THE TRILLION SENSORS Initiative

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The cost of designing and manufacturing sensors continues to decline and the ability to increase their functionality to create a 'total solution' to customer requirements rapidly increases through the adoption of a 'systems solutions' approach This results in their high adoption rate into a broad range of applications, especially those of associated with the Internet of Everything (IoE) and the Internet of Things (IoT). Cost, size, weight, power consumption and performance are no longer barriers to their widespread adoption.

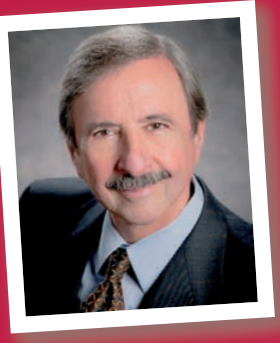
A large proportion of these sensors will be MEMS, based on their inherent ability to be low cost, rugged and miniature. MEMS is a technology enabling fabrication of mechanical, optical, chemical, bio and nano structures using IC fabrication technology. Multiple organisations are starting to plan to exploit MEMS potential for a trillion sensors market within a decade.

Emerging technologies

Emerging technologies are defined by the World Economic Forum and Cientifica as those that arise from new knowledge or the innovative application of existing knowledge. They lead to the rapid development of new capabilities. Such technologies are projected to have significant systemic and long-lasting economic, social and political impacts as well as create new opportunities and challenges to addressing global issues. Emerging technologies also have the potential to disrupt or create entire industries.
The Summit on the Global Agenda 2011 in Abu Dhabi led to the compilation of the Top 10 Emerging Technologies with the greatest potential to provide solutions to the most compelling social, economic and environmental challenges includes the following segments:

- Informatics for adding value to information
- Synthetic biology and metabolic engineering
- Green Revolution 2.0 — technologies for increased food and biomass
- Nanoscale design of materials
- Systems biology and computational modelling/simulation of chemical and biological systems
- Utilisation of carbon dioxide as a resource
- Wireless power
- High energy density power systems
- Personalised medicine, nutrition and disease prevention
- Enhanced education technology

Dr. Janusz Bryzek is considered to be one of the pioneers of MEMS and has cofounded nine Silicon Valley MEMS companies: Sensym (now Honeywell), ICSensors (now Elmos/MSI), NovaSensor (now General Electric), Intelligent MicroSensor Technology (now Maxim), Transparent Networks (now Intel), LVSI (now Atmel), Jyve (now Fairchild Semiconductor), BN Ventures (Strategic Consulting) and TSensors Summit. In 1989 he was recognised as "Entrepreneur of the Year" by Arthur Young. In 1994 he was awarded the Lifetime Achievement Award by Sensors Magazine and in 2003 by MANCEF. Janusz serves on the Boards of several companies and is an Advisory Board Member of The Global Medical Microtechnology Association and on the Board of Directors of the Micro and Nanotechnology Commercialization Education Foundation (MANCEF). He is also a member of IEEE-MEMS Program Committee. Dr. Bryzek received his MSEE and Ph.D. from Warsaw Technical University, Poland. He completed the Executive Management Program at Stanford University. In 2013, Bryzek started the TSensors (Trillion Sensors) initiative, aiming at the accelerated development of new sensor types to support the concept of 'Abundance', targetting the elimination of major global problems in one generation.



Roger Grace is President of Roger Grace Associates of Naples, Florida, a marketing consulting firm that he founded in 1982, specialising in the commercialisation of MEMS. His firm provides business development, custom market research, market strategy and integrated marketing communications services to high tech clients worldwide. He has published over 20 articles in industry publications, organised and chaired over 50 MEMS technical sessions and conferences and is frequently quoted in the technical and business press as a MEMS industry guru. He was a visiting lecturer in the School of Engineering at the University of California, Berkeley, from 1990 to 2003. He holds BSEE and MSEE (as a Raytheon Company Fellow) degrees from Northeastern University where he was awarded the "Engineering Alumni Engineer of the Year Award" in 2004. Roger is a co-founder and past president of MANCEF.

