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Edge ai technology in the defense industry via reinforcement learning in simulation environments

Simülasyon ortamlarında pekiştirmeli öğrenme yoluyla savunma sanayinde uç yapay zeka teknolojisi

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Abstract

Edge artificial intelligence (Edge AI) technology helps to avoid vulnerabilities while benefiting from the advantages of cloud technologies, which are widely used today, especially with artificial intelligence and big data. In the case of transferring systems to the cloud, and needs such as protection of sensitive information and high bandwidth emerges in cloud approaches. Edge AI, which provides solutions to issues such as the security of sensitive data and reducing system traffic, while meeting the needs in this field, can offer a new perspective, especially to projects in the military field, when used with digital twin and autonomous system technologies. In this study, we evaluated the "Forces in virtual environment machine learning (FIVE-ML)" simulation system technically in which we use edge AI technology, analyzed the results obtained with the use of this technology. It has been determined that the current work is at the 2nd level in Edge AI levelling system, also there is a 54% performance (in terms of time with accuracy) increase with edge AI. Besides, the accuracy of hitting the target in simulation system is also increased, with the rate of 34%.

Keywords: Aerospace simulation, Artificial intelligence, Digital twin, Edge ai, Edge computing

Öz

Edge AI teknolojisi, günümüzde özellikle yapay zekâ ve büyük veri ile yaygın olarak kullanılan bulut teknolojilerinin avantajlarından yararlanırken güvenlik açıklarının önlenmesine de yardımcı olmaktadır. Sistemlerin buluta taşınması durumunda, hassas bilgilerin korunması ve yüksek bant genişliği gibi ihtiyaçlar ortaya çıkmaktadır. Bu alandaki ihtiyaçları karşılarken hassas verilerin güvenliği ve sistem trafiğinin azaltılması gibi konulara çözüm sunan Edge AI, dijital ikiz ve otonom sistem ile birlikte kullanıldığında özellikle askeri alandaki projelere yeni bir bakış açısı sunabilmektedir. Bu çalışmada edge AI teknolojisini simülasyon sistemlerinde kullanımı teknik olarak ele aldık. Bu teknolojinin kullanımı ile elde edilen sonuçları analiz ettik. Edge AI seviyelendirme sisteminde mevcut çalışmanın 2. seviyede olduğu tespit edilmiş, Edge AI kullanımı sayesinde %54 performans artışı elde edilmiştir. Ayrıca simülasyon sisteminde hedefi vurma isabet oranı da %34 oranında artırılmıştır.

***Anahtar kelimeler**: Havacılık simülasyonu, Yapay zekâ, Dijital ikiz, Uç yapay zeka, Uç hesaplama*

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1. Introduction

With the use of new trends of industry 4.0, digital twins, autonomous systems, smart IoT devices, developing artificial intelligence approaches; the management, use, and processing of large amounts of data in real-time or in scalable times are carried out using big data, distributed systems, and cloud computing technologies (Ahmed et al., 2017). Although the management, maintenance, and consistency of data and systems become easier with the use of cloud computing and cloud services in many areas, the increase in transaction density and the storage of critical information in the cloud poses a dangerous situation in various areas. There is an important problem such as ensuring the high level of confidentiality of military systems and system information. Even when institutions create their own cloud systems, it is not simple to maintain security, confidentiality, and data consistency stored in the cloud, and the use of such distributed and cloud systems is preferred in military areas either in mandatory situations or whenever possible because it creates an extra workload for institutions and countries (Anciaux et al., 2019; Dursun & Çuhasdar, 2018). There is a tendency not to be preferred. However, both edge computing and edge AI technologies are emerging technologies that take the use of cloud technologies to a different dimension, especially in terms of time and. Considering the digital twin, autonomous systems, and smart IoT devices that are widely used today and will see more widespread use in the future, their use is expected to increase with edge technologies as the cloud inference paradigm becomes less appropriate as the demand for real-time predictions rise.

According to Gartner, evolving hardware, innovative software techniques, and evolving micro-AI technologies are accelerating the adoption of edge AI that performs more and more transactions from the cloud to the edge, being at the center of the "2023 Emerging Tech Impact Radar: Artificial Intelligence" the most effective in the past few years (Figure 1). It has been emphasized that it is and will be one of the artificial intelligence technologies (T. Nguyen, 2023).

