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CoRaLi-DAR

RADAR, LIDAR: A BETTER UNDERSTANDING OF THE MARKET REQUIRMENTS FOR VARIOUS APPLICATIONS

COLLABORATING RADAR AND LIDAR, SENSING THE FUTURE

Tommaso Cassese
Silicon Austria Labs

Amin Chegeni
FH Karnten

Ion Vornicu
Silicon Austria Labs

Marcus Hennecke
Infineon Technologies Austria AG

Cristina De Luca
Silicon Austria Labs

Martin Gschwandtner
Infineon Technologies Austria AG

Lars Zimmermann
IHP

Javier Perez Santacruz
Stichting IMEC Nederland

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1 ABSTRACT

The combination of radar, cameras and lidars is the key element to process data in real time and respond to the security demand in different applications. The CoRaLi-DAR Project is dedicated to innovating sensor technology, particularly focusing on the **RADAR** section's objective to significantly reduce the area occupied by radar sensors while preserving their operational effectiveness concerning range and resolution. Simultaneously, the project focuses on the design of the **LiDAR** sensor, incorporating various electronic and photonic components. The primary goal is to enhance critical parameters such as signal-to-noise ratio, angular resolution, field of view, maximum distance range, depth resolution, and points per second, aiming to surpass current limitations. Despite notable advancements, achieving satisfactory sensor performance remains a formidable challenge due to the complexity of signals and demanding environmental conditions. To address this, **adaptive sensing**, involving the combination and extraction of information from multiple sensors, is pivotal. The project aims to reduce power consumption, enhance frame rate, elevate the quality and reliability of 3D point clouds, and introduce features like object recognition and target tracking. The proposed LiDAR and RADAR integration illustrates the interconnectedness between sensors, algorithms, and the various specifications of the adaptive scheme. The CoRaLi-DAR project strives to overcome sensor technology challenges by integrating radar and LiDAR systems, creating a versatile, compact, and high-performing sensor tailored for a multitude of real-world applications.

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2 INTRODUCTION

"We will see different generations of sensors and computing that will be more performant, enabling different levels of autonomy," says Yole Intelligence analyst Pierrick Boulay [1].

The combination of RADAR, cameras and LiDARs is the key element to process data in real time and respond to the security demand in different applications like automated driving, environment, etc…The preliminary overview of the specifications crafted in the CoRaLi-DAR project during its first year reveals several challenges derived from the analysis of RADAR and LiDAR. To effectively identify applications where the new sensor can offer advantages, it's beneficial to recall the distinct unique selling points (USPs) of the CoRaLi-DAR sensor:

- ***Sensor fusion on very low level:*** The sensor fuses information from RADAR and LiDAR already on a very low level resulting in a very compact, light-weight, low power and low cost sensor. This makes it possible to design the sensor into systems where space, weight or power are at a premium.
- ***High reliability, higher performance in challenging conditions:*** Due to the combination of two complementary sensor principles, the sensor performs robustly and reliably even in difficult situations.
- ***Fog, dust, low visibility:*** In particular, atmospheric conditions such as inclement weather or bad visibility are handled with the support of the long range and penetration of the RADAR part. This is relevant in the outdoors (fog, rain), in agriculture (dust, grains) or in disaster situations (smoke).
- ***High resolution of LiDAR:*** On the other side the LiDAR part is contributing to the sensor with its high resolution, making it possible to resolve close objects and to better classify objects and evaluate potential hazards.

3 RADAR

The RADAR market is rapidly evolving and is expected a significative amount of growth, it is valued at US$ 35,06 million in 2023. Market size is expected to reach US$ 97,2 million by 2033. In the coming years, the RADAR market revenue will increase at a CAGR of 10,7% [2], or according Yole only the automotive RADAR market is expected to grow at 14% CAGR by 2027 [1]. The trends are driven by vehicles for advanced driver assistance systems (ADAS) and autonomous driving. Simultaneously, security and surveillance strategies are emerging as significant market trends. The prevalent demand goes around technologies that offer elevated performance, reliability, and precision.

The primary focus of the radar section within the CoRaLi-DAR Project is to halve the area occupied by the RADAR sensor while maintaining its operational effectiveness in terms of range and resolution. The driving force behind this size reduction is the overarching goal to integrate RADAR and LiDAR functionalities into one sensor, showcasing efficient sensor fusion, as outlined in the introduction. Analysis of current RADAR sensors indicates that the main contributor to their size is the antenna area. While the antenna area directly influences the antenna aperture and the ability to direct the antenna beam, it appears feasible to further minimize it.

The first approach to reach the goal will be to reduce the antenna count by half in the

TX/RX duplexers. This is supposed to be achieved by using active circuitry to separate transmit and receive signal paths while routing them to/from the common antenna port. The second step is related to the increase the frequency by reducing the area consumption of the TX and RX antennas.

