Edge Computing Technologies as a Crucial Factor of Successful Industry 4.0 Growth. The Case of Live Video Data Streaming

Joanna Gąbka(✉)

Department of Laser Technologies, Automation and Production Engineering, Wroclaw University of Science and Technology, 27 Wybrzeże Wyspiańskiego Street, 50-370 Wrocław, Poland
joanna.gabka@pwr.edu.pl

Abstract. This article presents edge computing as a new approach which can significantly benefit development of Industry 4.0 in different areas. The edge computing was explained in comparison with cloud computing. Its main advantages can be obtained implementing both edge and cloud computing as a hybrid solution. The advantages of the new data management method were assigned to the topics comprised within each of the three differentiated main research areas built in the Industry 4.0 paradigm: Individualization of production, Horizontal integration in collaborative networks, End-to-End digital integration. The tables designed show impact of the advances resulting from edge computing on the development possibilities in manufacturing and production while realizing the most probable exploitation and growth scenarios. To make the predictions based on the literature more realistic there was presented a case study of the project where edge device for stereoscopic 180° live video streaming was planned to be implemented bringing significant improvements into the data capturing and management process. The algorithmic possibilities presented may be analogically exploited in the topics mentioned in all the three main Industry 4.0 theme groups.

Keywords: Edge computing · Industry 4.0 · Live stereoscopic video data streaming

1 Introduction

Industry 4.0 is described as a next important step in the evolution of production and all the connected fields. It is very complex movement consisting of many fields. In the [1] authors indicate three main research streams supporting the development process with numerous topics contained in each of them. The mentioned taxonomy is as following: 1. Individualization of production which is closely correlated with such areas as mass customization, modularization, Flexible Manufacturing Systems (FMS) and Reconfigurable Manufacturing Systems (RMS), Distributed control, Self-optimization, Rapid

J. Trojanowska et al. (Eds.): *Advances in Manufacturing II* - Volume 1, LNME, pp. 25–37, 2019.
https://doi.org/10.1007/978-3-030-18715-6_3

Manufacturing, Cloud computing; 2. Horizontal integration in collaborative networks comprising Collaborative Networks, Distributed Manufacturing, Supply – Chain Flexibility, Supply – Chain Visibility, Internet of Things and Services; 3. End-to-End digital integration correlated with Virtualization of the process chain, Individualized Traced Data, Real-Time Operating Systems, Simulation and Modeling of products and processes, Simultaneous planning of products and production processes, Value Added Services. If we take closer insight into each of the topics it will be obvious that fast collecting, transferring and processing huge quantities of data from different sources is the essential condition of progress in any of the specific research fields. The cloud computing indicated within the first research stream actually became visible in all other places [2]. Its importance is especially highlighted when Internet of Things (IoT) is discussed [3, 4]. The practical implementation of the Cloud computing altogether with IoT shown limitations connected with bandwidth, costs, speed, predictive analytic, remoteness and maintenance [5–7]. As an answer to this drawbacks and edge computing approach was brought into being. It is based on idea of devices which intermediate layer between the equipment used and the cloud database [8, 9]. This kind of solutions indicate great potential and are a chance for acceleration of the Industry 4.0 growth. This article presents technologies connected with edge computing, provides definitions, shows a case of study of the particular device usage for video data streaming and potential of such solutions for manufacturing.

2 Cloud Computing vs. Edge Computing

Cloud computing is defined by The National Institute of Standards and Technology as "model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [10]. Due to the rapid increase in demand for data storage and processing this solution became popular in different domains and specializations both in industry and private sector [11]. It gained its position offering low price, easy management and the transparency of clearance resulting from pay-for-use strategy, distributed and uninterrupted services, delivering fast unlimited space and powerful computing capacity for data storage and administering [12]. In addition it is associated with green computing because of economic energy, computing space and power use. It is also associated with effective remedy to the crises providing reliable backup. There are three main service models referring to the cloud computing [13]:

1. Software as a Service (SaaS) – in this model cloud offers software, service or application which can be used after subscription. The delivery is made directly through network on-demand. The most popular SaaS in this category are Google Docs and Spreadsheets and IBM LotusLive.
2. Platform as a service (PaaS) – it provides set of runtime environments hosted on the provider's server. After paying certain price the platform and framework for software deployment is given to application developers, implementers, testers and

administrators which shows that this model operation covers all phases of software lifecycle. Here the well-known commercial are Amazon AWS and Microsoft Azure.