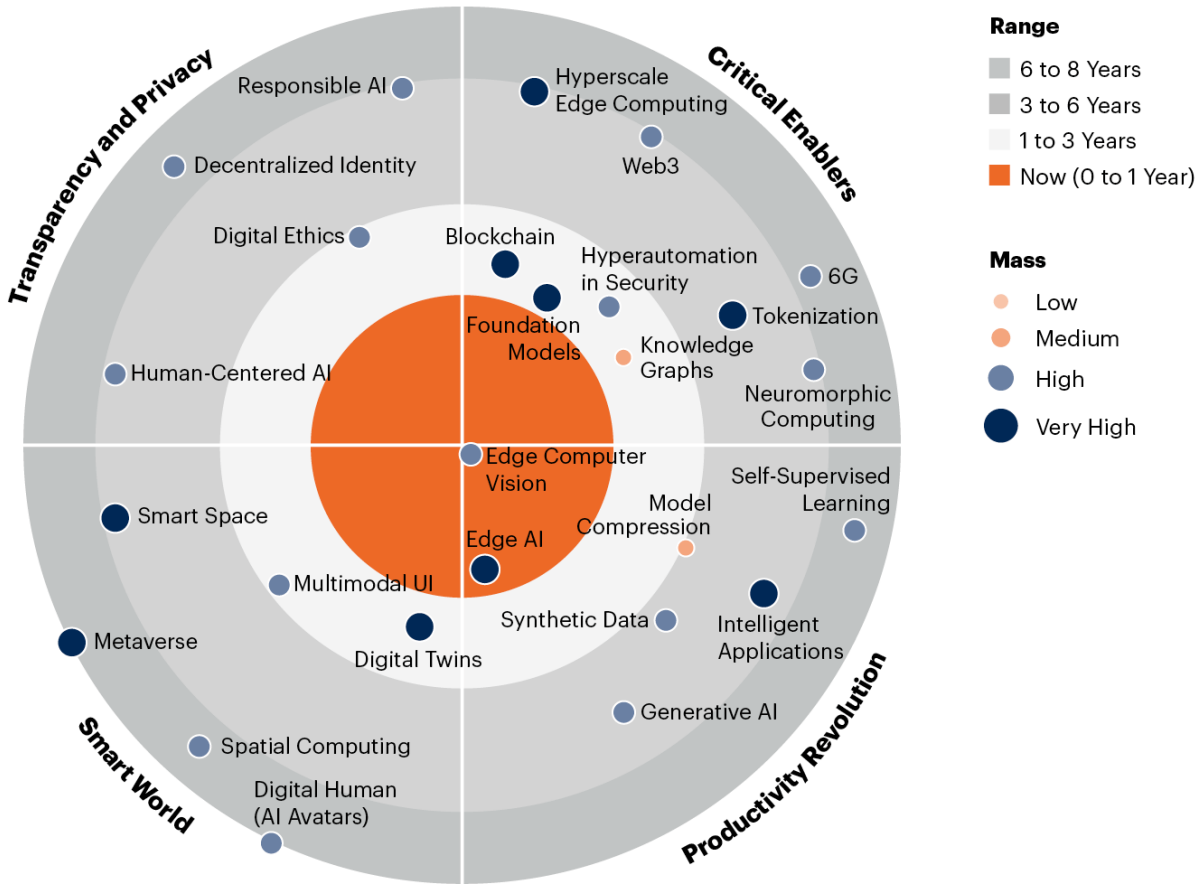

Figure 1. Gartner 2023 Artificial intelligence emerging technologies impact radar (T. Nguyen, 2023)

According to the Global edge AI Software Market Growth research, it is stated that the market of edge AI software is anticipated to increase from $346.5 million alone to around $1.1 billion by 2024, and that the edge AI hardware and the consulting market will also expand at the similar rate (360 Research Reports, 2019). In addition, Grand View Research, predicts that the entire global market of edge computing will expand each year and reach a value of $43.4 billion by 2027 (Grand View Research, 2021). As can be seen from the evaluations and the increasing number of applications, edge AI is taking firm steps forward to be among the common new generation technologies.

HAVELSAN, which is a global leading system integrator firm with advanced technology-based software-intensive original solutions and products in the domains of defense, security, and informatics, produces high-quality D level simulators at world standards, produces high quality flight simulators and training complements for both civil and military aviation, decision support and systems for war games in many fields. With the Forces in Virtual Environment (FIVE), one of the simulators developed by HAVELSAN, the behaviors of virtual platforms for land, air, and sea, which can perform defense and offensive objectives needed for tactical training of simulators of combat platforms, could be modelled and so the required tactical scenarios for simulators can be provided. The FIVE-ML structure has been revealed as a result of the studies on making this autonomous rule-based software built on artificial intelligence learning. Developed to make improvements in the rule-based structure and alleviate some workloads in the system, this system has been developed to work closely with field experts, improve standard and predictable performance, etc. offers advantages with its innovative artificial intelligence infrastructure. In this study, the use of reinforcement learning was preferred, which helps to train multiple actors with a reward-punishment system. Reinforcement learning examines behaviors that create the highest worth of long-term return from the environment (N. D. Nguyen et al., 2017). One of the parts of such an innovative project is the implementation of the edge AI approach. Thanks to the edge AI approach applied, it is aimed to make significant progress by facilitating the management of data.

In this study, after discussing the concepts of edge and edge AI, we will examine the advantages of technology and then the use cases, especially FIVE-ML simulation system developed by HAVELSAN. After that, we will discuss the possible opportunities that can be used in the defense industry and the use of digital twin and edge AI technologies together. We will also present the works planned to be done in the near future and our predictions.

The novelty and contributions of this proposed study are:

- Edge AI technology has been shown to be usable in military projects, taking it from basic to level 2 (in edge co-inference).
- 54% performance increase with the use of edge AI technology.
- The accuracy of hitting the target in simulation system is also increased, with the rate of 34%.
- Edge AI technology and reinforcement learning technique give beneficial results together.

2. Definitions and conceptual basics

In this section, the brief definitions of the technologies that are the basis of the study and that are planned to be used together will be explained.

2.1. Edge computing

In order to decrease the response times and preserve bandwidth, edge computing is defined as a distributed computer paradigm that moves computing and data storage closer to the location where they are needed. Although it may seem contradictory when compared to the cloud systems that are widely used today, the advantages of edge computing could be gathered by using edge and cloud computing together. In edge computing, systems run on local devices, meaning the entire system is not on the cloud (Figure 2). These edge devices can be servers as well as IoT devices. It is seen that especially sensor technologies take place more frequently in our agenda with the developments in robotic technology (Wang et al., 2018). These edge devices transfer data to the cloud to make some special calculations in the cloud when necessary. In other words, some, if not all, of the data and processing load is moved to the cloud.

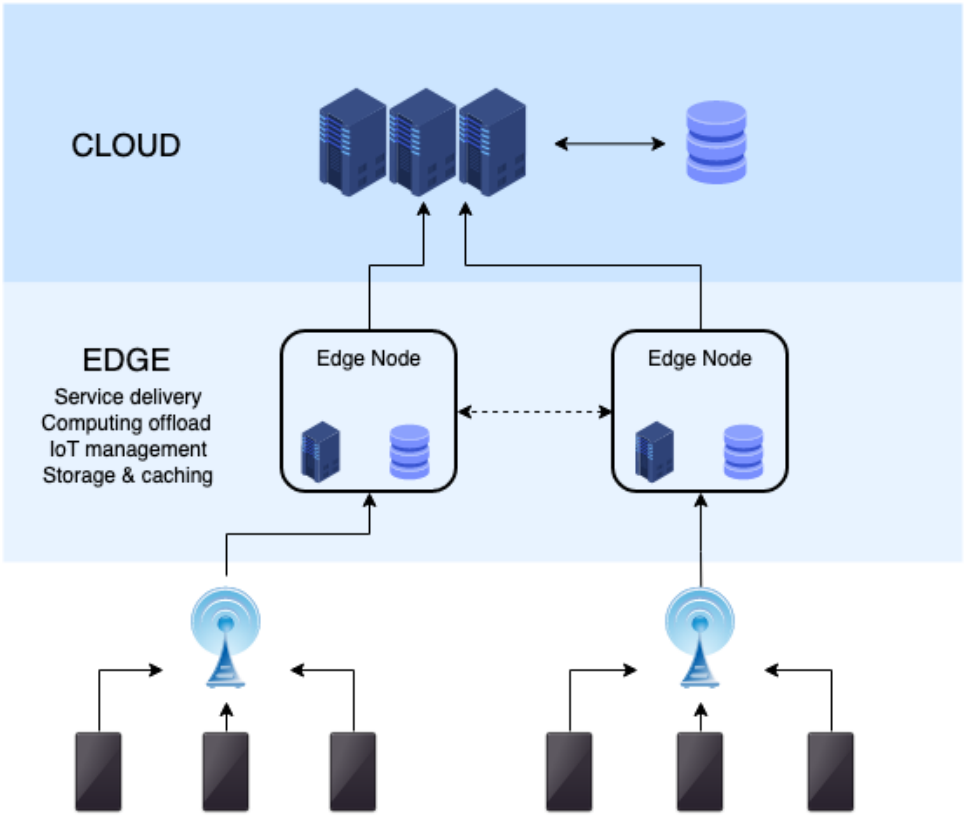

Figure 2. Edge computing infrastructure (Watkinson et al., 2021)

