2022 International Conference on Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER) | 978-1-6654-8716-0/22/$31.00 ©2022 IEEE | DOI: 10.1109/DISCOVER55800.2022.9974941

A Survey on use of FPGA in Automotive System

Aishwarya G
Research Scholar, School of ECE
Reva University
Bengaluru, India

Bhoomika Patil
Research Scholar, School of ECE
Reva University
Bengaluru, India

Prashant V Joshi
Associate Professor, School of ECE
Reva University
Bengaluru, India

K M Sudarsham
Professor, HOD, School of ECE Reva University Bengaluru, India

Krishnamurthy Vaidyanathan
Spark Minda Technical Centre
Bengaluru, India

Parag Parandkar
Spark Minda Technical Centre
Pune, India

Allan Dsouza
Spark Minda Technical Center
Bengaluru, India

***Abstract*— Automotive systems are real-time basis systems and are required to be highly fault-tolerant systems. Microcontrollers became a prominent part of the automotive sector. Microcontroller-based ECUs are easier to program, debug and design. However, they lack in non-availability of hard and softcore design suites, processing speed, etc. The Field Programmable Gate Array (FPGA) is one of the System-On-Chip (SoC) units. FPGAs are the best choice for low-volume, high-end applications and for pre- and post-silicon validation and firmware development. FPGAs provide access to hardcore and softcore processing. This makes it more likely to be utilized in automotive systems. Clusters with more difficult performance make FPGAs a better choice over microcontrollers as they have higher performance, and parallel processing ability due to which they provide a quicker solution. FPGAs have an Advance Encryption Standard (AES), which protects the hardware from cyber threats. They are also less susceptible to data flip which causes a soft error in the hardware while processing. This paper presents a survey on the role and significance of FPGA in Automotive systems. This survey aims to showcase the opportunities and challenges of FPGAs in next-generation automotive systems.**

Keywords*— *Automotive systems, Open-Source, RISC-V, Performance Cycles, PULP, GAP8, MACs

I. INTRODUCTION

A. Automotive Systems

Electronics systems made their way into the automotive industry in the ’60s. Ever since the introduction of electronics has altered the market structure. Hardware and software play a major role in the innovation of automotive systems today. Introduction of software has improved performance and has increased the safety of automotive vehicles by enabling active and passive systems for instance antilock braking and electronic stability control (ESC) [1]. Figure 1 gives a detailed view on the car software. Software used in the vehicle is more reliable for a failure rate of one part per million in a year.

In the modern era, electronic control units (ECUs) are interconnected by a complex in-vehicular network. ECUs communicate using a standardized bus system such as MOST, CAN, Flex Ray, and LIN are used for the ECUs to communicate. The amplification in the number of connected ECUs has driven advanced structures. Dedicated electric and electronic architecture designs are used in-vehicle networks [2]. To achieve the intricacy of these networks, the vehicular system is divided into domains such as body engineering, display electronics, telematics, and infotainment. The principal difference between automotive software and application software including personal computers and telecommunication is its robust nature, reliability, functional safety, minimal resource consumption, and real-time behaviour [3].

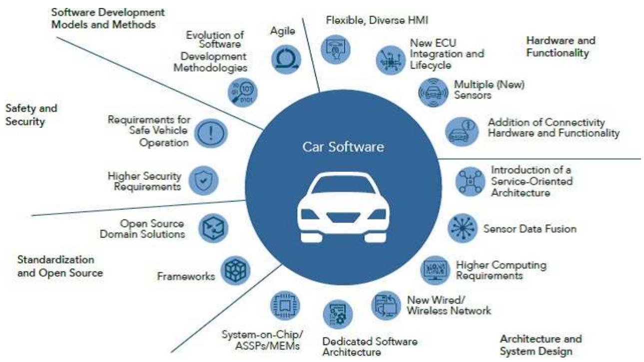

Figure 1 Car Software [Source: Wind River]

B. Embedded Computing units for automotive systems

An embedded system is also a computer system that is mainly meant for the functioning of a large mechanical or electrical system. Embedded system controls engine management systems in automobiles, monitor home heating systems, and regulate the function of a washing machine [4].

