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The autonomous and connected vehicle: photonic technologies are paving the future of intelligent mobility

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Summary

Photonics is one of the six European Key Enabling Technologies, introducing massive amounts of innovation and contributing to several societal challenges (smart, green and integrated transport, reducing impact on the environment). In the automotive field, photonics provides not only essential components for the vehicle itself (sensors, lighting, HCI/HUD, cameras and LIDAR …) but largely contributes to the car making process itself through advanced manufacturing processes and technologies. This paper provides insight on emerging photonic technologies for smart mobility, the changing business models and the RespiceSME[1] European project aiming to help photonic SME overcome development challenges.

Keywords: photonics, smart sensors, connected and autonomous vehicle, smart mobility business models

1 Context

One of the six European KET, Photonics offers the promise of disruptive and green innovation for numerous domains. The automotive industry was faced during the last decade with numerous challenges related to the environmental impact but the advances made in the field of powertrain electrification coupled with optimization for improved energy consumption, on the one hand, and the development of new materials and manufacturing processes allowing to reduce the vehicle's mass, and thus reduce consumption, offer today interesting perspectives. The advent of the connected car, ADAS and the complete autonomy brings further optimizations of the vehicle and provides more added value to the car owners/users. These emerging opportunities attract new players that induce deep transformations to the automotive domain and might soon change the entire value chain. Besides allowing unexpected stars like Google, Tesla, Uber … to arise in the automotive domain, they also provide development opportunities for high-tech (Velodyne, mobilEye), and lead more recently to the emergence new companies like Quanergy and LeddarTech, that will probably become key players in the field of the autonomous vehicle.

[1] http://www.respice-sme.eu

2 Overview of photonic technologies for the autonomous and connected car: state of the art and future trends

Nowadays drivers expect more and more from their cars and this highly impacts car manufacturers have to answer ever increasing demands very fast. The number of vehicles also increases rapidly: over one hundred million cars would be sold in 2020 [1]. Since the beginning of the automotive industry in 1900, car features have evolved from basic driving options – allowing to only use the vehicle as a mean of transportation – to a multi-feature digital environment. Three main concepts have appeared for the past decade: the car as an enhanced mean of transport, the car as an infotainment environment and the car as an industry of the future's product [2]. Following the emergence of the information and communication technologies, car manufacturers and OEM both made the offer deeply evolve toward autonomous and connected vehicles which provide new added value features to their owners. Photonics, recognized by the European commission as a Key Enabling Technologies, is clearly involved in the transition of the automotive industry and helps transforming the vehicles from basic mean of transport to fully digital, connected and soon completely autonomous systems providing new added value services. The first part of the article will give an overview of the photonic technologies transforming the automotive industry.