2.2. Artificial intelligence (AI)

Artificial intelligence mentions to the simulation of human intelligence in devices that have been designed to think and act like humans. The notion can also be used to refer to any machine that demonstrates aspects of the human mind, including learning and problem solving.

2.3. Edge artificial intelligence (edge AI)

Data is one of the most important elements for artificial intelligence and big data analysis. In the literature, we see that there are various concepts such as the management of data within channels (Navrat et al., 2004) (Lechtenbörger & Vossen, 2003). With the right data management and the use of emerging technologies successful results are expected to be achieved (Hung et al., 2019). The accuracy and security of the data are key to making the analyzes and simulations accurate and healthy (Van Den Bussche et al., 2005; Senderovich et al., 2019; Karaarslan, 2019).

One of the most remarkable emerging fields in artificial intelligence is called edge AI. In particular, it aims to allow AI processes to run by removing concerns about privacy or slowdown due to data transmission. Edge AI offers an AI approach that allows smart devices to quickly react to inputs that do not have access to the cloud. Most next-generation AI processes are performed in the cloud as they require large amounts of computing power. But there is the problem that these processes are sensitive to downtime. Edge AI systems can process data locally before sending it when an internet connection is established since the systems are running on an edge computing device. This decreases the data processing time. For example, with the use of edge AI, deep learning algorithms can run on the actual device, on the edge where it is located, in case of disconnection from the internet or cloud. Additionally, by limiting data transfer to only the most vital information, the volume of data held in the cloud can be reduced and communication interruptions minimized. Steps followed in a traditional cloud-based data collection and analysis system and edge AI-based systems are expressed in Figure 3. Using edge AI, data analysis can be accelerated as the edge nodes are closer to the data source, reducing backhaul data bandwidth requirements by up to 400x and lowering latency (Nvidia, 2021).

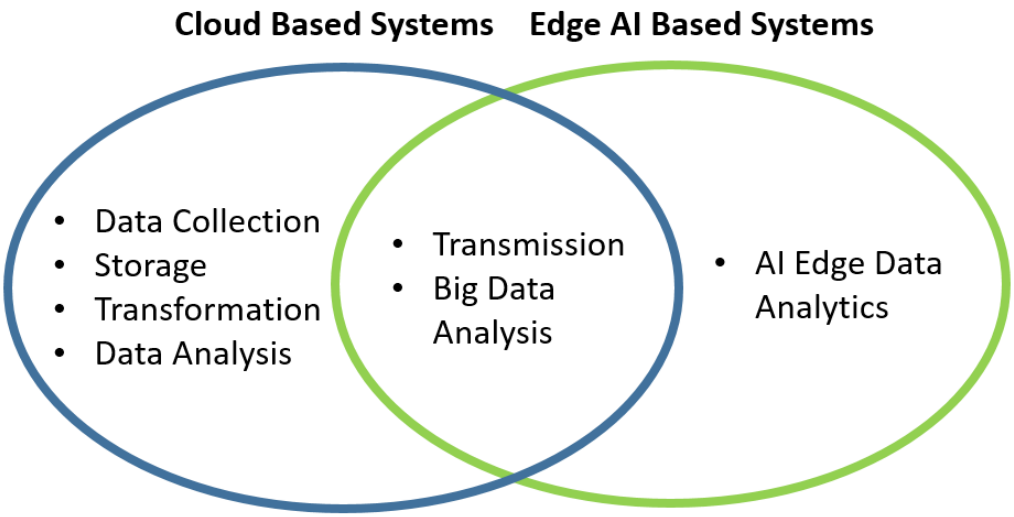

Figure 3. Cloud-based systems and edge ai-based systems comparison

At the bottom of the “Levels of Edge Intelligence” pyramid, we see that there is "cloud intelligence". Here, the infrastructure for training and interface is created. At level-1, the "cloud-edge co-inference" level comes. At this level, only the basic interfaces are covered at the edge. After level-2, we see that the rate of transactions made at the edge is increasing. When we come to level 6, all the operations are performed on the end device (Figure 7).

2.4. Digital twin

The technology called digital twin has a promising future in many disciplines and continues to carry out many studies and research activities, is expressed as a digitally modelled copy of an object/system that exists physically in the earth (Bernard Marr, 2017). With the use of technologies such as sensors and IoT, data/information flow from physical assets to digital assets is provided. In this way, the processes operated on the physical assets are monitored remotely, while at the same time, future predictions can be made with the artificial intelligence infrastructure used.

3. Advantages of the edge ai technology

Edge AI technology offers many advantages in controlling data and optimizing systems. Some prominent advantages are listed below.

- Ability to produce real-time analytics and analyze streaming data
- Security
- Bandwidth savings
- Enables automation
- Reduces costs

Below parts, this advantages will be discussed in detailed way.

3.1. Ability to produce real-time analytics and analyze streaming data

In a fraction of a second, analysis can be finalized. For instance, in the case of self-driving cars, even a one-second delay in brake applying can result in a fatal collision.

3.2. Security

Edge usually runs on a private network, which makes it harder to steal information. Fewer cloud-based data means fewer attack opportunities online, helping to improve security. Also, crashing a network of multiple devices is more difficult than crashing a single central cloud system. In general, it can be said that everything

with a security element should be done using the edge approach. In addition, not being able to access the existing data system in any way without access to the internet connection can also create a security weakness. For example, in autonomous vehicles, it is not desirable to take risks when making a decision when the internet connection is weak, so it is an important technology to be used especially for autonomous vehicles.

3.3. Bandwidth savings

Edge technology could help in saving bandwidth, reducing the requirement for data transfer. Therefore, the devices become more energy-efficient as a result.

