrough technology based on Dutch innovative products.

- Mid term solar array development

Focus is on cost reduction, being at present the main market requirement. This implies improving the robustness of the present design. As a preparation for a next generation communication satellite platform to be developed by our customers, it is necessary to incorporate state of the art technology, including composites and thin film high efficiency solar cells.

- Solar Array for the Next Generation Platforms

Development of a new generation solar arrays for the communication satellite market with spin-off to Earth Observation and Science programs excelling in strongly reduced production costs and significant 'power to mass' performance improvement is needed in the highly competitive market. These next generation solar arrays utilize ultra high efficiency thin film solar cell blankets. Potentially unique features developed at Radboud University will be incorporated. Focus will be on the qualification of cell blanket production; the solar array will differ strongly from today's version, the array will consist of frames with tensioned blankets. Budget: 2.0 M€/year

- Hold down and release mechanisms

Large Communication Satellites demand a low shock release of deployable appendages, such as solar arrays, antenna's and booms, thus protecting the electronic equipment on the inner side of the platform side panels. Dutch Space will enhance a hold down and release

mechanism fulfilling the economic and technical requirements by extending its well proven thermal cutter release mechanism for solar array's into one solution for these varying applications.

Budget: 0.4 M€year

- Deployment systems

In order to allow the payload of communication satellites to grow, the focal length of the antennas and the diameter of the antenna dishes will increase. This feature requires mechanisms to allow for stowage of the sub-systems in the launcher envelope. The mechanisms are not available on the market and can be developed with the knowledge gained for existing solar array deployment systems.

Budget: 0.1 M€year

Roadmap 6 AOCS

Ambition: Become in the coming 5 years a major supplier of AOCS components and (sub)systems to the prime-industries in Europe and beyond.

This domain concerns the technology- and product development and space qualification of components and subsystems needed for attitude and orbit control (AOCS) of satellites. Dutch research institutes and industry both have a longstanding and recognized position in this field. Since the early developments in the 1980s many of the technologies developed in research institutes and manufactured in industry have made it to a wide variety of space-qualified products which currently find their application in the institutional- and the commercial space markets.

The market for AOCS components and (sub-)systems is ever increasing and has made a shift from analogue technologies to digital technologies. The adaptability of the Dutch sector has led to a product portfolio with meets evolving market demands and ongoing trends like miniaturisation, mass reduction, cost reduction, reliability, etc. The Dutch research institutes and industry active in this domain have continuously adapted their developments to these evolving market needs and trends which in turn have resulted in a well-established and globally recognized market position.

In general, the domain of AOCS components and subsystems can be divided into AOCS actuators and AOCS sensors. AOCS actuators covers the area of reaction wheels and magnetorquers in which certain Dutch industries have reached the maximum technology readiness level (TRL 9) and are therefore fully space-qualified. Current investigations with international partners are focussing on the feasibility for the development and manufacturing of a so-called Control Momentum Gyroscope (CMG's). AOCS Sensors mainly covers the area of analogue and digital sun sensors, of which the first all have reached TRL 9 and of which the second are still in on-going development.

Reflecting on the past and preparing for the future, one can conclude that with appropriate government funding and incentives for technology development at research institutes and follow-on industrialization at Dutch industry, the Dutch entities in this domain have become extremely successful in development- and recurring work for institutional and commercial markets. Future ambitions for this cluster for the years to come are also quite significant. First

indications and projections by the sector regarding ambitions versus required funding show that for the coming years (2011-2017) this cluster targets roughly 30M€ of external funding (national and ESA) for technology- and product development. Regarding own investments the sector foresees roughly an additional 30% for work which can be considered as 'recurring', whereas an additional own investment of 100% can be added to developing and qualifying new technologies and products.

Roadmap 7 Satellite propulsion

Ambition: Extend the good position of Dutch industry in this field to one of the world class suppliers for (micror)propulsion for satellites.

Industry and Institutes has in the past 25 years individually and together built a broad portfolio of components which have found applications in the satellite propulsion systems of both institutional and commercial space programmes. Examples are valves, pressure transducers and cold gas generators.

The ambition is to bundle these individual technologies and grow into a supplier of end-to-end systems which encompass everything from the fuel supply to the thruster itself. Through this it would be possible to provide the end user with a number of benefits, including lower cost, increased reliability, ITAR free systems and weight reduction. More than in the past this means that there has to be a close cooperation with potential customers to ensure these systems develop into the actual needs of those customers. The ESA technology plans up to 2015 also show a strong emphasis on the further development of the technologies covered in this road map.

Spin off is seen mainly from the cold gas generation technology, which is expected to have significant non-space applications.