3. Infrastructure as a service (IaaS) – is a collection of servers, storage spaces and networks. This model is very closely correlated with virtualization which was mentioned among the main topics included in Industry 4.0. In this model Cloud Service Provider (CSP) gives an access to storage, network, routers, servers through virtual desktop. The transaction value is calculated on the base of utilization in different dimensions such as Central Processing Unit (CPU) hour, data GB stored per hour, additional services like scaling, network bandwidth consumed, network infrastructure per hour. The exemplary services available on the market are Amazon S3 and EC2 and VMWare.

In each of these three categories user can find such qualities as elasticity which is appreciated due to dynamic working conditions in today's environment and resource pooling helping risk management.

The service models are distributed in four different ways: public/external cloud available to all users. It offers services to the third part acquiring spare capacities from various enterprises such as Sun Cloud, Windows Azure Service Platform and others. The second way preferable in industry due to the security issues is private/internal cloud build specially for the particular organization which is exclusively authorized to control and owns the solution. Another cloud deployment form is hybrid cloud/virtual private cloud (VPC) with combination of both previous approaches. Some system is hosted and the rest of it managed externally. The last way of the cloud distribution is community cloud where both on the user and management side can be many related organizations. The service models and distribution options are presented in the Fig. 1.

The cloud computing has also some disadvantages and implemented risks, mostly connected with security, such as data loss, data cleaning, account hijacking, limited control over the process, unwanted data inspection by CSPs, lack of portability/ migration from one service provider to the other, lack of auditability, issues resulting from diversified quality of service [14, 15]. One of the important flaws in context of industry is long response time resulting from raw data transferring, processing and then sending back to the device connected. The fast growth of demand for such a services resulting also from the digitalization of Industry led to the significant challenges with virtualization, interoperability, resource scheduling, multi-tenancy, load balancing and most importantly security [16, 17].

This issues altogether with fast development of this field motivated to create a new solution. As an answer to the identified shortcomings a fast evolution of the cloud computing occurred towards solutions known as edge computing. The other terminology associated with this topic contains such a terms as fog, mist computing and cloudlets.

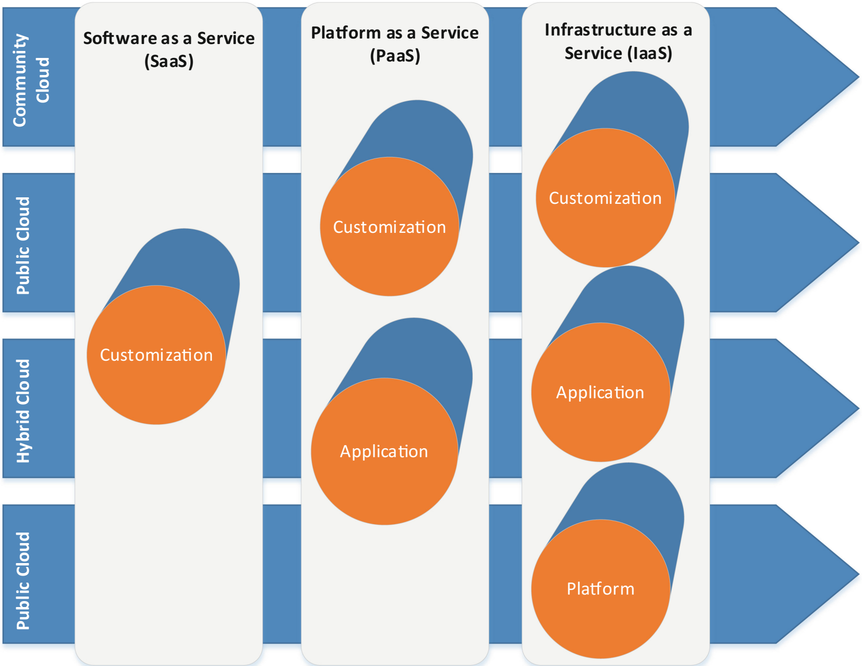

Fig. 1. Combination of cloud computing service models and distribution options.