While broadly diversified, many of emerging technologies represent or use smart systems, a fusion of sensors, computing and communication, thus representing a significant opportunity for MEMS sensors.

Emergence of Abundance
In 2013, a vision of Abundance has emerged (www.abundancethebook.com). This visions forecasts that all major global problems, such as hunger, lack of medical care, lack of clean water and lack of energy, can be solved in one generation (20 to 30 years) through:

- Exponential technologies, producing goods and services faster than demand growth.
- DIY (Do-it-Yourself) revolution, which deployed global scale project (e.g. flying to space) by individuals.
- Technophilanthropic force unrivaled in history, providing significant funding for addressing global problems, such as malaria.
- The rising billion of poorest people on earth being plugged into economy, enabling growth of global GDP.

Eight technologies are classified as exponential and include:

- Biotechnology and bioinformatics
- Computational systems
- Networks and sensors
- Artificial intelligence
- Robotics
- Digital manufacturing and infinite computing
- Medicine
- Nanomaterials and nanotechnology.

Sensors are not only one of the eight exponential technologies, but are also embedded in other exponential technologies. Abundance projects the need for 45 trillion networked sensors in about 20 years, helping to solve global problems for all people on earth.

Global Tides Driving Demand for Sensors
Several (somewhat overlapping) global economic tides (defined as global market pull) which drive the demand for sensor-based applications (smart systems) have emerged. The most visible tides support Abundance objectives and include:

Internet of Things (IoT)[2] and Everything (IoE)[3]
IoT is defined as sensors and actuators embedded in physical objects, often using Internet Protocol[4] . IoT is starting to gain a major momentum resulting from:

- Introduction of IPv6 Internet addressing, increasing the number of IP addresses from $3x10^9$ to $3x10^{38}$, effectively enabling addressing every object in the world.
- Recent modifications of Internet architecture by major network providers Cisco, IBM, Amazon and GE to include two layers below Cloud: Fog and Swarm, significantly simplifying deployment of IoE.
- 2020 forecast for IoE growth released by major companies, Cisco's at $19 trillion (over 20% of global GDP) and GE's at 15.5 trillion, with sensors expected to represent about $1 trillion.
- Recent acquisition of Nest by Google for $3.2B, one of the first IoT startups.

Major IoT sensor applications are expected to be focused on information and analysis (such as tracking behaviour of people, things and data through space and time, enhanced real time situational awareness of physical environment and sensor driven decision analytics through deep analysis and data visualisation) and automation and control.

Libelium[5] and Beecham Research[6] forecasts IoT deployment to create smart cities, environment, water, materials, energy, agriculture, farming, buildings, retail, transportation, public safety, industrial controls, ehealth and IT.

In the current China's 12th five year plan, IoT was promoted to one of the seven Strategic Emerging Industries with about $1B government funding allocated during the next five years[7].

CeNSE
Hewlett Packard, in multiple presentations from 2010 to 2012[8] , introduced a Central Nervous System for the Earth (CeNSE). CeNSE is based on detectors and actuators, forecasted to reach trillion units by 2018. Key market segments include climate monitoring, oil exploration and production, assets and supply chain tracking, smart highway infrastructure, tsunami and earthquake warning, smart grid and homes and structural health monitoring.

The first deployed CeNSE system included 1 million wireless accelerometers on 10 x10 km site for Shell oil exploration.

Context-Aware Computing
Intel presented[9] the emergence of sensors for Context-Aware Computing. Sensors supporting such systems are expected by Intel to absorb a trillion sensors by 2020-2022. Out of trillion sensors, 70% will be solving problems and 30% will be enhancing lifestyles.

The applications will include sensing all around you and your needs, understanding situations (e.g. mood of the person you meet), all around devices, personal health, social interactions, planet context and universe context.

Emergence of location based advertising, and forthcoming location and activity-based advertising will be based on sensors in the body, on the body and out of the body. These systems need personal behaviour information derived from sensors.