For the coming three years an investment level is foreseen of EUR 21 mln. Of this EUR 13,5 mln is expected to be financed out of institutional programmes (Artes and ESA Science) including EUR 1,5 mln in PEP. The remainder is to be financed by industry itself through commercial programmes from EADS/Astrium, TAS, and American based prime companies like Orbital Sciences Corp., The Boeing Company and possibly Lockheed Martin Corp, and Bigelow Aerospace.

Roadmap 11 EGSE and simulations

Ambition: Supply EGSE (and simulation devices) to all Prime industries in Europe including the major programmes of ESA itself

Within The Netherlands, clear competence in the domain of EGSE and simulation is available and successfully used both within ESA and the commercial space markets. In the context of space, EGSE and simulation relate to configurable test and simulation of satellites and satellite flight hardware. It is supporting the development, assembling, integration and operations of a spacecraft.

Partners in The Netherlands involved in in the EGSE and simulation roadmap are Dutch Space, SSBV, Terma, Nspyre, ISIS and NLR. For more than 25 years they have realized successful space products and programs in the field avionics/Real-Time Simulation, AOCS testing, the design, development, deployment and support of EGSE, SCOEs and Front-End, and integrated simulation and test solutions, CCS systems and CMDVS integrated EGSE for very small satellite mission

The roadmap structure aligns the EGSE & Simulation activities from the perspective of the different roadmap cluster members. It has led to the breakdown into four cluster segments taking into account the capabilities and interest of the parties within the EGSE and Simulation cluster:

- Front-Ends & Special Check Out Equipment SCOE (SSBV);
- Real-Time Simulation & Modeling (Dutch Space);
- Integrated EGSE (SSBV);
- Central Check-out System CCS / Core EGSE (Terma).

Each segment has a segment lead assigned (between brackets) who is responsible for the segment roadmap coordination and description. Harmonization and alignment between segments is coordinated by the overall roadmap manager SSBV.

From a recurring EGSE and industry perspective, throughout the years, a clear shift in the EGSE development and use philosophy has been noticed. Whereas in the early days of testing, each project developed and procured a specific EGSE that was only used *once* and ended up in storage after project closure; nowadays EGSE is treated more as a *re-usable element* and within many prime contractors as *infrastructure*.

This means that *standardization* and the provision of EGSE on a *commercial / product* basis has become increasingly important for long-term involvement and industrial success.

It can be stated that Dutch industries and organisations are actively pursuing a development and commercialization approach that goes beyond the scope of incidental and satellite project driven activities.

The ambitions laid down in the roadmap are aiming at maximizing mutual benefits and cooperation between the participating partners in the above mentioned four fields of technologies. The focus is on increasing the added value and reducing the cost by realizing a total test solution instead of division into separate subsystems. This opens up new opportunities in demand-driven commercial space markets. In addition, the partners foresee spin-off potential in high-tech industry markets with similar technology requirements like defense & security and silicon manufacturing & test equipment.

On the shortterm it is expected that that almost 5M€ is needed for R&D in this sector, of which 1/2 will be provided by companies and institutes. For the midterm (until 2017) it will be 10 M€ with an investment of 5 M€ by the companies/institutes.

Roadmap 12 Igniters

Ambition: Stay the sole supplier of igniters to the European launcher builders.

Dutch industry and institutes have since 1985 built a successful track record in providing igniters for European launch systems. Igniters have been developed and built for both core stages of the Ariane 5. Recently the igniters for all three solid fuel stages of the Vega have been added. They have secured a position as the premier centre of competence in this technology in Europe.

The ambitions are to retain that position and build on it in the future. For the medium term the attention is focused on the development of the igniter for the Vinci engine, a critical part of the Midlife Evolution of the Ariane 5. This engine will be reignitable, which puts totally new demands on the design of the igniter. For the longer term work is being carried out on igniter concepts for the Next Generation Launcher, under the auspices of the FLPP programme. Catalytic igniters, a new technology, are being investigated for this application.

At present most activities and production are geared to the European launcher market. Industry however see significant spin off potential. This is both in their core business, with leads in Korea and India , as well as other applications such as fire suppression systems and cold gas generation applications.

In the coming ten years Industry expects to undertake developments amounting to a cost of approx. EUR 44 mln. This will be financed mostly through ESA technology programmes. Very little internal financing is expected. For spin offs an investment of EUR 1 mln p.a. is foreseen, which will be financed internally and recouped from the production cash flow.

Roadmap 13 Satellite cluster technology

Ambition: make available satellite constellations of nano-sats with different objectives to end-users around the world in the coming 5 years

This document presents the roadmap Satellite Constellations within the framework of the NSO Roadmap 2.0 exercise started in 2010. This document provides an overview of the targeted end-users and the associated market perspective, as well as a detailed technology requirement flow-down from these needs. Developments and trends are addressed as well as a SWOT analysis of this particular topic.