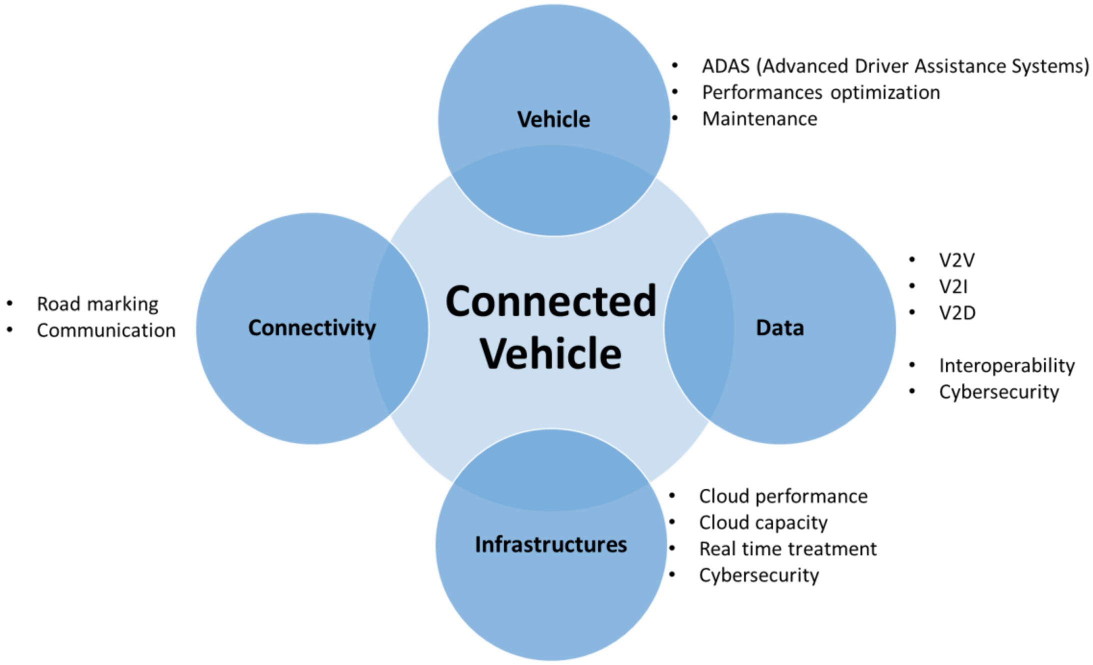

Figure 1: An overview of the environment of the connected vehicle

2.1 Photonic technologies driving the way towards innovative features

The current developments for the connected vehicle not only improve the user experience but generally impact the whole vehicle's life cycle [3, 4]. They mainly enhance two important features today: driving assistance systems that largely improve security and facilitate driving and infotainment systems offering the possibility to use the cockpit as a digital environment.

Many Advanced Driver Assistance Systems (ADAS), like obstacle detection, lane departure detection, driver monitoring or parking assistance are based on photonic technologies and use the emerging technologies to facilitate the driving experience, improve security and optimize performances [5, 6]. The connected vehicle is considered to be the first step toward the autonomous vehicle, the advent of the completely autonomous driving will in the near future enhance the second feature which is infotainment. The connected vehicle allows its users – the driver and the passengers – to have a disruptive experience and answer their needs to have a seamless connectivity and access to features similar to or complementary to those they have on their smartphones. Capitalizing on the knowledge from the field of VANET (Vehicular Ad-Hoc Networks) and exploiting the new technologies of the Internet of Things, an emerging domain, the “Internet of Vehicles (IoV)”, is beginning to take shape around the V2X (Vehicle-to-Everything) ubiquitous communications [7, 8].

2.1.1 The emerging Human Machine Interface for natural interactions

Human Machine Interface (HMI) is one of the key elements of the connected and the autonomous vehicles. The way people interact with devices has to be simplified to allow natural interactions both through voice commands and gesture recognition. Natural means practical, easy, human-like and non-intrusive interactions with the driver and the passengers. But this is not enough. As the number of technologies is growing very fast, the HMI does not only have to become intuitive, it also has to allow transparent interactions with different technologies, guaranteeing the interoperability with smartphones and other connected devices [9].

Human-machine interfaces integrate by definition core photonic technologies. Displays, screens and the associated software, endowed with tactile functions for intuitive interactions, and more recently with haptic and 3D visualization abilities are developed for both the ADAS and the infotainment features. Car manufacturers imagine building an intelligent driver assistant (a 3D embodied avatar), who would interact with the driver and the passengers in a very natural way by exploiting artificial intelligence.

Figure 2: Human-centric HMI: progressing towards a holistic user experience (source : Frost & Sullivan [10])

Cameras and short range time of flight sensors for gesture detection and recognition, are other examples if photonics technologies providing new means of interaction with the automotive systems. Furthermore, face and eye tracking technology combined with artificial intelligence can also help the machine to understand the driver feelings and mood – which can not only improve the security on board but also improve the comfort of the driver and the passengers. They allow to monitor the driver and the passengers, understand their behaviour through data and image processing and adapt accordingly the driving, execute the commands, give access to information/applications and adapt the internal conditions (lighting, temperature, monitor the air quality …) to insure the wellbeing of the occupants.