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IBM 5 in 5
IBM unveiled the seventh annual "IBM 5 in 5" — a list of innovations that have the potential to change the way people work, live and interact during the next five years. These five sensor/actuator innovations include touch (ability to touch through your phone), sight (a pixel will be worth a thousand words), hearing (computers will hear what matters), taste (digital taste buds will help you to eat smarter) and smell (computers will have a sense of smell).
The IBM's 5 in 5 is based on market and societal trends as well as emerging technologies from IBM's R&D labs around the world that can make these transformations possible.

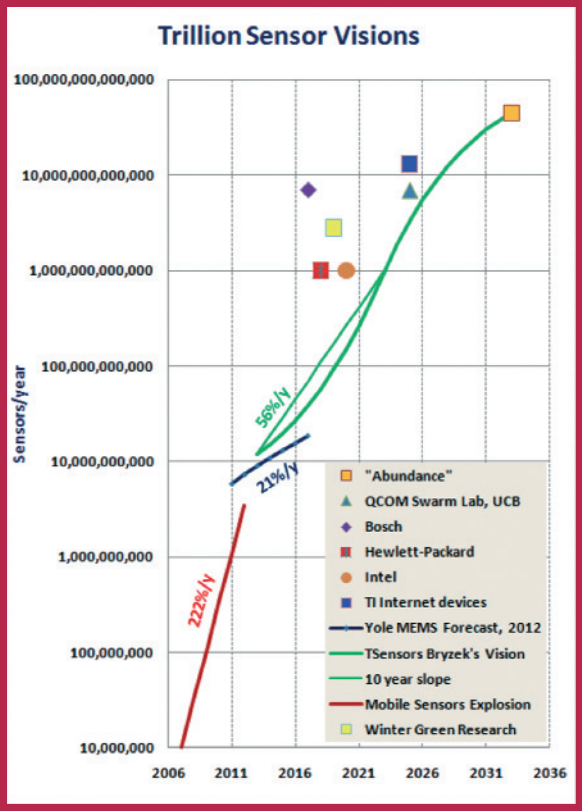
Digital Health
Digital Health (mHealth, eHealth) is based on broad range of fitness, wellness and health sensors connected to mobile platforms (cell phones, tablets, etc.) as a solution to the skyrocketing cost of medical care, aging population and lack of medical care in developing countries.

Visible examples of the evolving market include 2014 CES Show in Las Vegas, where there were 15 Digital Health conference sessions and about 400 exhibitors in Digital Health section. Another example is Qualcomm's $10 million Tricorder X PRIZE , a 42-month competition to bring the sensing of 15 most common human diseases to the cell phone. Samsung announced a similar competition with a $2.25M prize.

Emergence of Trillion Sensors (TSensors) Potential
In 2012 only four sensors (microphone, acceleration, gyro and compass) shipped about a billion units each. Several visionary organisations (some mentioned earlier) started to forecast sensor demand growing from billions in 2013 to trillions within the decade.

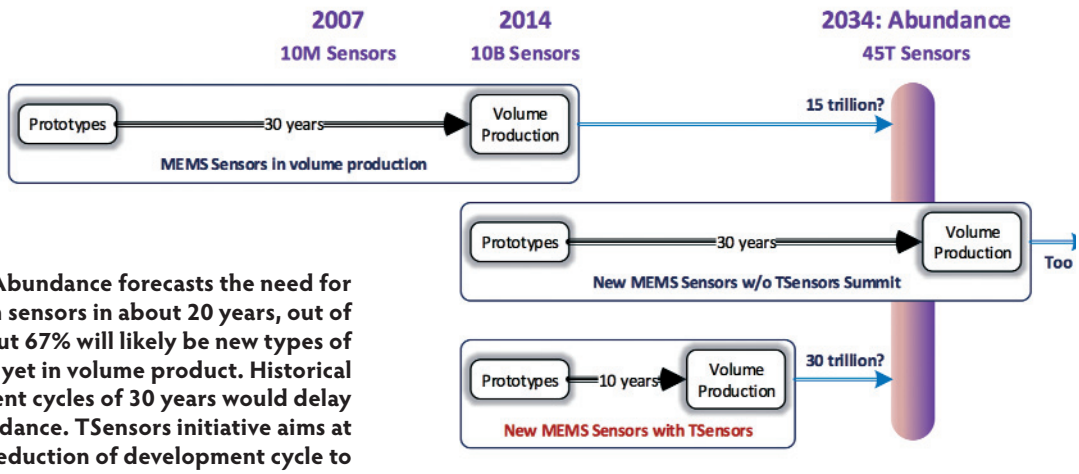
The demand is expected to be driven by global tides characterised earlier. Harbor Research considers sensor-based smart systems to be the biggest business opportunity in the history of business.