Edge computing is based on the idea of processing data on the dedicated device nodes known also as smart devices or edge devices which are placed on the edge of core process enabling fast calculation which leads to the particular action execution before the communication with a cloud is performed. The edge computing is rather enrichment and modification to the cloud computing paradigm rather than its replacement because it may also use the cloud to the less sensitive data collecting or less critical decision making. The edge devices are more in charge of the decision making in cases when instant response is required. The division of computing and storage tasks between edge device and cloud is dependent on conditions in which their service. Figure 2 shows the main difference between this two approaches.

It is easy to notice in the Fig. 2 that the main difference is additional element of the architecture on the side of edge computing. This small modification solves many problems identified within cloud computing and implies new possibilities like more autonomous factories able to operate more effectively without human involvement. The quick on spot computations enable to deal with problems such as downtimes in the more robust way. The less sensitive data can still be operated by traditional cloud computing especially in cases when there is a will to wide access to them from dispersed locations. It is likely that edge computing will complement cloud computing instead of replacing it. International Data Corporation research forecast shows that 45% of data produced by IoT devices will be stored, processed and analyzed on the edge of networks in the next three years. This gives over 6 billion appliances connected to the edge computing devices giving quick feedback and impacting the execution level.

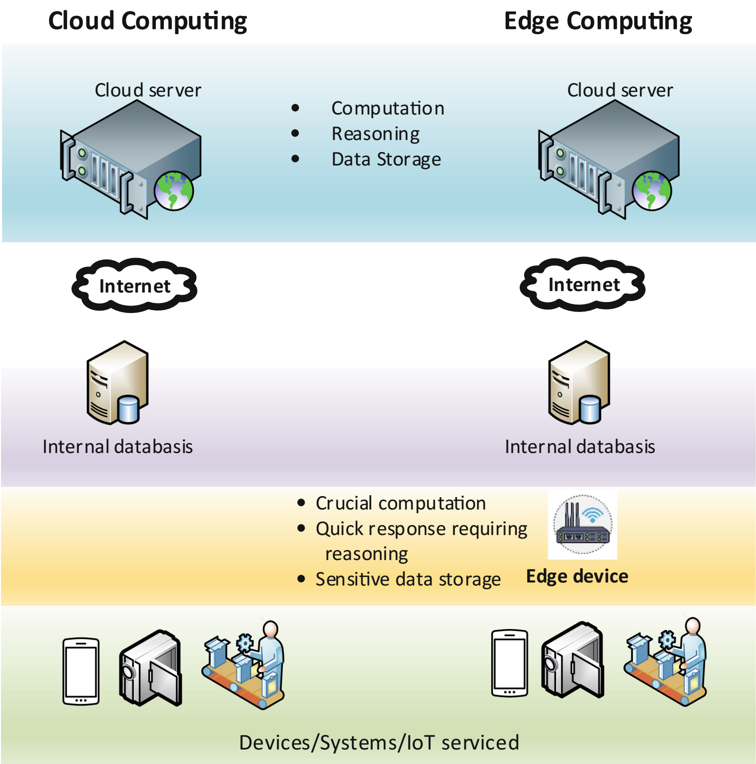

Fig. 2. Cloud computing in comparison with edge computing.

3 Edge Computing as an Important Element of Industry 4.0 Development

The findings regard first themes group – Individualization of production are presented in Fig. 3. The edge computing will bring more clarity towards data safety. Sensitive information from the customer may be managed and protected which can result in higher amount of clients willing to share date and buy customized products. On the side of manufacturer it means more timing in delivery due to the local fast decision making and more flexibility resulting from independence of outside service provider. The development of modularization may benefit thank to the integration of the design function and manufacturing process. The information gathered from previous series of products may be used to modify construction of the next series. FMS&RMS is the topic that seems to benefit most from edge computing. The quick communication between machines gives more reliability and independence of the system from human workforce. The problematic field of rescheduling may be solved more efficiently. The production system will be less prone to the attacks from outside, the human intervention will be minimized. All of this gives opportunity for more internal system integration and autonomous workload balancing which in turn leads to the cost