Figure 2 Embedded Control Units in Automotive system

Embedded system plays the main role in the automotive system because of their flexibility and versatile nature. To intensify the performance of the system, to allow plug and play of the subsystems, a system architecture evaluation for automotive electronics and the development of the robust

978-1-6654-8716-0/22/$31.00 ©2022 IEEE

design flow must be supported. Major embedded control units of an automotive system are shown in figure 2. The revolution of electronics has changed the design of automobiles for example fuel ignition, protection from power train crashes, etc. The introduction of the embedded system into cars has aided in assisting in pollution control, system monitoring, etc [5]. A typical automobile system consists of a computer-controlled electronic system. An anti-lock braking system, airbags, Voice Recognition, Audio Systems, ACC, Collision Warning, GPS, automatic parking, etc., as depicted in figure 3 are the most adapted embedded system units in an automobile.

Figure 3 Embedded System in Automotive System

C. Motivation for Study

Cars have a long history dating back to the late 1800s, but electronics have become an integral part of the automotive world in recent decades. However, it is tenacious for this CPU and GPU-based Electronic Control Units (ECUs) to keep pace with the long chip production cycle. The complexity of automotive electronic systems is escalating for the betterment of security and efficiency [6]. The automotive design focuses on minimizing the overall count of ECUs because they raise the total cost of the vehicle. The use of FPGA-based ECU has led to improvement in the performance of automotive systems which is difficult to achieve with microcontroller-based ECU. They support the physical specification of in-vehicle networks, hardware flexibility for functional extension, and the implementation of multiple ECUs on one chip. As stated, figure 4 shows that over the period the complexity of an automobile is increasing dramatically. Replacing MCUs with FPGAs doesn't mean that MCUs are eradicated from the automotive system. FPGA is good at the operation and calculations of huge data flowing in parallel.

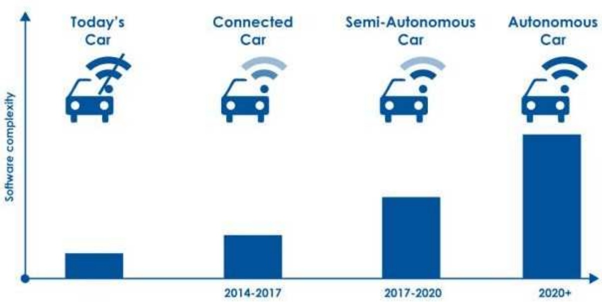

Figure 4 Software complexity for Automotive Industry

The paper by Jung Hwan Oh states that communication can be established between the FPGA and the microcontroller in an automotive system by the usage of the high-speed protocol which is a Zipwire communication unit FPGA engineers can modify the car without going through the ASIC design flow as shown in figure 5 [7].

The FPGA design flow provides a solution in high volume at low cost and very high standards with optimized vehicle performance. The authors proposed an In-System Reconfiguration (ISR) ECU system which is a co-designed architecture with FPGA and MCU to improvise the reliability of the system in internal communication and flexibility [8].

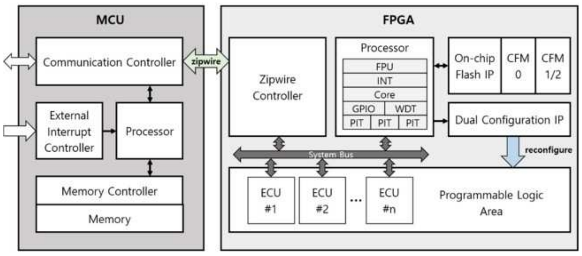

Figure 5 Architecture of MCU and FPGA Communication Over a Zipwire.

The paper presents a real-time and shared memory multiprocessor architecture which is to enhances the dual priority scheduling micro-kernel on FPGA [9]. They used an FPGA to present a shared-memory multiprocessor system. In light of the above decision. According to the research made, the reconfigurable nature of FPGAs can be used to replace MCU[10]. FPGA provides a more efficient and quick solution for the ECUs as FPGA can take in huge data and process it at a higher speed. Due to this, the burden on MCUs can be reduced.

The following are the deciding factors for the usage of FPGA in Automotive systems rather than MCUs [11].

1. High performance.
2. Reprogrammable.
3. Parallel Computation.
4. The period to market is faster when compared with MCUs.

II. LITERATURE SURVEY ANDRESEARCH METHODOLOGY

A thorough study was done on various papers that referred to automotive systems in FPGA to accomplish the work carried out deliberately. The papers referred were from IEEE Digital Xplore, SAE libraries, and some other journal papers. From the year 2004-2021, the most relevant paper for Automotive Systems in FPGA was found and reviewed. The Paper is organized in a manner where the reference paper citing relevant work was discussed accordingly.