Last but not least, emerging head-up display (HUD) technologies based on LED or laser projectors and holographic optical elements will play a decisive role in the automotive domain. Intensive research is done in the field of holography because of its promises for applications such as navigation systems, allowing to project the information in the field of view of the driver and increase thus security [11], or display (3D) information inside the car and provide intuitive interactions. Inspired from the aeronautic domain, especially in the defence field, HUDs are promising ADAS technologies for the connected vehicle. HUDs seem to be a relevant solution for the multiplication of sensors and as a consequence for the enhancement of the amount of data available for drivers. This systems allow to project/superpose digital information (driving directions, speed limit, warnings …) to the windshield or directly on the road and thus greatly enhance the driver's perception.

2.1.2 Light-enabled Communication Technologies

Two main photonic technologies used as a communication channel for automotive applications are represented by (plastic) optical fibers and visible light communications (VLC, also called LiFi for consumer applications). The optical fibers, despite their higher cost and sensitivity, used by the MOST (Media Oriented Systems Transport) networks for the automotive domain [12] offer immunity to electromagnetic interference, the advantage of lower weight and a higher throughput. An emerging technology is represented by visible light communications that would could serve as a channel for high-throughput, close range communications inside the vehicle, between line of sight vehicles and between vehicles and elements of infrastructure [12]. Current research and development is related to in-vehicle (Vehicle-to-Device – V2D), between vehicles and transport infrastructures (V2I) and between vehicles (V2V) communications, for which new emerging solutions provided by photonic technologies such as LED or LASER sources and detectors are used in complement to the current range of radio communications.

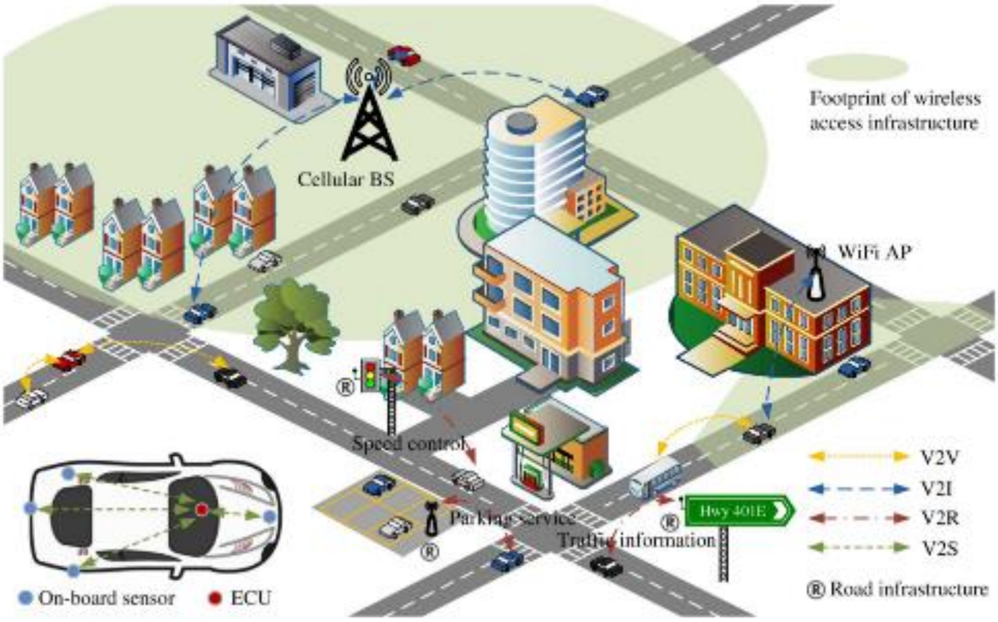

Fig 3: V2-X communication at the city scale (source : Kamaljeet Kaur [13])

2.1.3 Enhanced perception photonic sensors and systems for the autonomous vehicle

The completely autonomous vehicle of the future will need to perceive and understand its environment, not only by communicating with infrastructures or the other vehicles present in its environment, but also but also by its ability to detect, classify and decide how to interact with passive elements from its environment. Passive or active photonic sensing technologies, mainly represented by different types of cameras and LIDAR, are a key element for sensing applications on the road toward "full automation". Their use cases concern several important function for driver assistance and autonomous driving: object/obstacle detection, identification/classification and tracking; collision avoidance; blind spot detection; lane keeping; adaptive cruise control, parking assistance.

