Vision paper:
Sensing the future

Sensors development and the role of Functional Electronics for the digitalisation of European industries and societies

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5E - Federating European Electronics Ecosystems for Competitive Electronics Industries
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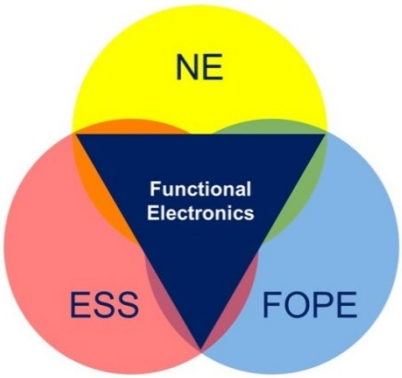
1. Functional electronics definition



At the convergence of unconventional nano-electronics (NE), flexible, organic & printed electronics (FOPE) and electronic smart systems (ESS), the term 'functional electronics' encompasses the ever-increasing capability to integrate digital technologies with cognitive functions in everyday objects, smart functional and hybrid electronic systems provide countless form factors through novel production techniques creating a unique ecosystem of sensing and monitoring devices for every market segment.

Functional electronics allows for the seamless integration of augmented sensing enabling the full potential of their sustainability benefits in a broad spectrum of new applications. Functional electronics will generate additional value from their use that is presently not realisable by using state-of-the-art electronics independently. It will enable new and efficient sustainable approaches at product, process and business model levels. It will have the capability to capture & manage multi-physics data and contextual information in real time, with high sensitivity, selectivity and reliability as well as being networked, autonomous and complemented by bespoke software (incl. Artificial Intelligence) solutions.

The 5E project aims to map the opportunities and limitations for sensor systems enalbed by flexible electronics, innovative nano-electronics, and electronic smart systems. It is mapping the technology towards known market sectors [1]. In this perspective, functional electronic sensor technologies are already finding numerous applications in almost every market section identified. The sensors and their counterparts actuators enable the divergence of flexible electronics and nano-electronics technology directly towards smart systems. The current position paper describes methods/ roadmaps / white paper on how the current sensor developements are strengthening the European technology and market position. It provides suggestion for further research actions and a European roadmap in this domain.

2. Introduction of the sensing landscape

2.1 Identification of the opportunity of sensors in a data centric world

The last decade has witnessed a tectonic shift in the possibilities that data and information systems permit. The rapid evolution of wireless communication, information storage and artificial intelligence has provided invaluable tools regarding insights in our society and industry. These advances have provided fruitful breeding grounds for bold visions, such as the Industry 4.0 initiative aiming to revolutionize manufacturing through digitation of parts. The impact of those European led initiatives was identified worldwide and others have followed such as Japan introducing Society 5.0 creating a data driven approach, addressing societal challenges. Realizing long terms visions towards a datacentric society will require substantial functional electronics developments. One major catalyst for the coming years will be the implementation of new 5G wireless communication networks. The deployment of those 5G networks will serve as the backbone enabling data transfers at unprecedented speeds and facilitate the rise unimaginably large swarms of connected devices.

In such a data driven future society, information streams will arise from multitudes of objects, each with their own specific challenges and needs. As examples large swaths of Internet Of Things nodes containing sensors will be used to monitor infrastructures such as roads, bridges, rails and waterways. Such swaths of sensors will power the smart cities of the future and allow the emergence of new concepts such as the internet of water. Sensors in roads and bridges will reduce maintenance cost and improving their quality through preemptive maintenance. The automotive

industry will greatly benefit from the electrification and digitation of cars, thus providing ever more sensors and eventually paving the way towards autonomous driving. The steady connectedness of cars will enable cars to tap into swarms of sensors along the roads as well as in the cars ahead providing real time information on the road ahead for safer and more efficient trips. In healthcare, big data and new medical devices are already rapidly changing how care is provided. As we are moving towards an ageing society, technologies are used to ensure that patients can stay longer at home, providing remote patient monitoring and support in the form of connected health patches. With digital medical records , medical data can be more effectively utilised. Beyond medical care, an explosion of wellness products (smart watches, heart rate sensors, fitness trackers, etc..) are rapidly becoming connected storing troves of data for creating accurate digital twins enabling more effective preventive healthcare.

The deployment of sensors is accelerating at such a rate that providing reliable and accurate context and situation based information to the user is soon within reach. Ultimately monitoring changing conditions and occurrences in real time will allow for proactive actions to be undertaken as a much larger scale than before. Functional electronics is poised to play a major role in the further sensor development as it opens up the opportunity to deploy multiplexing systems able to simultaneously monitor numerous parameter in a single system enable augmented sensing through sensor fusion. The data streams all those sensors streams are then aggregated to provide contextual information, exceeding the individual sensor information. Linked to these developments are the challenges in the domain to energy such as the development of autonomous sensor nodes and improvements in battery performance and lifetime.

In future products, sensors will define their functionality, attractiveness and position in the market. This will require radical new concepts towards embedding of sensors where functional electronics will play a key part. A convergence between other functionalities, such as actuating, signaling will define the usage. A critical aspect will be to ensure that the consumers trust can be maintained through transparent but strict privacy regulation.