Texas Instruments outlined in its presentation[13] the vision for growth of Internet connected devices to 13 trillion by 2025, with major markets being fixed and mobile communication, computers, industrial, medical, military and aerospace. They expect MEMS, specifically sensors, to be the enabling technology for such growth. Ambient Intelligence[14], based on wireless sensor nodes, will adapt, anticipate, be transparent, dependable and autonomous. Several other TSensors forecasts are shown in figure 1.



<< Figure 1: Several organisations presented their visions for a continued growth to trillion(s). Market research companies don't yet see this growth (see Yole's forecast). So the explosion to trillion(s) is likely to be driven by applications not yet envisioned by leading market research organisation. >>

To support the forecasted demand for 45 trillion sensors to make Abundance a reality, likely a 67% of this volume will be represented by new sensors. Historically, each new sensor type took about 30 years to move from concept prototypes to volume production due to complexity resulting from deployed 'multi-physics' and 'multi-bio-chemistry', as well as from lack of standardisation (one product–one process–one ASIC-one package-one test system[15]). To accelerate this cycle and thus accelerate solutions to global problems, a TSensors (Trillion Sensor) Initiative has been launched.



<< Figure 2: Abundance forecasts the need for 45 trillion sensors in about 20 years, out of which about 67% will likely be new types of sensors not yet in volume product. Historical development cycles of 30 years would delay Abundance. TSensors initiative aims at significant reduction of development cycle to support Abundance timeframe. >>

Graphical representation of TSensors Initiative is shown in figure 2.

TSensors Initiative is structured in three phases (figure 3):

- TSensors Summits conferences with invited sensor visionaries providing forecast for forthcoming ultrahigh volume new sensor applications. This enables structuring marketing development target (customers involvement), one of the most important contributors to accelerated market introduction. The first TSensors Summits were organised at UC Berkeley (April 2013), Stanford University (October 2013) and Tokyo (February 2014).
- TSensors Roadmap — a volunteer driven activity of over 100 sensor technology professionals worldwide who are developing a document with recommended sensor technology platforms best suited to support emerging applications. This will enable development to focus on a reduced number of technologies simplifying the overall resulting development effort and simplifying later standardisation.
- TSensors Supply Chain development — the activity focused on incubating start of accelerated development of required sensors using recommended technology platforms.

<< Figure 3: TSensors initiative is split into three phases: TSensors Summits, TSensors Roadmap and TSensors Supply Chain development. >>

The TSensors Roadmap is currently divided into the following applications, each representing one Chapter:

- One Chapter on education to support IoT and TSensors
- Eight Chapters focused on sensor technology platforms for the following TApps:
- Sensors for noninvasive fitness/wellness/health monitoring.
- Sensors for minimally invasive health monitoring.
- Sensors for personal imaging (e.g., acoustic, ultrasound, hyperspectral, THz, Xray).
- Computer senses.
- Environmental sensing (pollution of air, water, food, soil, etc.)
- Infrastructure sensors (roads, bridges, buildings).
- Sensors for smart food production.
- Sensors for energy generation and control.