	Industry 4.0 connected topics / *edge computing advantages*	***Fast response time***	***Robust data management (minimizing data loss and operational failure)***	***Filtering sensitive data locally***	***Processing locally saving computational power and bandwidth***
Individualization of production	**Mass customization**	Customized services generated faster (crucial in healthcare)	More trust due to personal data safety		Cost effectiveness less reliability on outsourced service
	Modularization		Cohesive design/production processes		
	FMS & RMS	Efficient communication between machines; Quicker reaction to the instant changes in the production schedule	Production systems less vulnerable to hackers attacks	Less need of human intervention into the system	Huge advance in production system integration and capacity load balancing
	Distributed control	More precise data analysis due to the lack of delay	Historical data gathered locally always available		and accurate calculations in the necessary field only
	Self-optimization	Efficient load balancing			More possibilities in resources capacity utilization
	Rapid Manufacturing			Advancements in work on digital twin and security issues connected	Correcting process parameters online
	Cloud computing	Less pressure on responsiveness from customers	Less responsibility on the side of CSP	Less security concerns	Cost savings

Fig. 3. Cloud computing advantages as growth factor in individualization of production.

	Industry 4.0 connected topics* / *edge computing advantages	***Fast response time***	***Robust data management (minimizing data loss and operational failure)***	***Filtering sensitive data locally***	***Processing locally saving computational power and bandwidth***
Horizontal integration in collaborative networks	***Collaborative Networks***	More flexibility and time efficiency in cooperation	More integrity internal and external	Mutual trust due to sensitive data internal protection	Cost effectiveness less reliability on outsourced services Less requirement for manual data input
	Distributed Manufacturing	Less human interaction in checking available capacities	Easy access to data, undisturbed, quick data exchange	Mutual trust due to sensitive data internal protection	More transparent rules towards operational cost of collaboration.
	Supply – Chain Flexibility	Fast modification in response to the changes	Increased reliability, increased efficiency	Less need of human intervention into the system	Cost effectiveness
	Supply – Chain Visibility	More trust due to the reliable answers and subsequent accurate actions	Historical data gathered locally always available for audits or procedure improvements	More control over data (access and authorization easier to be done)	
	Internet of Things and Services	Smarter cities (security/communication/services) Smarter houses (safety/comfort) Smarter healthcare systems and devices (integrated/balanced approach, early warnings before emergency)	More control over data More reliable actions More possibilities for AI (self-learning algorithms)	Easy popularization of the IoT thanks to the information security.	Cheaper solutions commonly used by society.

Fig. 4. Cloud computing advantages as growth factor in Horizontal integration in collaborative networks.

	Industry 4.0 connected topics* / *edge computing advantages	***Fast response time***	***Robust data management (minimizing data loss and operational failure)***	***Filtering sensitive data locally***	***Processing locally saving computational power and bandwidth***
End-to-End digital integration	***Virtualization of the process chain***	More embedded intelligence and autonomous communication/decision making	Less failures due to communicational disturbances	Increased security, increased trust	Cost effectiveness less reliability on outsourced services
	Individualized Traced Data	Less human interaction in data completion and integration	Easy access to data, Preferable data ordering formats	Safety in aspects crucial for competitiveness.	More control on costs and flexibility in this field
	Real-Time Operating Systems	Autonomous breakdown fixing/replacement systems	Increased reliability, increased efficiency	Security of the system without additional legal efforts	Cost effectiveness
	Simulation and Modeling of products and processes	Rapid progress in augmented reality New possibilities	More control on the process Smaller gap between reality and models	More control over data More security especially while innovations tested	Cost effectiveness
	Simultaneous planning of products and production processes	Progress in area of digital twin creating and management; Progress on mass customization	More control over data More integration between construction and technology areas	Safety for producer and customer	Cost effectiveness
	Value Added Services	More autonomous and accurate customer service systems; Embedded communication between producer and user	Accurate actions and reactions	Customer private data safety	Cost effectiveness, lower price of the products with bonus services.

Fig. 5. Cloud computing advantages as growth factor in End-to-End digital integration

reduction. Distributed control has obvious advantage thanks to the local accurate data analysis. Similar results will refer to the self-optimization. Rapid manufacturing will benefit from accelerated efforts put on digital twin development. Cloud computing as mentioned before will not be replaced but stay an important ingredient of hybrid cloud and edge solutions with less security concerns and pressure on CSP.