The paper has been written in the manner of a narrative review with some elements of a status-quo review. This is done to facilitate an easy understanding of the technology and timeline that the paper is concerned with.

III. FPGAs FOR AUTOMOTIVE SYSTEMS

A. Role and Significance of FPGA in Automotive Systems.

Field Programmable Gate Array (FPGA) plays a major role in Automotive Industry. Traditionally, most of the computational tasks in the autonomous vehicle were performed by microcontroller units (MCUs). Typically, a mid-range vehicle contains microcontrollers of about 25-35 MCUs, whereas luxury cars have 65 or more. FPGAs are also used in ASICs as a precursor[11], [12]. However, FPGAs have a programmable feature, which helps in solving the errors in a function until the final design is made. After the verification, synthesis, and simulation are done, the main product is sent out for manufacturing. One of the well-known companies, Intel, also uses FPGA as a prototype before manufacturing the device. An overview of the contributions and limits of FPGAs is also given along with the two complete and timely case studies presented [13]. The automotive industry is using continual acceleration with an electronic system for offering higher security and efficiency.

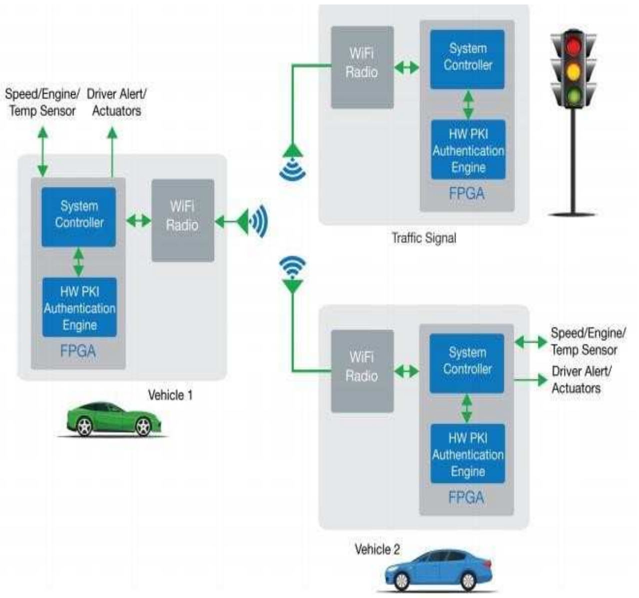

Figure 6 FPGAs can implement a secure communication system.

The FPGA plays a major role in providing flexibility to system architecture. FPGAs have a distinguishable advantage over the other silicon fabrics, and they are very optimal for the evolving requirements of the Autonomous Driving Industry. Nowadays FPGAs are being used under Automotive systems as a single unit or with the cluster along with CPUs, as they are more efficient and quicker when compared to several hundreds of ECUs within a vehicle. A low-cost FPGA-based fail-safe ECU system was proposed that is configured to be a fault detector and monitors the control circuits [14]. They can consume less power with higher performance due to which the customization and scalability factors are ameliorated is demonstrated in figure 6. FPGA can contribute to lowering the total cost of an automated system by integrating external components to

FPGA by which the time to mark is achieved sooner. With all the above advantages provided by FPGA to the automation field, we can say that a field programmable array is more suitable than ECUs [15]. In addition to that, they often provide a lot of applications under motion or motor-control systems with cost-effective solutions. FPGAs are used in various on-road transportation modes which embed several Artificial Intelligence (AI), security, sensors, and actuators. work done by M Komorkiewicz, an FPGA-based device designed to capture a real-time video and inject it into the video processing unit [16].

Nowadays the automotive industry is using higher complex electronic devices to offer the best security and accuracy to drivers. The paper aims at creating and providing a multi-FPGA platform based on a smart algorithm system to increase road safety. FPGA plays a major role in the state-of-the-art performance and flexibility of the system architecture [17]. The main aim of the automotive system design is to lessen the total units of ECUs, as they contribute to increasing the cost of the whole system. FPGAs help in reducing the total cost. As per the new advancements in FPGAs, now it is possible to combine electronic elements within a vehicle.