2.2 Statement of the position in Europe

The digital transformation presents an enormous growth potential for EU business and society [2]. Consequently, the proliferation of electronic devices is expected to continue. In the meantime, global electrical and electronic waste production is expected to increase from 47 to 72 Million tons from 2017 to 2022 with 6.5 CAGR% [3]. It is then essential and urgent to understand the role and mitigate associated environmental & societal risks of novel electronics in a transition towards a circular economy.

The European position towards sensing systems is connected to the sustainable development goals: “Shaping of a digital future” and (to a lesser extent) the “Green deal”[4]. European strategies involving sensor systems can be found in e.g. “increase access to high-quality data while ensuring that personal and sensitive data is safeguarded”, “expand Europe’s super-computing capacity to develop innovative solutions for medicine, transport and the environment”, “invest in digital competences for all Europeans”, “ensure Artificial Intelligence is developed in ways that respect people’s rights and earn their trust”[5]. It will play a critical role in ensuring a strong European technology and market position in all aspects of data (artificial intelligence, data mining etc.).

To ensure that European technology and market position towards data remains competitive with respect to other continents, new steps towards data gathering are required. Thereto technologies are developed for bridging virtual and physical worlds, via e.g. smart sensor swarms [..], networks of ultimately trillion sensors […] connected in smart grid, enabling ambient sensing at a new level. It is critical to ensure that the European position in this digital revolution is consolidated, allowing to

match the US based data giants (Google, Facebook), as well as the Asian hardware manufacturing dominance (Samsung, LG, Huawei).

Breakthroughs in sensor technology are now happening at a quicker pace than before due to advances in material science, nanotechnology, photonics, (3D) printing and data analytics. While new sensor types are expensive to develop, many recently developed sensors have proven to be deployable for a wide range of applications.

To concretely address sustainable development goals, the transition towards a green economy with electrical self-driving cars will require a new generation of sensors. A considerable development in monitoring will also be needed to reduce the costs in health- and well-being in an ageing society. Feed a growing population and reduce famine while reducing our reliance on pesticides will require a shift in how the agricultural sector produces food through better monitoring.

Thanks to Europe's position in "Functional Electronics", it is well positioned to take the lead in implementing such smart grids of sensors. The technologies blocks that underpin "Functional Electronics" namely (i) unconventional nano-electronics, (ii) flexible and printed electronics, (iii) electronic smart systems have strong basis in European. Within 5E and in this vision paper, we highlight how "Functional Electronics" will contribute in shaping the future of sensor systems.

3. Positioning of sensors in Functional Electronics

3.1 Unlock the potential of functional electronics (Technical challenges)

Functional electronics is a transversal enabler and differentiator of European digital transformation. It supports a multitude of key enabling technology breakthroughs from 5G and Digitalisation to the Internet of Things and Artificial Intelligence (to name a few).

Sensors allow a fundamental change of electronics usage through the amount of reliable and accurate data that is generated in a situation based matter. Distributed sensing systems will allow high density monitoring, for a large area coverage and sensors integrated in existing products. Multiple digital applications will arise from these sensors, serving numerous markets. Thereto the sensors must comply with market specific demands, involving e.g. medical standards, food contact safety, automotive and (IoT) data protection. Moreover the sensors are deployed in very large numbers which rises the necessity of autonomous operation, with remote communication, long lifetime products, power management and long lifetime reliability and stability. The multiplexing ability of the sensors is an important feature as sensors will act simultaneously using single driver systems. Single operating systems are currently explored featuring simultaneous sensing of pressure, shock, acceleration and environmental properties (temperature, humidity) combined with human parameters (e.g. ExG, bioimpedance, SPO2, PPG, blood pressure) in a complex environment generating data that exceeds the individual sensor information using a single system.

The complex systems necessitate innovative processing methods to create the sensors in large sensor numbers, large area coverage and product integration (e.g. structural electronics). The deployment of the sensors will require high amounts of computational power to monitor fast changing occurrences (e.g. self-driving cars), and conditions (e.g. urban monitoring). This requires innovation in e.g. antenna development, high density batteries and innovative circuitry built up through e.g. (3D) printing.