In the second field (Fig. 4) - horizontal integration in collaborative networks – edge computing will make collaborative networks and distributed manufacturing easier in context of data reliability and quick exchange. The information directly from the process will shorten the procedure of the network configuration for the given project/order. The mutual trust issues may be also resolved. Similar effect may be predicted for Supply-Chain. IoT is the most visible in the research tackling edge computing impact on Industry 4.0. It is predicted that here will be the most opportunities to be utilized and changing life standard of entire societies.

The third theme package (Fig. 5) - End-to-End digital integration will win thanks to the more embedded intelligence in the virtualized process chain as well as in simulation and modelling. Advancement in this steps will make simultaneous product planning and production process possible.

4 Example of Implementation Concept in Video Data Streaming

The edge computing solutions are being developed in other fields than manufacturing but their functionalities and architecture prove that they may easily be adopted and contribute to the Industry 4.0. The case study shows a concept of innovative edge computing device dedicated for 180° spherical live video data streaming. The system is designed to make high quality live video transmissions dedicated for viewers using AR/VR goggles and share them on media platforms. The core element of this solution will be device for capturing and transmitting video stream (DfCT) which plays a role of edge device. The unique computer unit (Figs. 6 and 7) is responsible for processing signal coming from cameras. The algorithms that are going to be implemented in the device enable to achieve four times smaller delay in comparison to the solutions available on the market. It was assumed that maximal value of this parameter is 15 fps. The designed computer unit will not only be able to quickly capture and share the pictures from cameras but also provide exceptional quality. The resolution is supposed to reach 4 K (3840 $\times$ 2160) with minimum 30 fps with the expectation of 21.3 pixels per one degree. The algorithms implemented will be able to make modifications of the picture geometry, color field (LUT3D color grading) as well as optics and cameras imperfections correction. Beside that the video picture will be adopted to the appropriate protocols required by the media platform. The important function of the DfCT is data saving. All the captured video data are saved so beside the online improvements offline postproduction work can be done. Here is also the point where safety issues are resolved because only chosen data can be transmitted further to the online platform.

The edge device described above is a part of a complex solution for multi-camera video capturing and multichannel transmission servicing live stereoscopic 180° data streaming for Virtual Reality (Fig. 8). The system consists of the special camera rig adopted to this kind of transmissions, minimum two cameras for 180° video production (the system may serve for multi-camera transmissions as well), the edge DfCT video stream and efficient redistribution platform equipped in universal integration module enabling third part video streaming.

Fig. 6. DfCT view from the side. Copyright © BIVROST Sp. z o.o.

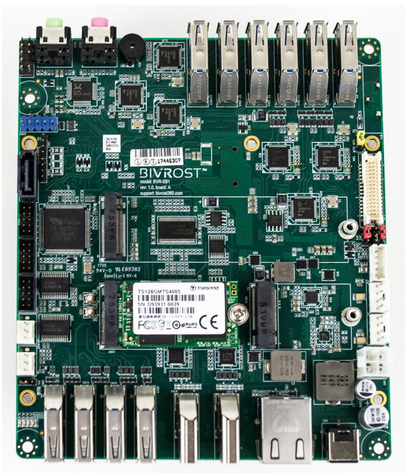

Fig. 7. General PCB view. Copyright © BIVROST Sp. z o.o.

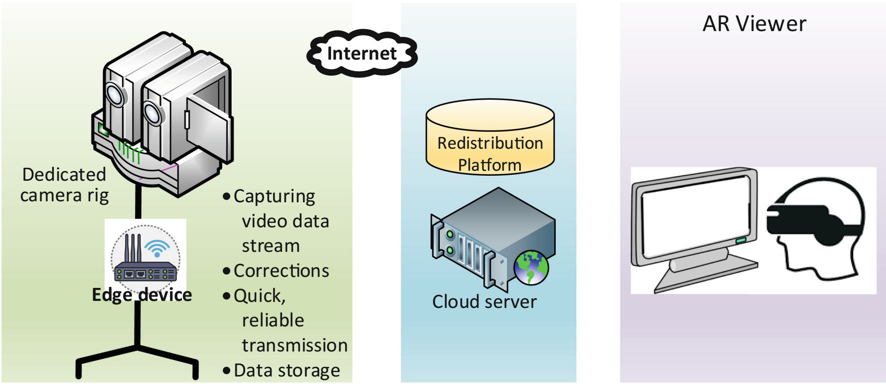

Fig. 8. Schematic view of the solution developed for live video streaming.