3.4. Enables automation

In a self-driving car, for example, there are countless different types of sensors that continuously measure the speed of rotation of the tire and the vehicle position. Based on the gathered information from the sensors, the driving computer can automatically decide how to steer, brake and use the throttle.

3.5. Reduces costs

Large-scale data processing and analysis in the cloud is considered as expensive. When analysing fixed data streams or large amounts of historical data, a lot of capacity has to be purchased from a cloud service, likewise GPU computing, whether a truly quick response is necessary. Sometimes this becomes so expensive that it disrupts business state calculations and can break the system. Although edge AI requires native computing power and good hardware, it still often offers the most cost-effective solution. When examined technically, the decrease in required bandwidth also results in a decrease in the costs of contracted internet service which contributes to cost savings (Paajanen, 2020).

4. Edge ai use cases

Although edge AI is a new field according to many technologies, there are studies in various fields because it appeals to many fields. Many topics cover use cases for edge AI where processing data can be established more efficiently on a local device than via the cloud. Yet, a few examples of typical use cases for edge AI are autonomous vehicles and drones, facial recognition systems, and digital assistants.

Autonomous vehicles are one of the most suitable use cases for edge AI privacy (Yılmaz, 2022). Autonomous vehicles must constantly scan the surrounding environment and assess the situation, adjusting to its trajectory based on nearby events. Processing data in real-time is essential for these situations, and as a result, embedded edge AI systems are responsible for data storage, processing, and analysis. Edge AI systems are essential to bringing tier 3 and 4 (fully autonomous) vehicles to market.

Since autonomous drones are not controlled by human operators; for autonomous vehicles, the requirements are remarkably similar. A drone's loss of control or malfunction during flight could result in a crash and the destruction of lives and property. Drones, on the other hand, can fly very far because they cannot be controlled from within the range of an internet access point, so they must be capable of edge AI. It is predicted that edge AI technology will be essential for providing services such as Amazon Prime Air that aim to deliver packages by drone.

The use of edge AI in facial recognition systems is another instance. Computer vision algorithms are used in facial recognition systems to examine data that are gathered by the camera. Apps for facial recognition that are used for purposes like security must function consistently even when they are not connected to the cloud.

Another typical application for edge AI is digital assistants (Arisoy et al., 2016). Smartphones and other digital devices should be able to use digital assistants like Google Assistant, Alexa, and Siri even when they are not online. When data is processed locally, there is no need to transfer it to the cloud, reducing traffic and preserving privacy.

The number of connected devices collecting data is constantly increasing in modern life. This requires more storage and computational capacity to be brought to the edge and more use of artificial intelligence. Eurotech

combines embedded and edge computers, computing power, and IoT components to enable edge AI. By bringing this high-performance computing capability to the edge, Eurotech enables AI applications directly on field devices. They can autonomously process data and perform machine learning(ML) in the field and apply deep learning models and algorithms for advanced autonomous applications such as autonomous driving. Machine learning is a trustworthy method of looking through a large dataset for undiscovered patterns (Koohestani et al., 2019).

In addition to these, expectations from devices on Edge are increasing. The amount and quality of data are increasing exponentially, and for some applications the need to process them autonomously becomes imperative. An example of an edge AI application is the autonomous driving task, which relies on terabytes of data from HD cameras, Radar, Lidar, and other high-speed sensors that need to be processed in short periods. The capability of deep learning algorithms to perform edge training and inference directly on the vehicle is a must-have for such applications in automotive and industrial environments (Eurotech, 2021).

Today, most of the autonomous vehicles, which have become very common especially in the defense industry, need to process exceeding 50 GB of data per minute in real-time to evaluate driving decisions, and it is usually not enough to transfer all of this data to another server due to its bandwidth capacity. This is particularly a problem in herd intelligence systems. In addition, it creates a technical bottleneck problem in the management of a large number of autonomous vehicles, where the decision mechanism is made from a single-center, or in the creation of digital twins of these vehicles. For this reason, the use of edge AI technology is very appropriate in systems that both allow the use of the cloud structure by reducing the burdens and need to increase the processing capacity at the edges. Looking at ML-based autonomous system applications made from edges, Liang et al. have used reinforcement learning to learn the vehicle networks dynamics to manage network resources.

An internet of vehicles (IoV) system called DeepCrash uses deep learning to detect and report collision events so that urgent notifications could be sent. It indicates a 96% accuracy rate for collision detection and an emergency notification delay of almost 7 seconds (Chang et al., 2019).

Considering a Tesla for its relationship to the cloud as a simple edge computing use case, situational awareness is all that many of the car's sensors and cameras are capable if they can react in near real-time to what they see (other vehicles, trees, traffic). There is no time, delay, or bandwidth to transfer data back to a main public cloud data center. The cloud should be moved aside instead. Therefore, Tesla is not only the latest model of vehicle but also an edge computing node. Tesla's use of this edge AI technology to create and deploy the edge node is just the beginning and more extensive work is expected (Orrin & Chehreh, 2020).

Real-time decision making is necessary for edge AI applications and industrial automation. Hence, in order to be able to respond to urgent problems right away, data analytics must be established on the edge. With the "Everyware Software Framework (ESF)", Eurotech makes edge analytics and data management in field-deployed IoT gateways and computers easier. With the help of the IoT edge architecture, assets may be digitally twinned and managed for sophisticated analytics and data management in a user-friendly and straightforward environment (Tao et al., 2018).

Both hardware and software environments are offered by MediaTek to optimize edge AI performance. Special APU(AI Processing Unit) is created to be more power efficient. With the APU, energy usage can be reduced by up to 95% compared to CPU operation. Second, the task scheduling between CPU, GPU and APU is managed by the heterogeneous runtime in the NeuroPilot software development kit (SDK). It also supports current cutting-edge AI frameworks including NeuroPilot, NNabla and MXNet. Also it supports important design tools like Tensorflow, Caffe that are trained using like these frameworks. Toolchains with model translators in NeuroPilot, programmers can initiate AI implementation on devices (Figure 4). Finally, it offers SDK and libraries to quickly connect PC-based prototyping to edge AI high performance (Lee et al., 2018).