Cameras

Cameras, coupled with image processing algorithms and also with RADAR/ultrasound systems for range finding, are one of the photonic technologies largely deployed in the automotive domain for ADAS and autopilot applications. The imaging sensors/cameras can be used alone (at classic or high frame rates), in pairs to create stereoscopic systems for low/medium range obstacle detection or disposed in a particular configuration to create a 360° view around the vehicle. The applications vary from simple tasks like parking assistance to more complex traffic sign recognition and obstacle detection applications. Emerging technologies are based on infrared passive or active sensors, that could also be used in a time gated configuration (the sensor shutter is synchronized with the pulse emission to cover the scene situated beyond a desired range) for night and bad weather obstacle detection or high dynamic range sensors, immune both to dazzle and low lighting conditions. Other emerging imaging technologies are represented by bio-inspired vision systems like the fish-eye lenses offering a very wide angle of view or systems acquiring only the dynamic (changing) elements of the scene based on conditional integrative exposure measurements at the pixel level.

LiDaR

Exterior sensing for obstacle detection applications is currently done with RADAR (Radio Detection and Ranging) for middle and long range applications and ultrasound for short range applications on most mass market vehicles. Due to its increased precision and its ability to perform a complete scan of the environment of the vehicle, that will soon extend to real-time 3D, LIDAR technology will definitely play a key role in the large scale deployment of the autonomous vehicle; some experts sustain that a LIDAR might have allowed to avoid the fatal crash involving a self-driving Tesla Model S [14]. The laser rangefinder exploiting the time of flight principle exists for a long time. Nevertheless, these mechanical systems based on a mirror deviating the laser beam to cover the scene also come with some shortcomings: besides (still) being too expensive for mass market vehicles deployment, they are also large, heavy and have reliability issues. Moreover, their performance is limited in some high-speed scenarios and they're currently not 3D real-time mapping ready.

Emerging players provide new systems particularly suited for the automotive domain, and mainly for obstacle detection applications. But the current trend is mainly focused on technologies allowing a full 3D scan, in real-time, of the complete environment of the vehicle. Current developments in the field of LIDAR systems focus on emerging technologies related to 3D (and) solid-state LIDAR systems [15].

2.2 The autonomous vehicle value chain: photonic SMEs breaking the old links with disruptive technologies

Google had set the pace for rapid changes in the automotive domain landscape. The disruption in the automotive industry could not have come from classic stakeholders, such as car manufacturers, without an outside impulse, since they had a completely different vision of the vehicle and different interests to defend. Despite the strong position still occupied by the classical players in the field, mainly car manufacturers and tier one suppliers, the new players from the digital landscape (Google, Apple, Uber …) massively deploy their resources to seize the emerging opportunities in the mobility domain around services and data since the vehicle of the future is transforming to a service. These players identified the key enabling technologies for the autonomous vehicle, which are using mainly digital ones, and provided a huge opportunity for SMEs and start-up to develop. New pure automotive players, such as Tesla, also emerge, their offer focusing as well on digital added value services. Even though tier one suppliers or key players from the semiconductors domain massively invest in the emerging technologies for the connected and the autonomous vehicle (LIDAR, sensors, machine vision, artificial intelligence …), the changes in the landscape represent an opportunity for the SMEs to provide solutions, most of which coming from the photonics domain, for these players and develop their activities. Velodyne is one of the well-known players benefiting from these mutations, but newcomers such LeddarTech or Quanergy work on the new generation, low cost light detection and ranging solutions, ready to deploy on the mass market vehicle [16]. These players have gained a huge interest from the tier one suppliers and either collaborate with players such as Valeo or have been acquired by them ; it is the case for example of Advanced Scientific Concepts whose Hi-Res 3D Flash LIDAR activities have been acquired in 2016 by Continental[2]. It is also the case in the field of machine vision : one of the key players, mobilEye, was recently acquired by Intel for the impressive amount of 15 B$[3] and other big players, such as Bosch and Renault invest in emerging solutions such as the one provided by Chronocam. But numerous other SMEs bring added value solutions, such as night vision and/or bad weather sensors provided by Ulis/Sofradir or BrightWayVision or logarithmic sensors provided by New Imaging Technolgies. The figure below gives an overview of the ADAS and autonomous technologies value chain, several SMEs occupy an important place in the upstream part, next to big players like Sony or NXP.