Five Chapters focused on technology platforms for TSensors infrastructure:

- Digital manufacturing (e.g. 3D printing) for sensors, ICs and packaging.
- Energy harvesting and ultralow power electronics for sensors and networks.
- Ultralow power wireless communication.
- Network infrastructure for Internet of Everything, including security.
- Analytics for sensors.

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The TSensors Roadmap will represent a set of white papers (updated after each TSensors Summit) including the following:

- Definition of sub-applications and validation of their ultrahigh volume potential.
- Definition of sensor specifications necessary to enable given TApp. e.g. accuracy, spectral resolution, sensitivity, etc.
- Reviews of sensor technology platforms from the perspective of:
- Delivering required performance/specs…
- In expected volumes…
- At expected selling price…
- With applicability to other TApps.

Current schedule includes:

- 30 July 2014: Internal alpha version of the Roadmap.
- 31 October 2014: Internal beta version of the Roadmap.
- 31 December 2014: Availability to Sponsors of the unedited version of the Roadmap.
- 31 March 2015: Global availability of the edited version of the Roadmap.

Summary
We believe that the growth of the sensor market to trillions of units is not unrealistic and it will result from multiple global applications using sensors as their basis to provide a link to physical and biological worlds. Funding of deployment of these applications is expected to be strongly incentivised by expected benefits including, e.g. a 35% savings of medical care costs and a 35% savings in energy creation, distribution and consumption cost for sensor rich based systems implementations. The byproduct of this explosive growth will be Abundance in two decades, a dream that slowly becomes a reality.

In parallel, these global transformations will bring us longer and healthier life, enable all of us to live in less polluted and more energy-efficient world, and have more fun than ever.

We believe that the growth of the sensor market to trillions of units is not unrealistic and it will result from multiple global applications using sensors as their basis to provide a link to physical and biological worlds.

Due to the sheer size of forthcoming changes driven by global tides (growth by $19 trillion in six years), multiple business opportunities will be created. The byproduct of these opportunities was the emergence of the first MEMS Billionaires (resulting from the acquisition of sensor-based Nest by Google).

If you'd like to learn more or become involved, please come and see us at one of the following events:

TSensors Summits in Munich, Germany, 15-17 September 2014; San Diego, California, USA, 12-13 November 2014; Tokyo (currently in the planning stage for December 2014); China (currenty in the planning stage for April 2015).

TSENSORS
www.TsensorsSummit.org
Those of you who may be interested in joining the TSensors Roadmapping effort are encourage to contact Dr. Janusz Bryzek on jbryzek@TSensorsSummit.org

References:
1 Grace, R; Think Outside the Chip:MEMS-Based Systems Solutions; MEMS Technology Review:pp.12-14; November 2010.
2 http://www.technologyreview.com/view/509546/2013-the-year-of-the-internet-of-things/ 3 Cisco definition.
4 McKinsey: http://www.mckinseyquarterly.com/The_Internet_of_Things_2538.
5 http://www.libelium.com/top_50_iot_sensor_applications_ranking. 6 http://beechamresearch.com/article.aspx?id=4 7 http://technode.com/2012/05/14/internet-of-things-not-just-a-concept-for-fund-raising/
8 Friedrich R.: CeNSE: Awareness through a Trillion MEMS Sensors; the decade of sensing and sense-making. MEPTEC, May 2012.
9 Bhide S.: Emerging Usages & Apps for Sensors in 2016+, MEMS Business Forum, May 2012.
10 http://www.qualcommtricorderxprize.org/ 11 http://www.nokiasensingxchallenge.org/
12 http://harborresearch.com/smart-systems/ 13 Ajith Amerasekera: Ultra Low Power Electronics in the Next Decade. 2012 MIG Congress, October 2012.
14 http://en.wikipedia.org/wiki/Ambient_intelligence 15 Grace,R.; Walsh,S ;MEMS Industry Roadmap; MANCEF; Chapter 2:1990: www.mancef.org