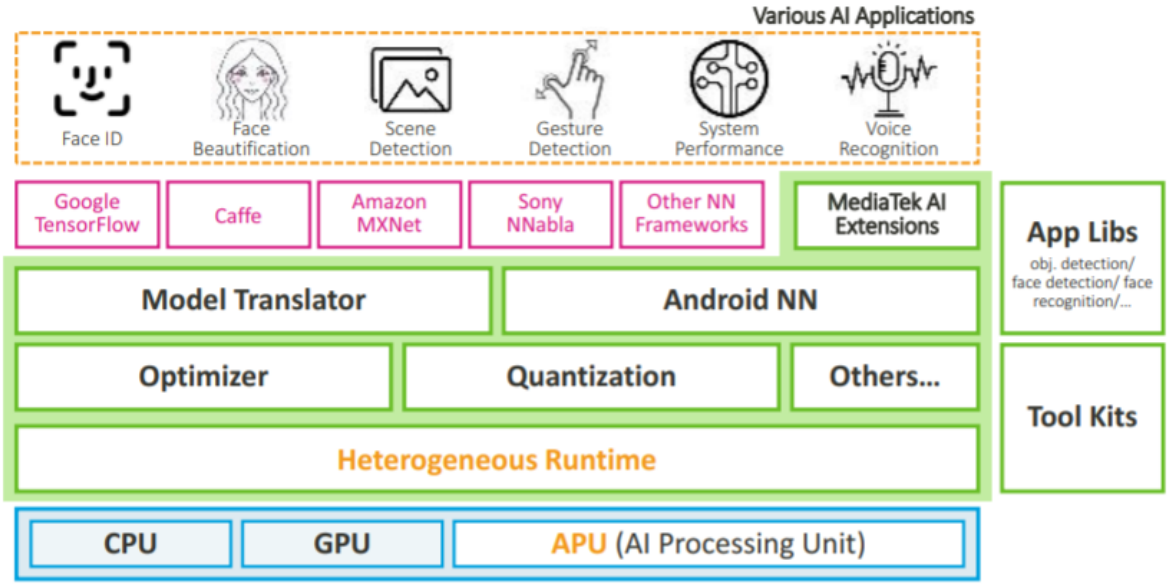

Figure 4. MediaTek neuropilot framework (Lee et al., 2018)

Xilinx has done extensive work over the past 3 years to create a complete end-to-end flow that permits software, hardware developers, and data scientists to utilize the current machine learning ecosystem. According to this approach, they have designed tools, including Caffe and TensorFlow, that enable customers to directly parse the trained weights and model graphs saved from well-known machine learning frameworks. Developed pruning, quantification tools, compiler, run-time, and productive programmable Internet Protocol (IP) that allow networks to be deployed on a variety of platforms, however at the edge, or well-known cloud and server architectures (Figure 5).

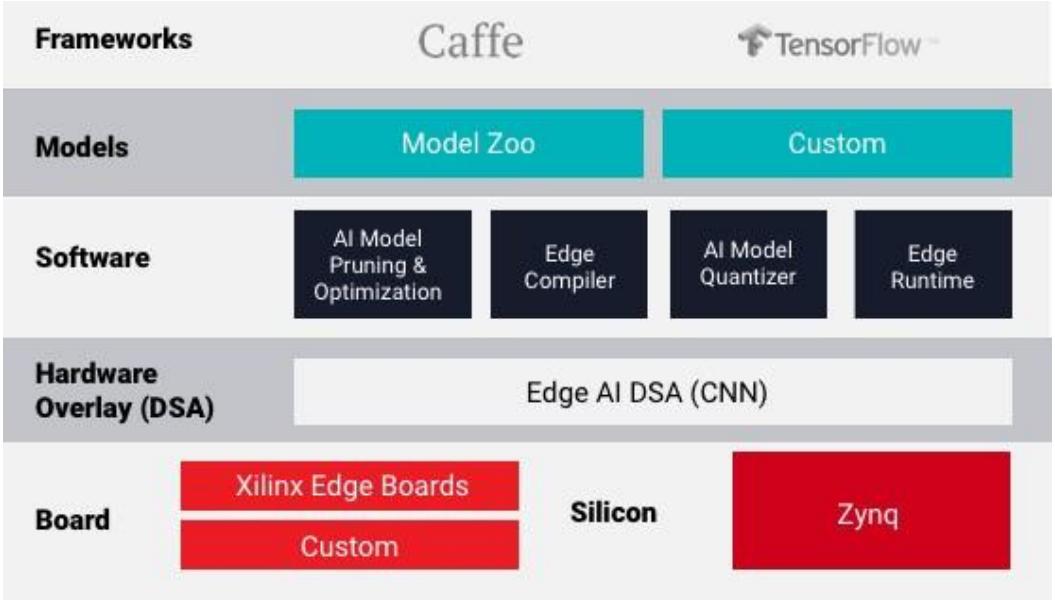

Figure 5. Xilinx edge ai framework structure (Xilinx, 2021)

5. Edge ai in the defense industry

It is expected that the use of edge AI technology in the defense industry will become widespread, especially with the security advantages it provides and increasing system efficiency. As an exemplary edge AI application area in the aviation field, in swarm intelligence systems, it may be possible for each player to make their own decisions regarding their flight planning, but also to give the maneuvers to be made according to the strategies they will follow as a swarm. This could be ensured by the machine learning mechanism on the cloud, and in this case edge, AI will be an intermediate step that can be used to switch to.

We realized one of the best examples of the use of edge AI technology in the defense industry with the FIVE-ML simulation system of HAVELSAN. HAVELSAN, which creates high-quality D-level simulators at global standards, produces high-quality flight simulators, training complements, decision support and systems for war games in many fields for both civil and military aviation. With the Forces in Virtual Environment (FIVE), one of the simulators created by HAVELSAN, the behaviors of virtual land, air, and sea platforms, which can establish defense and offensive objectives needed for tactical training of simulators of combat platforms, can be modelled and therefore, the required tactical environments for simulators can be provided. The FIVE-ML structure has been revealed as a result of the studies on making this autonomous rule-based software based on learning artificial intelligence. Developed to make improvements in the rule-based structure and alleviate some workloads in the system, this system has been developed to work closely with field experts, improve standard and predictable performance, etc. offers advantages with its innovative artificial intelligence infrastructure. In this study, the use of reinforcement learning was preferred, which helps to train multiple actors with a reward-punishment system.