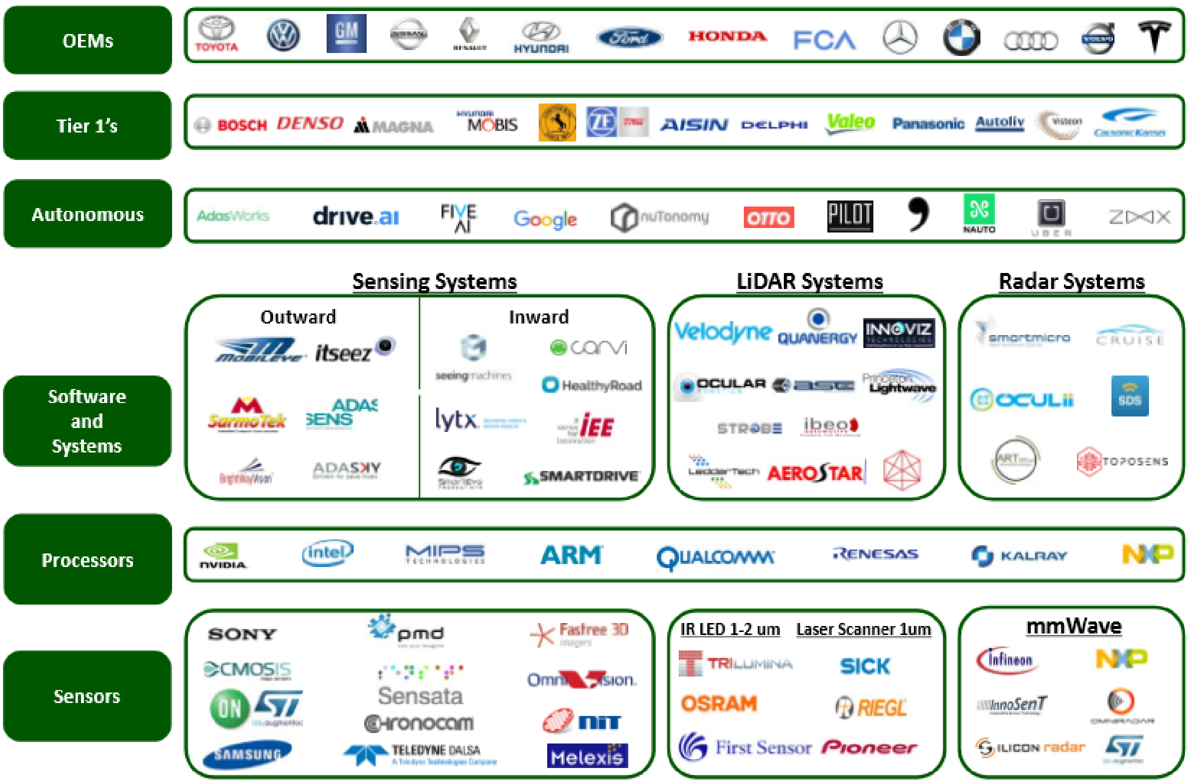

Figure 4: An overview of the leading players of the ADAS autonomous vehicles technologies value chain (source: Woodside Capital Partners [17])

3 Technology development leveraging new business models: a virtuous circle

Photonic technologies contribute to modify the whole economic environment of the automotive industry by providing opportunities for the emergence of new businesses, with respect to traditional car manufacturers (assemblers and technology integrators) activities. The emergence of the connected and autonomous car leads to an evolution of the traditional value chain in the automotive industry, from the upstream of the sector to its downstream [18, 19]. This evolution is consubstantial of a shift in added the value of the vehicle. In the case of connected vehicles, the value (margins) is less and less concentrated in the sale of the product (or its maintenance), but rather in the sale of services (driving services, embedded internet…). New companies in the automotive industry bring new business models and new industrial strategies, who force the traditional automotive industry players to react by repositioning themselves and adopting emerging technologies, in