Table 1 TX/RX Duplexer specifications

Key parameters	
TX loss	<7 dB
Tx leakage power to RX	<-20 dB
Integrated LNA gain	>12 dB
Integrated LNA NF	<10 dB

The second approach to be investigated is the use of a frequency extender which will be placed after the 79-GHz MMIC. In a first step the antenna area requirement reduces by a factor of 2x2=4. However, doubling the frequency comes at the drawback of higher loss in the substrate of the antenna – including the signal routing – as well as reduced power added efficiency (PAE) for the signal generation/amplification. Hence, a balance must be struck between minimizing antenna size and ensuring adequate RADAR range.

Table 2 Signal specifications at both input and output of extender

	At extender input	At extender output
TX output power	10 dBm	6 dBm
RX noise Figure	14 dB	16 dB
RX 1-dB compression point	-12 dBm	-10 dBm
RF frequency range	76 – 81 GHz	152 – 162 GHz

4 LIDAR

If we think about LiDAR we are in emerging technologies and trends, with few players that are able to deliver products at high volume. A forecast of the market trend shows that the global LiDAR market size was valued at USD 1.81 billion in 2021 and is expected to expand at a compound annual growth rate (CAGR) of 9.8% from 2022 to 2030.In this context the main driving need is the cost reduction which is obviously linked to high production volume [1]. Drivers of the period are civil engineering, defence, installation of advanced safety featured, self driving cars, mapping weather conditions, etc…

The LiDAR photonic integrated circuit (PIC) chip is at the core of the light-based part of the CoRaLi-DAR sensor. The PIC has to be designed considering the requirements set by the application envisioned for the sensor i.e. automotive medium range, and the limitations related to technology available i.e. electro-photonic platform from IHP. Figure 1 shows a simplified schematic of the LiDAR PIC envisioned for CoRaLi-DAR, it will be using the well-known frequency modulated continuous wave (FMCW) approach, already known in the detection and ranging sensing field. The chip will consist of: a tuneable laser acting as light source, a splitter to separate the local oscillator (LO) from the transmitted (TX) signal, a transmitter optical phased array (OPA), a receiver antenna, and a balanced photodetector. In this paragraph we are going to define the system-level specifications that will then be used as guidance for the design of each component integrated in the PIC chip. In this report the component-specific performance is not mentioned. This requires a long activity of modelling and design that has already started.

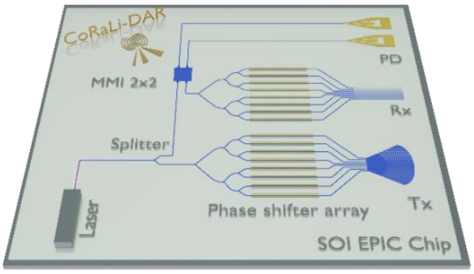

Figure 1 Schematic of the LiDAR PIC under development in CoRaLi-DAR

Typical requirements for LiDAR may be found in H.Holzüter work [3], they typically depends on range and application field. Table 3 shows current requirements for short and long range in the automotive field. These data can be used to define what LiDAR sensor of CoRaLi-DAR should aim to achieve in order to position itself beyond the state of the art.

Table 3 CoRaLi- DAR Automotive LiDAR sensor requirements

	Short range	Long range
Field of view (hor. x ver.)	120° x 30°	40° x 20°
Hor. And ver. resolution	~1°	<0.1°
Range (10% reflectivity)	60m	200m
Range resolution	<5cm	~5cm
Frame rate	25Hz	25Hz

The design of an electronic-photonic LiDAR sensor requires a good understanding of the interactions between all electronic and photonic components. The goal is to improve the key parameters of a LiDAR system such as: signal-to-noise ratio (SNR), angular resolution (Φa), field of view (FoV), maximum distance range, depth resolution and the number of points per second (PPS).

5 ADAPTIVE SENSING

Increasingly profound comprehension of the fundamental scientific principles of sensor functionalities coupled with engineering optimization methods, has consistently propelled advancements in sensing capabilities. Despite the advances, achieving satisfactory sensor performance remains a difficult objective for numerous critical application scenarios. Complex and dynamic nature of signals, changing or harsh environment are the primary sources of challenges. Often no single sensor can meet high performance expectations therefore extending technical sensing capabilities to align with the demands of critical applications is becoming essential in realizing the progresses in several crucial areas. Additionally, methods for interpreting sensor outputs that vary over time are crucial. Optimizing the potential of adaptive sensing strategies requires also intelligent integration.

Adaptive sensing consists of combining and extracting information from multiple sensors. Two main strategies can be adopted concerning multi-sensor systems: using the same type of sensor and locating in different locations (e.g., a set of cameras placed in different locations of a car); or utilizing different sensor technologies and mixing their complementary advantages. In this project, two sensor types are employed to extract information of the environment that surrounds them. The main objectives of the adaptive sensing system are reduce power consumption, increase frame rate, improve 3D point cloud quality/reliability, and support extra features such as object recognition or target tracking.