Learning what to do and how to match situations with actions to maximize a digital reward signal is called reinforcement learning. To find out, the agent is not informed about the course of action but is rather asked to identify actions that are the most rewarding. In this discovery process, almost every possibility is tried and the most appropriate behavior is learned. But there is a very long and heavy processing load with too many parameters in it. For example, we train a model with reinforcement learning on a simulation or the behavior of a device. When we think that we are training this model in the cloud, there is a case of moving a lot of data to the cloud from devices during the training of the model. In this case, the bandwidth problem arises. In addition, as a result of printing all data to the cloud, information security vulnerability may occur in military simulations. Generally, the principle of not removing military data from the working environment is followed. For this reason, it is preferred not to be presented to the cloud environment, which is an environment open to many attacks. However, in the case of using the cloud, it is necessary to take high-security measures or use a secure cloud infrastructure developed specifically for that institution. In order to meet such requirements, each institution needs to develop and secure its own cloud infrastructure. This can also be very costly to do. Instead, edge AI technology can be used to create an environment that meets the desired standards with minimal tradeoffs.

Many artificial intelligence modules can be run on edges, as well as reinforcement learning modules, many of which may require expensive and high hardware with the training process.

Edge AI, which emerged with the reinforcement of artificial intelligence-based studies using edge technology, is also used for FIVE-ML performed using reinforcement learning (Figure 6). Especially in the method used in FIVE, while the players are being trained, the subsystems on the player, the number and types of ammunition, etc. many parameters are used. While many parameters flow instantly to the system/model in long-term training, it creates certain data traffic. In case the model is kept completely in the cloud, there is an additional process of processing the data coming to the edge and transferring it to the cloud. As a result of moving the machine learning system made in the cloud to the edge, the amount of data in the cloud is reduced. The latency and reduction in network traffic caused by this transmission offer the advantages of moving military projects and model data to the edge where data security can be more easily ensured.

Similarly, a safer and more efficient approach can be followed with the use of edge AI in terms of ensuring data security and minimizing the bandwidth requirement of digital twins used in the military field. Similarly, Tesla uses the edge principle to create a digital twin of each vehicle (Orrin & Chehreh, 2020).

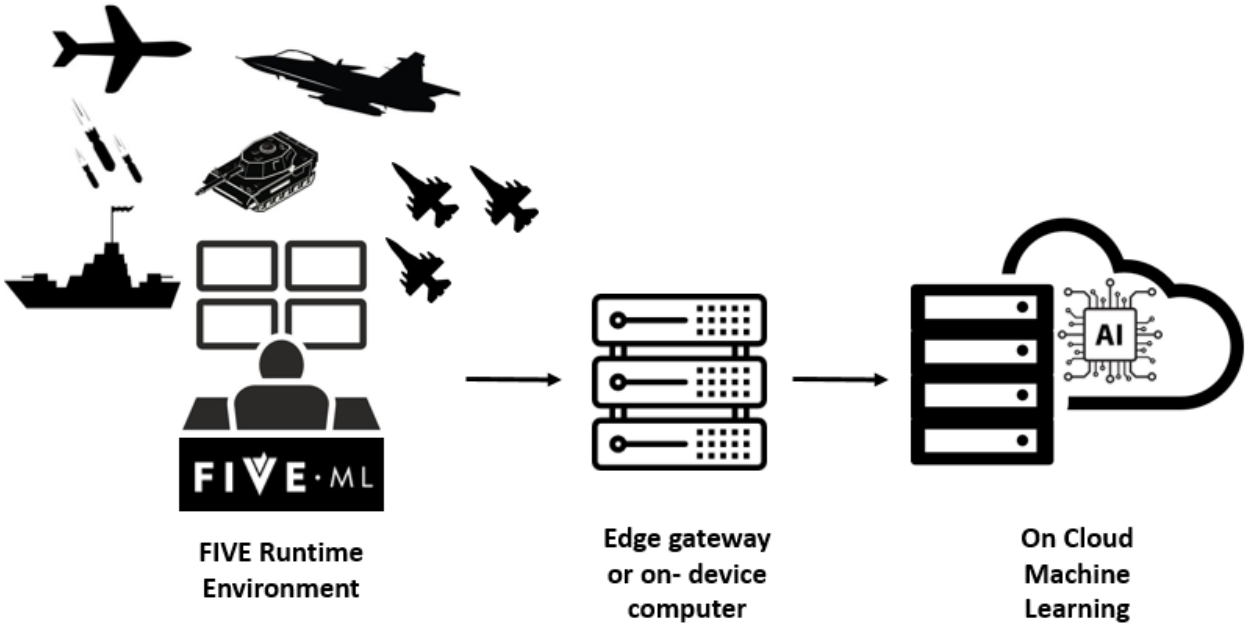

Figure 6. FIVE-ML edge ai structure

6. Discussions

Although edge computing is a one of the latest versions of technology, the world's giant software companies continue their investments in this field without slowing down. Some important examples are Amazon and Google. Thinking that taking the lead and investing in these technologies is the only way to stay competitive, these companies also consider that increasing demand for IoT devices will encourage the use of 5G, Edge computing, and edge AI technologies. Gartner highlighted technology providers that are improving and accelerating the use of edge AI in its 2020 "Emerging technologies: Tech Innovators in Edge AI" report. The report includes Atos as an edge AI Technology Innovator for his work in this field (Atos, 2020).

Edge AI will be more useful as a result of the rollout of 5G technology networks, which will result in faster and very low latency mobile data transfer. The launch of 5G-based edge solutions from IBM and Red Hat will help businesses more easily manage workloads across numerous devices from various vendors, aiming to serve their customers quickly, providing the agility the telecommunications sector needs. Additionally, there will be high potential to use edge AI technology in the image and video analysis, creating responses to audio-visual stimuli or in-the-moment recognition of scenes and areas, for instance, on smartphones (Satyanarayanan & Davies, 2019). Edge AI technology will also cut costs and increase security in terms of Industrial IoT (IIoT). Artificial intelligence will monitor machines for any possible glitches or mistakes in the production chain, and their use will become widespread with digital twins.

The FIVE-ML simulation system is one of the exemplary projects where Edge AI technology is used, especially in the field of defense. When we look at the edge levelling (See Figure 7 for details of levels) in the study, it is seen that the works done in FIVE-ML, are at the level of 2. Predominantly, education is carried out in a single-center, and partially at the edges. It will be in the direction of bringing this level to level 3-4 with the improvement of the current system.