FPGAs have a unique network acceleration capability for which they were used in a neural network in late 1994. FPGA consists of several built-in hardware units by which dynamically programmable logic functions can be achieved These abilities enable FPGA to be highly applicable in many domains. Some of the FPGA features were high performance and low power consumption [18]. These flexible features in FPGA give them an advantage when compared to other hardware with fixed features.

Automotive systems uphold some of the features such as park assistance, autonomous emergency braking, autonomous driving, autonomous driving assistance system, etc. They are undergoing a changeover with time. To stay in the race of cutting-edge of this competitive landscape, automotive system engineers need to design the best computing architectures. FPGAs furnish a distinctive advantage over other silicon solutions. FPGAs are well-suitable for the evolving requirements in the autonomous driving industry. In today's automobiles, Advanced driver assistance systems (ADAS) have become very eminent. [19] discusses introducing an efficient traffic sign detection as a driver assistance system.

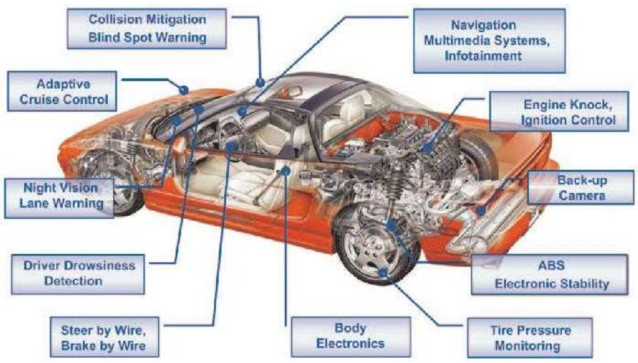

Figure 7 FPGA Development for Automotive Application

Some of the key challenges faced in the automotive system are performance and efficiency. This can be achieved by the usage of FPGAs in the autonomous driving industry. Safety and security would promote the importance of cyber security. FPGAs are making their way into self-driving car systems. In [20] Cong Hao and the team proposed a primary system GPU-based and FPGA-based secondary system for a hybrid computing system in self-driving cars Figure 7.

B. Market share of FPGA in Automotive Systems

The global FPGA market is projected to reach USD 9.1 billion by 2026 from an estimated USD 6.2 billion in 2021, at a CAGR of 7.8% from 2021 to 2026. The rising deployments were high performance and low power consumption. The fusion of FPGA in automotive applications such as ADAS is the factor driving the growth of the FPGA market Figure 8.

Figure 8 Market share of FPGA in the Automotive Industry

C. Evolution and trends in FPGA Architecture

By the 1980s, the Field Programmable Gate Array production was established through PLD and PROM. Contradictory to that, the devices had to be hard wired. The first reprogrammable logic was designed in the year 1984 by Altera. By the mid-1990s, Field Programmable Gate Array evolved and was well recognized in the industrial sector [21]. FPGA is also expanded into the automotive, industrial, and consumer application fields.

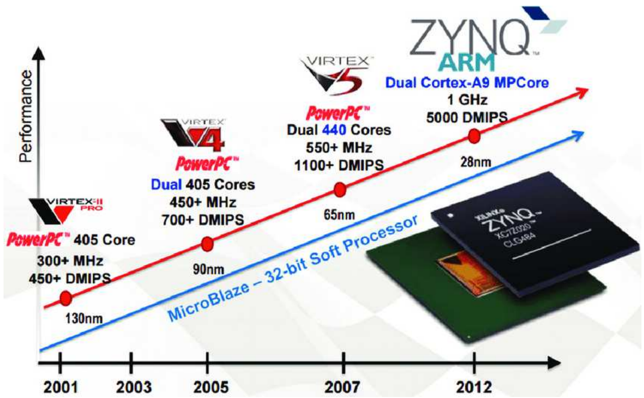

Figure 9 Evolution of FPGA from 2001- 2012

One of the first series of FPGAs, XC2000 was launched in 1985 with 2000nm technology. In the year 1985 Xilinx launched the very first FPGA of the industry- XC2064 [22]. Though the term FPGA was not popularized until 1988 by Actel. Over the period the capacity of FPGA has increased by more than a factor of 10000 with an increase in speed by a factor of 100 Figure 9 [23]. The 1990s was a period of rapid growth in FPGA devices, both in-circuit and the volume of production.