[2] https://www.continental-corporation.com/en/press/press-releases/hi-res-3d-flash-lidar-will-supplement-continental-s-existing-portfolio-for-automated-driving-15758

[3] https://techcrunch.com/2017/03/13/reports-intel-buying-mobileye-for-up-to-16b-to-expand-in-self-driving-tech

particular through the deployment of open-innovation approaches. This is one of the opportunities for photonic start-ups and SMEs in this field.

3.1 A shift toward business models interpretations

All the underlying technologies and functionalities outlined in the second section of the article contribute to deeply modify the way a car is designed and used. Indeed, the whole value chain of the automotive sector is impacted by an evolution towards the connected and/or autonomous vehicle, which leads to the prevalence of the value of use on the proper value of holding the product.

From now on, and increasingly, the economic valorization of the automotive product for the companies of the sector, no longer belongs solely to the sale of a vehicle, to satisfy a “function of transportation”, but in the sale of multiple seamless and ubiquitous mobility services that together contribute to improving the experience of car transportation. We then enter the world of the “mobiliy as a service”.

However, the work of Schumpeter [20], prolonged by Christensen [21], showed that it is necessary to prevent any “technological determinism”, in order to interpret the economic mechanisms occurring in a major industrial change characterized by a change in technologies, firms, but also the pace of innovation. Theories of innovation thus suggest moving the debate from a categorization perspective in terms of “incremental technologies” (i.e improving marginally existing products) and “radical technologies” (i.e inventing new categories of products that are both new to the market and to the company), towards an explanation in terms of business models [22].

To understand the dynamics of success in a market between incumbents (existing firms) and new entrants, proposing new technologies, what is important is then to analyse whether innovation is compatible with the business model of dominant firms or not. Some innovations, however radically in terms of technology, are well adapted to the existing business model. This was the case of mobile telephony for fixed telecom operators. Even if the gap was technologically very important, the skills and fundamentals were very similar. Thus, fixed operators have succeeded in becoming mobile operators. By contrast, if radical innovation conflicts with the current business model of incumbents, the success of innovation and its effects on competitive positions is more difficult to assess. For example, Kodak has badly managed the arrival of digital photography, notably because the gap in terms of revenue generation model was equally important as the technological gap [22]. Indeed, the revenue generation model was previously based on the control of the sale of the camera and consumables (the film). It has evolved on the solely sale of the device because the marginal cost of pictures has become extremely low, like other products of the digital economy.

Following Christensen [21], we propose the opposition between “sustaining innovation” and “disruptive innovation”. One the one hand, sustaining innovation is done in accordance with the business model of the company, whether the innovation is radical or not from a technological point of view. On the other hand, disruptive innovation breaks down with the business model of the company, again, independently of whether it is radical or not in terms of technology.

From the point of view of the traditional players in the automotive industry (manufacturers and equipment manufacturers, in particular), the emergence of a new breed of innovation allowing the development of connected and autonomous vehicles may be seen as a breakthrough, both technologically and in terms of Business model, as a result of moving value over service, rather than just selling vehicles. The situation is different for firms originating from other industrial sectors or for firms, mainly start-ups, emerging with these automotive technologies. For the latter (3.2 and 3.3), the breakdown is mainly technological and more marginally related to the business model, because these players have strategies for gaining access to the automotive market that are not only innovative, but also consubstantial.

3.2 Multinationals enter the automotive sector thanks to the connected and / or autonomous vehicle

The advent of the connected and/or autonomous car is an opportunity to penetrate the automotive industry for 1) firms firstly positioned on other industries and 2) for firms that emerge with these technologies. To illustrate this, we propose to highlight the emblematic and representative cases of Google and Tesla.