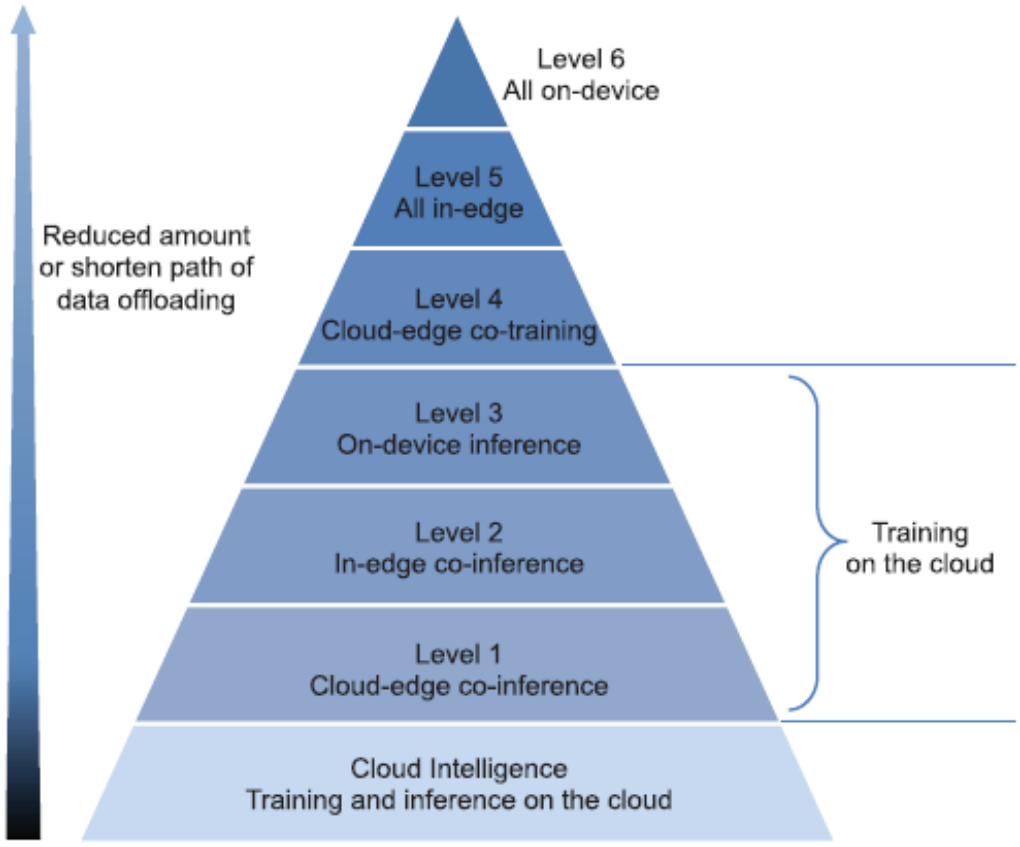

Figure 7. Levels of edge intelligence (Zhou et al., 2019)

The focus of the study is on air to air and air to ground engagement scenarios with up to six virtual entities. Three friendly and three hostile entities are featured in the scenarios (Figure 8). Two of the three friend entities are under the control of RL-based behavior models. The current HAVELSAN rule-based behaviour rules law the other entities. It can be seen that RL-based entities perform better than HAVELSAN rule-based entities in the same starting position scenarios. These experiments also demonstrate that using supervised learning as an initial point for RL significantly reduces training time and results in more realistic behavior models. The rule-based HAVELSAN rules that are currently in use are used to train the supervised learning models.

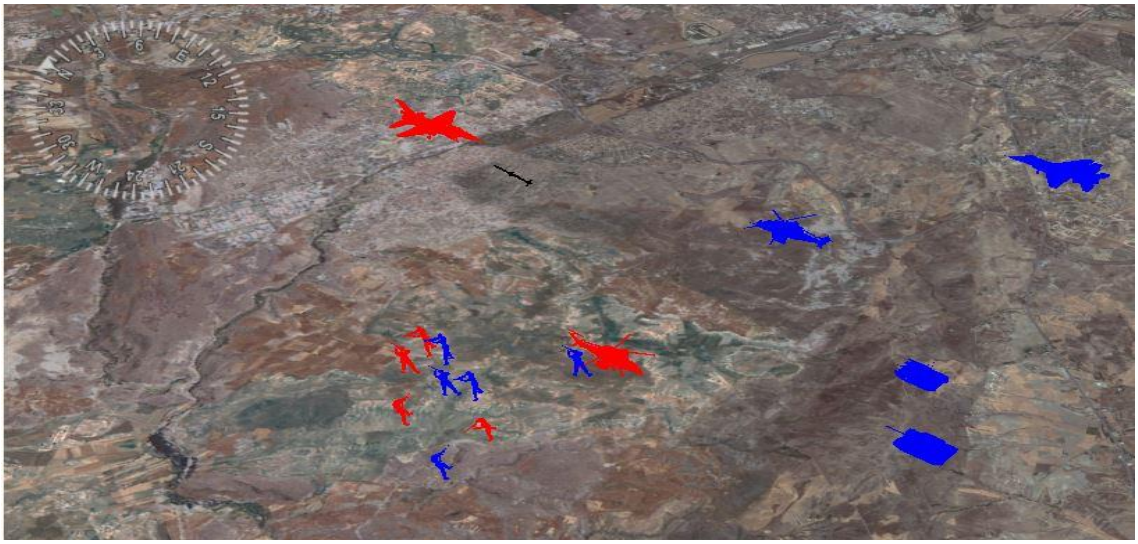

Figure 8. A screenshot of air and ground platforms from FIVE-ML

The score values obtained from the air-ground scenario in the FIVE-ML study carried out using reinforcement learning are shown in Fig. 9. The point values here are obtained from the calculation of the penalty and reward

values obtained at the end of the section. For example, hitting an enemy target is a reward, while hitting friendly forces is considered a punishment. FIVE-ML may open the way for decision support systems that can be applied in the real-world operation environment. Totally 34% increase of the pointing the correct target is gathered. It is also anticipated that it will be actively used as a military and strategic decision support system.