Figure 2 shows an overview of the proposed LiDAR and RADAR cointegration. The purple block refers to the adaptive algorithm scheme. Observing each sensor is attached to its corresponding algorithm. The RADAR algorithm is interconnected with the RADAR sensor through a bidirectional link. In other words, the RADAR algorithm receives the data from the RADAR sensor and based on this data, the RADAR algorithm provides feedback to the RADAR sensor. This feedback consists of modifying certain configurations of the LIDAR sensor. A similar procedure occurs between the LiDAR sensor and its algorithm. The following subsections describe the specifications of each block concerning the adaptive sensing scheme: RADAR algorithm, LiDAR algorithm, data fusion algorithm, sensor controller, and processing unit (PU).

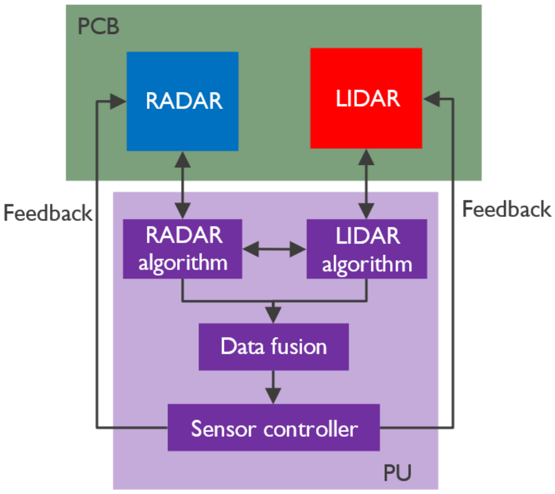

Figure 2 General schematic of the Adaptive Sensing Algorithm

The proposed fusion approach involves utilizing the RADAR sensor for an initial comprehensive scan of the environment, capturing complete range, Doppler, and angle resolution. Due to the use of a limited number of transmission and reception channels, the inherent angular resolution (i.e., without employing any super-resolution techniques) will be quite restricted. Utilizing this RADAR-only scan, the LiDAR sensor can be specifically deployed in areas where the RADAR sensor identifies distinct targets requiring higher angular resolution, effectively allowing for closer examination. Consequently, the radar sensor's role is to identify regions of interest, more specifically, range and angle "bins," which will be communicated to the LiDAR algorithm. The LiDAR algorithm then adjusts its beam direction based on this information to provide additional detail within those specific range/angle voxels.

As part of the RADAR sensor hardware on the PCB, an Aurix microcontroller by INFINEON technologies, will be provided, the full RADAR processing chain could be executed by the DSP accelerators (FFT's) and CPU on the Aurix processor itself.

Based on the obtained 3D point cloud in the data fusion algorithm, feedback to the RADAR and LIDAR sensors can be provided to increase the quality of the next 3D point cloud measurements.

All the mentioned algorithms run in a single or multiple process unit PU. In order to avoid synchronization problems due to high processing delays, the used PU needs to comply with a set of requirements.

For the CoRaLi-DAR project, a compute platform with the specifications below will be used:

- CPU: Quad core A53 MP Core @ 1.5GHz.
- RAM: 2 GB.
- ROM: 64 MB QSPI flash - 16 GB eMMC flash.
- GPU: Mali 400 MP2 @667 MHz.
- Interface: both USB3 and ethernet

6 PACKAGING AND DEMONSTRATION

For packaging and demonstration of the CoRaLi-Dar system, assembly and integration of the individual components reducing thermal crosstalk, electromagnetic interference, and size reduction, is essential. In CoRaLi-DAR we are going to use all the state-of-the-art assembly approaches to bring together the sensors without impairing their functionality but exploiting their collaboration.

7 CONCLUSION

In CoRaLi-DAR we aim at demonstrating an advanced detection and ranging sensor system based on a collaborative scheme, integrating on the same module radio and light-based ranging sensing. In this short paper we have introduced current market trends and device performances for both RADAR and LiDAR. CoRaLi-DAR is expected to have large impact in the detection and ranging field largely reducing size and increasing power efficiency. CoRaLi-DAR will also expand the current ranging platform performances and reliability thanks to the proposed collaborative approach. With these qualities, CoRaLi-DAR could be a disruptive platform in any application requiring detection and ranging: automotive, robotics, aviation, security and surveillance.

8 LIST OF ABBREVIATIONS

Abbreviation	Meaning
CPU	Central Processing Unit
FMCW	Frequency Modulated Continuous Wave
FoV	Field of View
LiDAR	Light Detection and Ranging
LO	Local Oscillator
MMIC	Monolithic Microwave Integrated Circuit
OPA	Optical Phased Array
PAE	Power Added Efficiency
PIC	Photonic Integrated Circuit
PU	Processing Unit
RADAR	Radio Detection and Ranging
RX	Receiver
SNR	Signal to Noise Ratio
TX	Transmitter
USP	Unique Selling Point
Φa	Angular Resolution

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9 REFERENCES

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[2] https://www.futuremarketinsights.com/reports/radar-market

[3] Hanno Holzhüter, Jörn Bödewadt, Shima Bayesteh, Andreas Aschinger, Holger Blume, "Technical concepts of automotive LiDAR sensors: a review," Opt. Eng. 62(3) 031213 (10 January 2023)