The system being developed has multiple applications. Its implementation in the production plant as an integral element of complex, industrial, multi-camera system enables significant reduction of expenditure on network infrastructure, giving also new technical possibilities. The predominance of the edge computing approach with DfCT usage is presented in Fig. 9. Multi-camera system in the case was simplified to eight cameras but it can be easily expanded to n-points with up to six cameras per each DfCT.

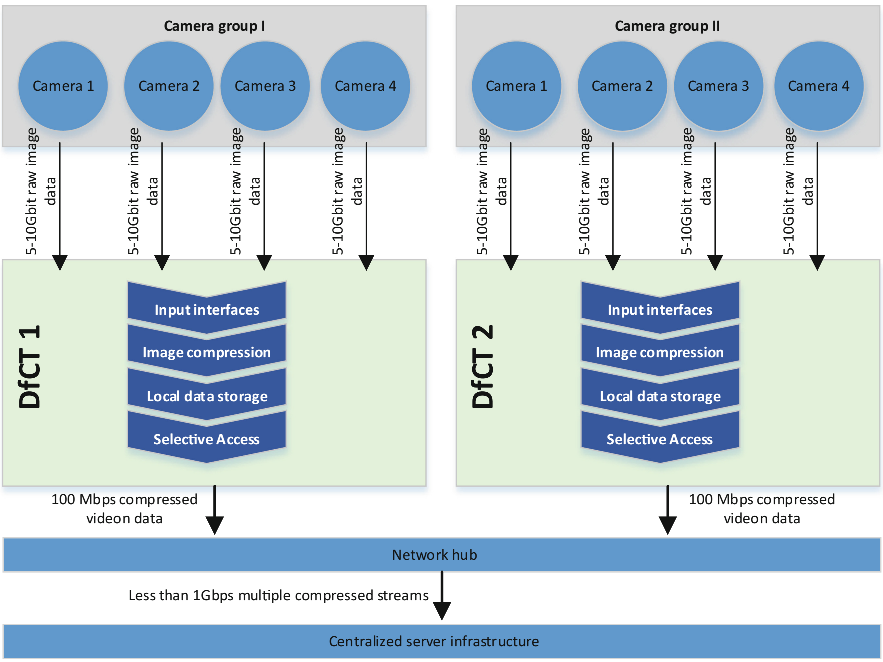

Fig. 9. Schematic view of the multi-camera system equipped in the designed DfCT.

The input interface of the Device for Capturing and Transmitting data is capable of receiving 5–10 Gbit of raw image data from the camera controller while the standard solutions equipped in a network hub at this place can only transmit maximum 1 Gbit of the raw image data. The data capturing, initial processing, analysis, compression and storage can be efficiently done locally by DfCT. The problem of costs resulting from consuming large bandwidth for sending significant numbers of data Gigabits which was identified while using GigE standard is solved this way. What is more the recorded material may be filtered locally and only the important interesting image or stream of image can be send to the centralized server. Simultaneously there is an option to reach pictures from other cameras or another time period thanks to the picture recording and compression functions embedded in DfCT. It can be estimated that after initial processing only approximately 1 Gbps of data needs to be transmitted to the main server. In the old standard systems, in comparison, it would be around 8–80 Gbps (depending on camera connection type), to maintain image quality and performance, in case of eight cameras operating. The described characteristics all together increase robustness of the centralized system. The plugins of Device for Capturing and Transmitting data can execute urgent tasks while waiting for the main system availability. It creates backup in situations when central system temporarily fails.

The described device delivers also value in other fields. It will enable to get a new sensations out of watching transmitted events like competitions, conferences, interviews. Beside the benefits resulting from the reality effects for the viewer it has great potential in field of education. E.g. there might be live transmission of a surgery for different groups of students showing another aspects of the procedure best from their professional specialty perspective.

5 Conclusions

It is visible that cloud computing widely spread in different application areas met certain constraints regard time of response, network bandwidth and data safety and operational service reliability in general. This problems may be resolved with a new edge computing approach which additionally brings a great opportunities in different fields connected with Industry 4.0. It is especially considered as an innovation engine for IoT but can also benefit most of research and consequently application areas differentiated within Industry 4.0. The case study of the Device for Capturing and Transmitting data designed by BIVROST Sp. z o.o. for stereoscopic 180° live video streaming shows clearly a broad spectrum of implementations that could be considered in context of manufacturing and related fields like simulations. The edge computing operating together with cloud computing not only reduces risks but enable to harvest a new opportunities unattainable before.