A detailed roadmap will be provided to describe the implementation path for the Dutch ambitions in the field of satellite constellations.

The definition of a satellite constellation is considered to be a system, comprising out of a space segment that consists of two or more satellites with a common purpose.

This roadmap deals specifically with hardware and software aspects of technologies aimed at the design, development, and operations of the satellite constellation. It does not focus on the individual constellation payloads or common spacecraft platform subsystems, but particularly on those elements that enable networking and provide added value when using multiple satellites for a specific purpose. Although the size of the spacecraft is not a constraint on itself for the technology roadmap, the current trend for networked satellites is to focus on small satellites (mini, micro, nano) and the involved parties and targeted technology developments reflect this global trend.

The roadmap is based on the harmonization of a number of national initiatives in the field of (small) satellite networks in light of international trends, developments and (market) opportunities. The presented results are partly based on the results and ambitions formulated in other plans and project such as:

- MicroNed MiSat
- NanoNextNL project
- STW ASSYS OLFAR project
- S5, STW Perspectief programme proposal
- Small Satellite Roadmap Outline document
- The Delfi nanosatellite programme at TU Delft
- The QB50 project from the EC's FP7 Space call 2011
- ISIS' Satellite AIS activities, both in ESA and outside of ESA
- Joint proposal from SSBV, NLR, ISIS for maritime monitoring
- The Nanosatellite Initiative (NSI)
- Individual business and development plans of the participants

The existence of small satellites enables space systems architectures to address problems that were either technically impossible or too expensive to tackle before. Deployed in larger numbers, such satellites can fulfill some user needs that more traditional space systems have a hard time to meet, in particular increased needs for improved coverage and timeliness of the data. Small satellites are increasingly being viewed as elements enabling new mission capabilities through constellations, be it swarms, clusters or formations.

When it comes to connecting technology development to the end-user needs, this is usually a complex process, resulting in a mix of technology push and market pull.

For several satellite constellation activities the intended system architect / system integrator is present in the Netherlands, which helps to give the required developments focus and momentum. In addition the end-user communities that these initiatives target have strong positions in the Netherlands and intermediaries are also well established. For the more commercial initiatives such as ocean traffic monitoring or space based radar observations, the Netherlands ranks very high in the domains of logistics and transportation, infrastructure development and water management.

Roadmap14 Miniaturised accelerometers

Ambition: Develop miniaturised accelerometers to a higher TRL-level in the coming years with as ultimate goal flight heritage as soon as possible.

This roadmap describes the development of miniature accelerometers serving three purposes: 1) AOCS, 2) Gravitational and vibration measurements, and 3) Gravitational gradient measurements. There are also similar applications for such sensors on Earth, especially for nature exploration and geology.

The technology for low-frequency miniaturized MEMS accelerometers / gradiometer is still at a low TRL. The availability of real products or instruments is still far away. Actually this roadmap subject is concerned as an 'incubator technology'. Developments are currently taking place at the university in the context of fundamental research. Cooperation with TNO will take place with the aim of deriving the specifications and user requirements. On the

institutional side ESA is interested in this topic. In the non-space sectors, Shell and Fugro actually are showing interest and will be involved as a partner (in-kind contribution) in the ongoing developments. The reason for this interest relates to the specific characteristics of the development referred to, namely small, lightweight, low power (MEMS), low noise at low frequencies, less complex interface architecture and the possibility of series production.

As in the Smartmix project in 2005 was examined, this topic provides a low-frequency (LF) miniaturized MEMS accelerometer / gradiometer technology that has commercial prospects outside the space sector. Local gravitational field mapping is very important in the exploration of natural resources (oil, gas, etc.)

There are some fundamental issues to be resolved before a working prototype can be developed (noise behavior at low frequencies, bigger mass, zero-length spring, etc.). Resolving these questions is also relevant for other possible applications of miniaturized MEMS accelerometer / gradiometer in space. Even some elements of the space qualification (such as temperature stability, gevoelgheid for shock and vibration) also play a role for terrestrial applications. There is, in this stage at the low TRL's, a useful synergy in the development of these sensors for space and non-space applications

There is a clear trend of research aimed on MEMS accelerometers with a bigger mass. At the University of Twente in 2005 a development has started with a specially designed production process based in the containment of the masses hanging on a silicon grid, so the the silicon wafer can also be used as an inertial mass. Also in the MicroNed research programme several structures of the gradiometer and gravimeter have been investigated. Recently the first gravimeter demonstrator breadboard was realized.