FPGAs advancement in the design technology such as SRAM-based FPGAs and the technological processes of 130nm. Along with the improvements made the price of FPGA attracted, even with mass production. The authors have presented an approach to reduce the cost of FPGAs by presenting a solution for mass production, even in the automotive industry [24]. Firstly the papers speak about the usage of FPGAs in automotive systems and more demanding, automotive applications [25]. Secondly, the paper discusses the trend of FPGA suppliers investing in International Organization for Standardization (ISO) certification and boosting the tolerance of high temperatures which is the most important aspect of the automotive industry. The authors proposed a Xilinx Zynq- based hybrid ECU approach which included an ANN-based prediction system [26]. The architecture built was to enroll with the emerging technology in communication. The presents an approach for security in FPGA, in terms of the software domain [27]. The focus of the proposed paper was to reduce the cyber threat and deliver a highly secured FPGA to the automotive domain.

D. FPGA for next-generation Automotive systems- Opportunities and Challenges

FPGA provides the reprogrammable feature with high performance and even has soft-core and hard-core processing units. The sensors and image processing are available in hard-core and soft-core Ips [28]. FPGA can deliver parallel processing depending on external devices such as Digital Signal Processing (DSP) for a faster response. All these features offered by FPGA make an optimal choice for next-generation automotive systems.

In a serial processing unit, the computation is time-consuming, but in FPGA computation is done parallelly. Most of the FPGAs have integrated peripheral cores that are used to complement the communication function over CAN protocol [29],[30]. Some of the FPGAs are lower power consumption than application-specific standard products (ASSP)-based solutions, figure 10. Modern FPGAs are getting advanced in features in secure fields such as Advanced Encryption Standard, Secure Hash Algorithm (SHA), ECC, Public Key Infrastructure, and resistance, crypto accelerators [31]. An important aspect of the architecture of the automotive systems is to have a highly reliable system.

- <u>Security Gateway:</u>
  It administers both permanent and reconfigurable security design to provide protection against cyber security threats, cloning, and tampering.

Figure 10 Advantages of FPGA in Automotive Systems.

- <u>Multi-threading and Parallel Processing Capabilities:</u>
  FPGAs can run tasks parallelly, which is a great advantage in applications such as ADSD, and power

control systems in electric vehicles because such applications need simultaneous processed data while providing the generated data as feedback to the drivers. For example, ADAS and Smart Park Assist system applications need simultaneously processed data coming from several sources such as sensors, cameras, etc., [32] By enabling a single device for processing IPs on the FPGA fabric to perform multiple tasks at the same time. Most of the FPGAs come with fused auxiliary cores that implement functions like communication over the CAN protocol. These peripheral cores are also be used in parallel processing to advance the co-occurrence of several input signals.

IV. CONCLUSION

This paper has aimed to present the unique features of FPGAs which makes it a suitable choice for automotive industry. After a short description of FPGAs and their uses in the automotive industry, the authors have focused on the role and significance of FPGA in automotive industry, Evaluation and trends in FPGA architecture, and FPGA for next-generation Automotive systems- Challenges and opportunities. FPGAs are cascaded with so many features which makes them a better choice in the automotive industry over microcontrollers. As FPGAs are fault-tolerant, high-processing speed, a parallel computation which makes it reliable for real-time systems. Authors have presented a perspective on FPGAs as to be well suited for real-time automotive systems when compared with microcontrollers. Microcontrollers lack processing speed, they are vulnerable to cyber threats, and time to market is high when compared to FPGA. FPGAs are reliable, cost-effective, less prone to cyber threats due to the presence of AES and are less susceptible to the soft error of bit failures caused by energetic particles. However, FPGAs have drawbacks in the design process, complex, programming of an FPGA is to be done by Verilog/VHDL language as they are not as simple as C programming. Features of FPGA when compared to MCU are more suitable for autonomous vehicles. All these attributes led the authors to take a survey on the role and significance of FPGA in automotive systems.

REFERENCES

[1] Mössinger, J., 2010. Software in automotive systems. IEEE software, 27(2), pp.92-94.

[2] Wang, C.C., Chen, C.L., Li, J.J., Sung, G.N., Yeh, T.H. and Juan, C.Y., 2013. A low-power transceiver design for FlexRay-based communication systems. Microelectronics Journal, 44(4), pp.359-366..

[3] Pretschner, A., Broy, M., Kruger, I.H. and Stauner, T., 2007, May. Software engineering for automotive systems: A roadmap. In Future of Software Engineering (FOSE'07) (pp. 55-71). IEEE.