The case of Google is emblematic of the ability of some large multinational groups to penetrate industries related to their original industry by resorting to specific economic strategies or business models. Indeed, Google (now Alphabet Group) has gradually expanded its business from the digital sector to the energy and transportation sectors. Google launched Google Energy in 2009, a wholly-owned subsidiary, producing, buying and selling electricity. The huge electricity consumption of its data centers and the willingness to ensure its energy independence have justified this strategy. Google also opened up to the automotive market with its "Google Car", an autonomous vehicle to be lunched by 2020, paving the way for other digital players which are currently developing similar technologies and strategies, such as Apple. For Google, the autonomous car can be considered as an extension of the development of Google Maps and Google Street View mapping services, but also relies on the prolific calculation capacity of its servers. As Bainée and Le Goff [23] (2016) argue, Google is developing an "augmented market strategy".

On the connected and communicating car, Tesla's move can be interpreted thanks to the same concept of "augmented market strategy". Indeed, the Californian carmaker, born in 2008, has bought SolarCity ($2.6 billion in 2016), a solar energy company and second largest solar panel installation company in the United States. Tesla thus capitalizes on properties of the electric car, i.e. the capacity to be recharged by "clean" energy, but also to be able to reinject this electrical energy (stored in chemical form in the batteries) in the grid, generating incomes [24]. In the energy industry, electricity utilities are similarly developing smart grids in order to optimize the operation of their grids and to manage the intermittence of renewable sources of electricity production (wind, photovoltaic) by "crossing" the digital sector, with the use of home automation technologies, to reach the transportation sector with electric and hybrid plug-in hybrids vehicles, because their batteries can provide a "storage" function of electricity, as illustrated by the experiment conducted by Renault and EdF on the French island of La Réunion [25].

The strategies deployed by Google, Apple, Tesla and others are part of an "augmented market strategy", that is to say, following [23], the extension, or creation, of a market through the establishment of networks linking two or several autonomous markets (differentiated by their structure and players). It is enabled by the "decompartmentalisation" of sectors which share – occasionally or otherwise – the same physical (infrastructures, technology, etc.) and/or immaterial (knowledge, information, etc.) foundations, at different levels in their respective value chains. An "augmented market strategy" makes it possible to capitalise on sectoral decompartmentalisation, especially through the sharing of infrastructures providing services in areas of the digital economy, energy and transport. Furthermore, "augmented markets" lead to the emergence of product innovation, of goods and services, which can be called "augmented products", in terms of functionalities.

3.3 Start-Up and SMEs use the advent of the connected and/or autonomous car as a leverage to accelerate development

The advent of the connected and / or autonomous vehicle is also an opportunity for emerging start-ups which position themselves advantageously along the value chain of the automotive sector, through innovative business models. We propose to outline the cases of Chronocam, Quanergy and Velodyne, which are representative of start-ups developing photonic technologies, whose property is often to constitute "technological bricks" that allow applications on multiple markets and industries.

In the case of the French start-up Chronocam, the first applications of its bio-inspired vision technology (neuromorphic) by computer had a medical aim. Today, its sensor technology transmitting only event changes and not the entire scene (as traditional image sensors do) to generate less data to process, challenges conventional systems across many fields of application: automotive, aerospace & defence, gaming, industrial automation, etc. Similarly, the American start-up Quanergy, which makes laser (LiDAR) sensors, addressed multiple markets, related to transport, industry, or even security, including border security, for improved safety. As for the case of Velodyne, the key industries are automotive, industrial and UAV.

In fact, these start-up/SME rely on an all-round development strategy, aiming to circumvent the constraints of low scalability of photonic technologies and to shorten their time to market. Indeed, most of the current current work around the autonomous vehicle has been performed at a prototype level so the market is for the moment limited. Moreover, the safety constraints in the automotive domain requiring certification, as well as the cost reduction, imply longer term perspectives for the solutions providers that do not sustain solid business models. So the automotive domain has to be only one of their targeted markets, and deploying their photonics technology to other industries allows them to incubate their innovation, capitalizing on a strategy of cross-subsidizing markets. Thanks to this strategy, such start-ups will be technologically ready when the connected and/or autonomous vehicle market will become large and profitable.