3.2 Functional Electronics for sensors in future research

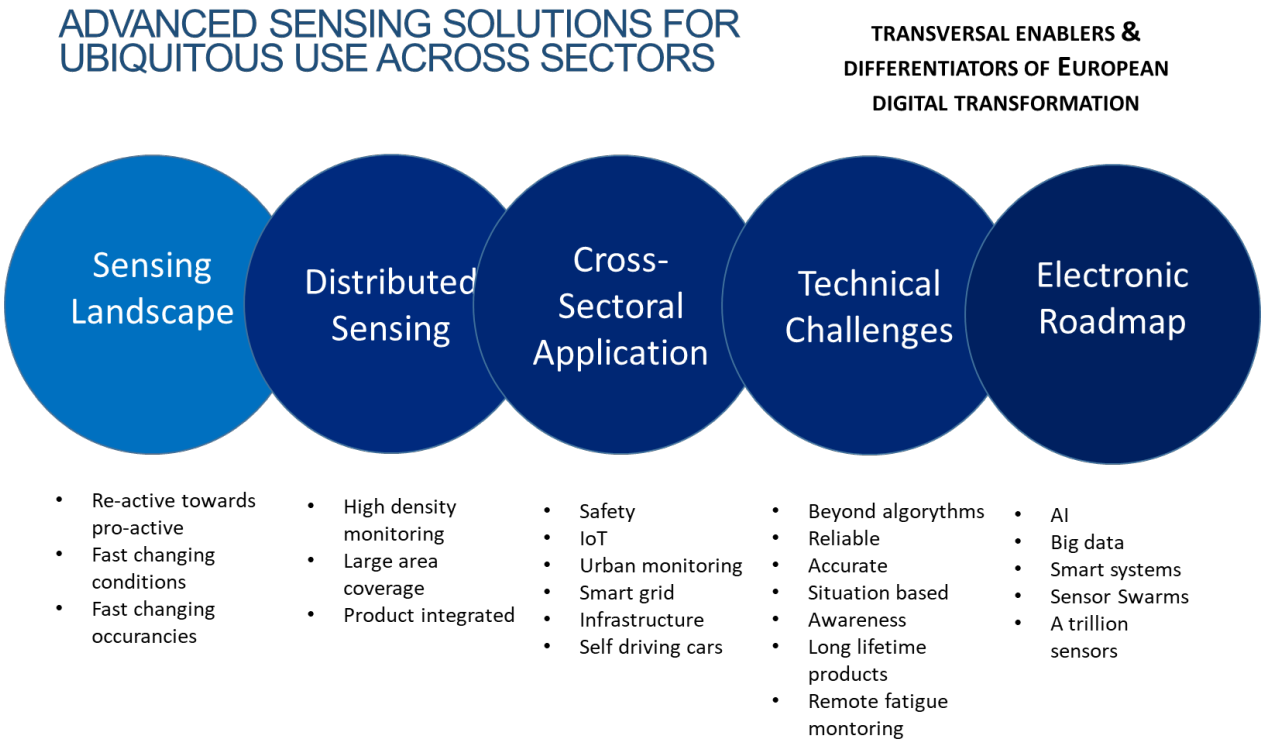
New sensor modalities will be enabled through Functional Electronics. It brings a different view at manufacturing based on developments in the field of nano-electronics, photonics and printed electronics.

Additive manufacturing combined with 3D printed electronic sensors is a key enabling technology towards reducing electronic waste. It will allow for customized parts and production on demand, reducing the need for spare parts stocks but also providing more dedicated solutions and eventually local manufacturing in Europe. It enables for sensor to be integrated on biodegradable supports reducing the ecological footprint of electronics and simplify their recyclability. As flexible organic and printed electronics are becoming a mature technology it provides great opportunities for products with new form factors that cannot be realized otherwise. It allows for large area electronics to be printed in an unconventional matter. Through emerging mass assembly methods combined with hybrid printed electronics, it will allow to fully utilize the performant silicon and MEMS technology.

The sensor system based on functional electronics will combine multiple types of modalities. The sum of the sensor's data generated will be greater than the individual sensors through the use of sensor fusion. When combining this in dense grids of connected sensors through 5G, LORA, and other wireless networks with real time intelligent network, a truly ambient sensing system is obtained. When such networks are created, the autonomous operation at a low energy consumption level is critical. The size, the sheer and number of sensor nodes does not lend itself to replacing batteries. Therefore efficient and flexible new energy sources need to be investigated. Energy harvesting based on functional electronics can provide solutions beyond those currently available. As well as rechargeable micropower sources in the form of batteries, super capacitors, that may provide the needed buffers to ensure reliable operation even in remote or inaccessible areas.

4. Conclusion (& policy recommendations)

Being ranked as the most R&D-intensive sector by the European Commission, the European semiconductor ecosystem supports approximately 200.000 jobs directly and up to 1.000.000 induced jobs in systems, applications and services in Europe. Overall, micro- and nano-electronics enable the generation of at least 10% of GDP in Europe and the world. For 2020, all geographical regions are forecasted to grow with the overall market up 5.9 percent, with Optoelectronics contributing the highest growth followed by Logic. This gives the opportunity for Europe to strengthen its resilience and build its sovereignty in the field of electronics and especially take the leadership in functional electronics. As a driver, the sensors landscape will enable the electronics community to form a leading position throughout Europe following innovation in electronics sensing systems, components, and processing methods.



Contribution/Support.

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[1] 5E project: identification of grey spots
[2] The World Economic Forum estimates that the combined global value of digital transformation to society and industry will exceed US$100 trillion by 2025, the European Parliamentary Research Service identified that an efficiently functioning digital single market could contribute €415 billion per year to EU economy for the period 2014-2019 and create hundreds of thousands of new jobs.
[3] Sullivan, M. Printed Electronics: Global Markets to 2022, BCC Research LLC. 2018
[4] SRA, Shaping-europe-digital-future (2019-2024)
[5] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/shaping-europe-digital-future_en