[4] Bello, L.L., Mariani, R., Mubeen, S. and Saponara, S., 2018. Recent advances and trends in on-board embedded and networked automotive systems. IEEE Transactions on Industrial Informatics, 15(2), pp.1038-1051.

[5] Wyglinski, A.M., Huang, X., Padir, T., Lai, L., Eisenbarth, T.R. and Venkatasubramanian, K., 2013. Security of autonomous systems employing embedded computing and sensors. IEEE micro, 33(1), pp.80-86.

[6] Jena, S.K. and Srinivas, M.B., 2012, October. On the suitability of multi-core processing for embedded automotive systems. In 2012 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery (pp. 315-322). IEEE.

[7] Oh, J.H., Yoon, Y.H., Kim, J.K., Ihm, H.B., Jeon, S.H., Kim, T.H. and Lee, S.E., 2019, January. An FPGA-based electronic control unit for automotive systems. In 2019 IEEE International Conference on Consumer Electronics (ICCE) (pp. 1-2). IEEE.

[8] Cho, K., Kim, J., Choi, D.Y., Yoon, Y.H., Oh, J.H. and Lee, S.E., 2021. An FPGA-Based ECU for Remote Reconfiguration in Automotive Systems. Micromachines, 12(11), p.1309.

[9] Tumeo, A., Branca, M., Camerini, L., Ceriani, M., Palermo, G., Ferrandi, F., Sciuto, D. and Monchiero, M., 2008, March. A dual-priority real-time multiprocessor system on fpga for automotive applications. In Proceedings of the conference on Design, automation and test in Europe (pp. 1039-1044).

[10] Becker, J., Hubner, M., Hettich, G., Constapel, R., Eisenmann, J. and Luka, J., 2007. Dynamic and partial FPGA exploitation. Proceedings of the IEEE, 95(2), pp.438-452.

[11] Shrestha, P., Subedi, B., Girard, M., Parikh, C. and Kandalaft, N., 2020, January. Wireless communication between FPGA and microcontroller. In 2020 10th Annual Computing and Communication Workshop and Conference (CCWC) (pp. 0402- 0405). IEEE.

[12] Cappelli, M., Memmi, F., Falconi, L., Palomba, M., Bove, R. and Sepielli, M., 2012, July. The Role of FPGA-Based Architectures in the Control Room Modernization Process: Preliminary Results of a Case-Study. In International Conference on Nuclear Engineering (Vol. 44984, pp. 653-660). American Society of Mechanical Engineers.

[13] Gabrick, M., Nicholson, R., Winters, F., Young, B. and Patton, J., 2006. FPGA considerations for automotive applications (No. 2006-01-0368). SAE Technical Paper.

[14] Chujo, N., 2002. Fail-safe ECU system using dynamic reconfiguration of FPGA. R & D Review of Toyota CRDL, 37(2), pp.54-60.

[15] Shreejith, S., Fahmy, S.A. and Lukaseiwycz, M., 2013, December. Accelerating validation of time-triggered automotive systems on FPGAs. In 2013 International Conference on Field- Programmable Technology (FPT) (pp. 4-11). IEEE.

[16] Komorkiewicz, M., Turek, K., Skruch, P., Kryjak, T. and Gorgon, M., 2016, October. FPGA-based hardware-in-the-loop environment using video injection concept for camera-based systems in automotive applications. In 2016 Conference on Design and Architectures for Signal and Image Processing (DASIP) (pp. 183-190). IEEE.

[17] Guillot, A., Jallouli, A., Ly, A., Sayarath, A., Rezakhanlou, L., Cabanes, Q. and Senouci, B., 2017. Multi-FPGA Platform for Smart Automobiles Embedded Electronics Design and Prototyping. In Proceedings of the International Conference on Embedded Systems, Cyber-physical Systems, and Applications (ESCS) (pp. 49-53). The Steering Committee of The World Congress in Computer Science, Computer Engineering and Applied Computing (WorldComp).

[18] Andina, J.J.R., De la Torre Arnanz, E. and Peña, M.D.V., 2017. FPGAs: fundamentals, advanced features, and applications in industrial electronics. CRC Press.