The corollary of this evolution is such that the traditional "players" of the automotive sector (manufacturers and equipment manufacturers) are weakened by: 1) the evolution of the traditional value chain of the automotive industry, from the upstream of the sector to its downstream, due to shift in the value of the good and the raise of "mobility as a service" logic and 2) by start-ups and multinational companies that benefit of the appearance of the connected and autonomous car to access advantageous competitive positions and which are able to capture an essential part of added value.

This dilemma drives the traditional car makers to adopt a defensive strategy in order to maintain their position and to ensure the sustainability of their business/company, in particular by using an open-innovation approach. For example, in 2016, the car manufacturer Renault announced that it has entered into a strategic partnership with Chronocam to deploy start-up technology in areas such as collision avoidance, driver assistance, pedestrian protection, detection of blind spots, as well as other essential functions to improve the safety and efficiency of human and autonomous driving. But several other players such as Intel Capital, iBionext, Robolution Capital, CEA Investissement, and Robert Bosch Venture Capital are also participating to the start-up's Series B financing of $15 million[4].

3.4 RespiceSME : program, aiming to enhance the global technological exploitation of photonics innovation capacity

The RespiceSME project, founded by the EU Commission through its H2020 Photonics KET ICT-27-2015 scheme, aims to reinforce the innovative capacity of Europe's photonics Small and Medium Enterprises (SMEs), clusters and national platforms by stimulating targeted collaborations in and beyond photonics. It focuses on the disruptive technologies proposed by photonic SMEs and their application in three domains; transports is one of the domains targeted by the project. Beyond the (self)assessment tools developed within the scope of the project to evaluate the innovation potential of the SMEs, the project allowed to develop a value chain analysis tool providing information on how a photonics SME can contribute through a certain technology to a specific technological industrial sector and identify gaps and commercial opportunities. In order to exploit the results provided by these tools for the members of the photonic clusters participating to the consortium, events are organized to allow SMEs to mutually discover their know-how and reinforce collaborations. Such an event was recently organized during the "Laser World of Photonics" trade show and focused on "Boosting the Collaboration of Photonics SMEs in the Automotive Domain". Following a series of presentations and discussions, allowing the participants to identify collaboration opportunities, a workshop focusing on mapping collaboration opportunities between photonics SMEs in the automotive domain took place by exploiting the value chain analysis representation. It allowed to identify the stakeholders from the nine countries involved in the project and will serve as a basis to establish business, innovation and R&D collaborations among the members of the photonics clusters involved in the project. The work is currently ongoing, emerging projects, future results and new collaboration perspectives will be presented during the IoT Solution World Congress taking place in October in Barcelona.

4 Conclusion

Photonic start-ups introduce massive amounts of innovation, especially in the automotive industry, in both fields of the connected and/or autonomous vehicle. Photonic SMEs, side by side to larger companies, and the technologies they provide contribute to deeply modify business models and reshape the value chains of the automotive industry, implying new public and private strategies to support firms to fasten the pace of innovation. In order to address the challenges of the connected and autonomous vehicles and provide added value solutions, photonic SMEs should reinforce their collaborations to leverage the benefits of their complementarity and mutually strengthen their offer. In this context, the RespiceSME European project aims to help photonic SME overcome development challenges by stimulating collaborations in and beyond

[4] http://www.cea-investissement.com/elements/actualite/pdf_91.pdf

photonics. A set of tools have been developed to support SMEs and help them reinforce their collaborations to provide novel solutions for the automotive domain. They have been recently exploited within the scope of a workshop focused on “Boosting the Collaboration of Photonics SMEs in the Automotive Domain”, involving different stakeholders in the field of photonics and the connected/autonomous vehicle domain (photonic SMEs, automotive SMEs, photonic clusters managers …), to map the European value chain and identify collaboration opportunities. The results of the workshop will be exploited to stimulate business among the SMEs and help innovation and R&D projects emerge; preliminary results and future collaboration opportunities will be presented during a new workshop for the SMEs, that will be organized during the IoT Solution World Congress in Barcelona.

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