Acknowledgments. The project is granted by European Union and financed from European Regional Development Fund under the Smart Growth Program. The project is implemented as a part of 'Szybka Ścieżka' competition organized by The National Centre of Research and Development. POIR.01.01.01-00-1111/17.

References

1. Brettel, M., Friederichsen, N., Keller, M., Rosenberg, M.: How virtualization decentralization and network building change the manufacturing landscape: an industry 4.0 perspective. Int. J. Inf. Commun. Eng. **8**(1), 37–44 (2014)
2. Liao, Y., Deschamps, F., Loures, E.D.F.R., Ramos, L.F.P.: Past, present and future of industry 4.0 - a systematic literature review and research agenda proposal. Int. J. Prod. Res. **55**, 3609–3629 (2017)
3. Ai, Y., Peng, M., Zhang, K.: Edge computing technologies for Internet of Things: a primer. Digit. Commun. Netw. **4**, 77–86 (2017)
4. Bizanis, N., Kuipers, F.A.: SDN and virtualization solutions for the Internet of Things: a survey. IEEE Access **4**, 5591–5606 (2016)
5. Razzaque, M.A., Milojevic-Jevric, M., Palade, A., Clarke, S.: Middleware for Internet of Things: a survey. IEEE Internet Things J. **3**, 70–95 (2016)
6. Chiang, M., Zhang, T.: Fog and IoT: an overview of research opportunities. IEEE Internet Things J. **3**, 854–864 (2016)
7. Gayathri, M.R., Srinivas, K.: A survey on mobile cloud computing architecture, applications and challenges. Int. J. Sci. Re. Eng. Technol. **3**(6) 2014
8. Mao, Y., You, C., Zhang, J., Huang, K., Letaief, K.B.: A survey on mobile edge computing: the communication perspective. IEEE Commun. Surv. Tutorials **19**, 2322–2358 (2017)
9. Shahzadi, S., Iqbal, M., Dagiuklas, T., Qayyum, Z.U.: Multi-access edge computing: open issues, challenges and future perspectives. J. Cloud Comput.: Adv. Syst. Appl. **6** (2017)
10. Mell, P., Grance, T.: The NIST definition of Cloud Computing, Version 15, 10 July 2009. https://www.nist.gov/sites/default/files/documents/itl/cloud/cloud-def-v15.pdf. Accessed 9 Nov 2018
11. Varela, M., Putnik, G., Manupati, V., Rajyalakshmi, G., Trojanowska, J., Machado, J.: Collaborative manufacturing based on cloud, and on other I 4.0 oriented principles and technologies: a systematic literature review and reflections. Manag. Prod. Eng. Rev. **9**(3), 90–99 (2018)
12. Khan, I., Trzcieliński, S.: Information technology adaptation in Indian small and medium sized enterprises: opportunities and challenges ahead. Manag. Prod. Eng. Rev. **9**(3), 41–48 (2018)
13. Birje, M.N., Challagidad, P.S., Goudar, R.H., Tapale, M.T.: Cloud computing review: concepts, technology, challenges and security. Int. J. Cloud Comput. **6**(1), 32–57 (2017)
14. Gibson, J., Rondeau, R., Eveleigh, D., Tan, Q.: Benefits and challenges of three cloud computing service models, pp. 198–205. IEEE 2012
15. Jadeja, Y., Modi, K.: Cloud computing - concepts, architecture and challenges. In: 2012 ICCEET, pp. 877–880. IEEE (2012)
16. Intharawijitr, K., Iida, K., Koga, H.: Analysis of fog model considering computing and communication latency in 5G cellular networks. In: IEEE International Conference on Pervasive Computing and Communication Workshop, pp. 1–4 (2016)
17. Oueis, J., Strinati, E.C., Barbarossa, S.: The fog balancing: load distribution for small cell cloud computing. In: 2015 IEEE 81st Vehicular Technology Conference VTC Spring, pp. 1–6 (2015)