[19] Schwiegelshohn, F., Gierke, L. and Hübner, M., 2015, June. FPGA based traffic sign detection for automotive camera systems. In 2015 10th international symposium on reconfigurable communication-centric systems-on-chip (ReCoSoC) (pp. 1-6). IEEE.

[20] Hao, C., Sarwari, A., Jin, Z., Abu-Haimed, H., Sew, D., Li, Y., Liu, X., Wu, B., Fu, D., Gu, J. and Chen, D., 2019, October. A hybrid GPU+ FPGA system design for autonomous driving cars. In 2019 IEEE International Workshop on Signal Processing Systems (SiPS) (pp. 121-126). IEEE.

[21] Mencer, O., Allison, D., Blatt, E., Cummings, M., Flynn, M.J., Harris, J., Hewitt, C., Jacobson, Q., Lavasani, M., Moazami, M. and Murray, H., 2020. The history, status, and future of FPGAs. Communications of the ACM, 63(10), pp.36-39.

[22] Gabrick, M., Nicholson, R., Winters, F., Young, B. and Patton, J., 2006. FPGA considerations for automotive applications (No. 2006-01-0368). SAE Technical Paper.

[23] Ahmed, S.Z., Sassatelli, G., Torres, L. and Rougé, L., 2010, August. Survey of new trends in industry for programmable hardware: FPGAs, MPPAs, MPSoCs, structured ASICs, eFPGAs and new wave of innovation in FPGAs. In 2010 International Conference on Field Programmable Logic and Applications (pp. 291-297). IEEE.

[24] Mencer, O., Allison, D., Blatt, E., Cummings, M., Flynn, M.J., Harris, J., Hewitt, C., Jacobson, Q., Lavasani, M., Moazami, M. and Murray, H., 2020. The History, Status, and Future of FPGAs: Hitting a nerve with field-programmable gate arrays. Queue, 18(3), pp.71-82.

[25] Shreejith, S., Anshuman, B. and Fahmy, S.A., 2016, March. Accelerated artificial neural networks on FPGA for fault detection in automotive systems. In 2016 Design, Automation & Test in Europe Conference & Exhibition (DATE) (pp. 37-42). IEEE.

[26] Karam, R., Hoque, T., Ray, S., Tehranipoor, M. and Bhunia, S., 2017, January. xSouth Pacific Design Automation Conference (ASP-DAC) (pp. 611-616). IEEE.

[27] Grimm, T., Janßen, B., Navarro, O. and Hübner, M., 2015, September. The value of FPGAs as reconfigurable hardware enabling cyber-physical systems. In 2015 IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA) (pp. 1-8). IEEE.

[28] Rodríguez-Andina, J.J., Valdes-Pena, M.D. and Moure, M.J., 2015. Advanced features and industrial applications of FPGAs— A review. IEEE Transactions on Industrial Informatics, 11(4), pp.853-864.

[29] Joost, R. and Salomon, R., 2005, November. Advantages of FPGA-based multiprocessor systems in industrial applications. In 31st Annual Conference of IEEE Industrial Electronics Society, 2005. IECON 2005. (pp. 6-pp). IEEE.

[30] Salewski, F. and Kowalewski, S., 2008. Hardware/software design considerations for automotive embedded systems. IEEE Transactions on Industrial Informatics, 4(3), pp.156-163.

[31] Banerjee, S. and Gupta, T., 2011, July. Multi-stage parallel processing of design element access tasks in FPGA-based logic emulation systems. In 2011 3rd Asia Symposium on Quality Electronic Design (ASQED) (pp. 301-309). IEEE.

[32] Maxim, V. and Zidek, K., 2012. Design of high performance multimedia control system for UAV/UGV based on SoC/FPGA Core. Procedia Engineering, 48, pp.402-408.

[33] Kvas, M., Valach, S. and Fiedler, P., 2012. Reliability and safety issues of FPGA based designs. IFAC Proceedings Volumes, 45(7), pp.201-206.

[34] Kahl, T. and Dieckerhoff, S., 2017, July. Comparison of FPGA- and microcontroller-based control of a high-dynamic power electronic converter. In 2017 IEEE 18th Workshop on Control and Modeling for Power Electronics (COMPEL) (pp. 1-6). IEEE.

[35] V.J., 1993. FPGA design technology. Microprocessors and Microsystems, 17(7), pp.383-389.

[36] Shaker, M.N., Hussien, A., Alkady, G.I., Amer, H.H. and Adly, I., 2019, June.