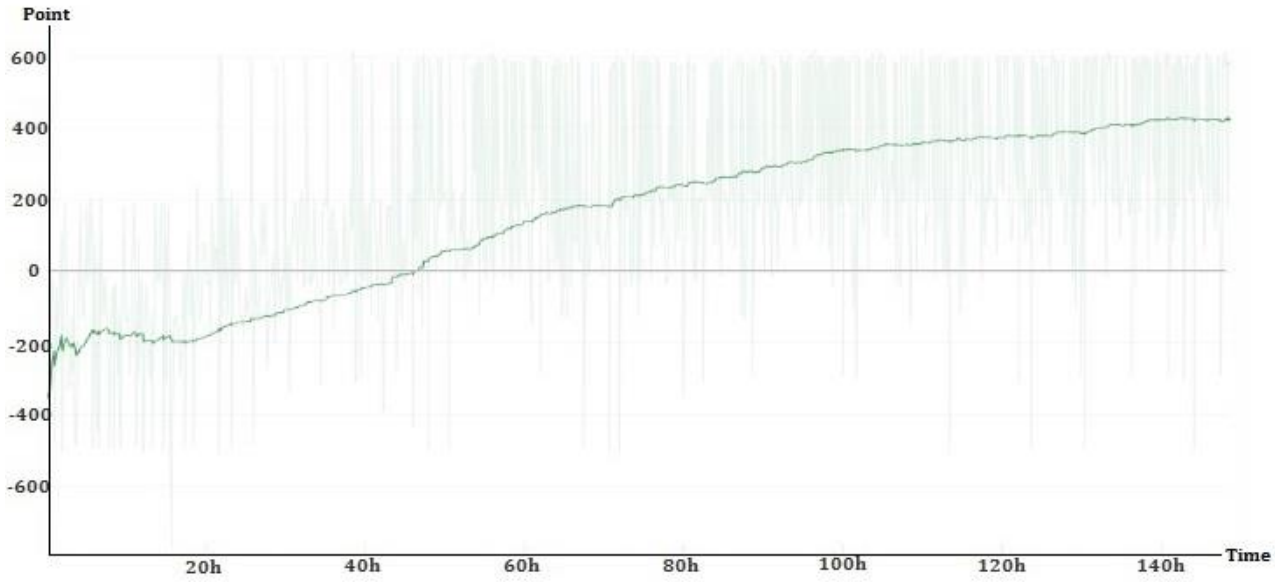

Figure 9. RL training score curve for air-to-ground scenario in FIVE-ML

The reinforcement machine learning technique was used in FIVE-ML. When evaluated according to the transition levels to edge intelligence, it has been determined that the current work is at the 2nd level and there is a 54% performance increase in terms of time with accuracy through edge AI. Reinforcement learning is a technology that is likely to be used in decision support systems, which will gain even more importance in the future, and in decision support systems where instant decision making and high performance are critical, studies can be made to improve performance in instant transactions with edge AI.

The positive developments we have achieved in this study encourage us to take our work further. One of the most important technologies to be used together with edge AI technology is digital twin technology. Digital twins are digital versions of a real-world entity that can be used for a variety of purposes, such as simulating the physical entity's behaviour, are typically located in the cloud and are protected in the cloud and facilitated with information from devices or simulations in the field. Digital twins are used to understand and predict former and current operations, utilizing machine learning techniques for failure prediction, condition monitoring and anomaly detection. There are two ways to use reinforcement learning in digital twins. First, reinforcement learning can be used as well as supervised learning to analyze data from digital twins and create optimization recommendations for twin-owning entities or systems. As a second use, studies could be made to use digital twins of assets trained using reinforcement learning.

In the past, edge devices were primarily used for data collection and basic calculations, while edge computing offers advanced calculations and cloud-powered analytics at the edge that enable faster and local decision-making. The new real-time AI applications will be possible once the digital twin is moved to the edge. Its advantages are described under three main headings: low latency, closed-loop integration of analytics and local control, and rapid development of the digital twin.

6.1. Lower latency

In some cases, round-trip delays to the cloud can become unacceptable. Applications that require sub-second delays are possible with the digital twin executed on the Edges. For example, when danger is detected or predicted by the digital twin analytics, device protection functions can be initiated instantly.

6.2. Closed-loop integration of analytics and local control

The data and analytical values produced by the digital twin can orient local control. This helps enable proactive control applications that result in autonomous operation. For example, a predicted critical anomaly can be mitigated without human intervention.

7. Future studies

Using approaches such as online machine learning and real-time reinforcement learning in the data flow, the digital twin is constantly self-learning and evolving. This is ensured by optimized system operation and devices that adjust themselves to situations. For example, by learning and developing its digital twin at the edge, a grid-connected power device can extract optimum operational or control parameters for maximum output without affecting grid stability.

While the use of digital twins has many advantages, there are also business advantages to running digital twins at the edge rather than the cloud.

- Provides lower cloud hosting costs. Normally it can be expensive to send all data to the cloud for storage and analysis. Even sending a certain amount of data instead of all data helps to reduce costs on a large scale.

- Data preprocessing reduces the volume of data transmitted to the cloud. Before the data is sent to the cloud, it is necessary to make the data available in the cloud through various pre-processes. In digital twins, multiple data flows from many sensor sources to the cloud. In addition, many data are related to each other and are in communication. While this is the case with physical devices, the situation is similar for twins in the digital environment. For this reason, the data should be sent in appropriate formats so that they can work in harmony with each other. In addition, the use of edge technology reduces the amount of data transferred to the cloud, resulting in a lower bandwidth requirement.

- Sensitive data does not need to be sent to the cloud. Sending all commercial or national confidential data to the cloud by companies and even countries can cause problems in case of any attack. For this reason, keeping critical data at the edges instead of being exposed to the cloud has an important place in facilitating the protection of sensitive data.

- With increased durability, operations at the edges can be performed smoothly even when the digital twin is disconnected.

Running edge AI applications and algorithms directly on field devices requires computational and processing capacity, making it an effective use case for machine learning and deep learning. The volume of data gathered by field assets is escalating rapidly. Edge AI applications are made possible by machine learning and deep learning for better, real-time management of this data. As a result, edge nodes are created where data can be stored, processed, and filtered before being sent to the cloud for additional processing, analysis and integration with different applications.
The widespread use of edge AI technology helps to solve the problem of transferring large amounts of data in digital twins from the physical asset to the digital twin of the asset, filtering certain data and partially printing it into the cloud. With the widespread use of edge AI technology, it will be easier to implement systems using digital twin technology. It is predicted that there will be an increase in studies conducted in direct proportion to this.

8. Conclusion

Although edge AI technology is a new technology, its prevalence is increasing day by day and it is a technology that many companies invest in. In addition, the most important factor that helps the spread of this technology is that innovative and rising technologies such as IoT, IIoT, digital twin, and 5G facilitate the application areas and become widespread with these technologies. Therefore, it will be possible to see edge AI-based technology applications in the future. It is expected to be used not only in the civil field but also in the military field due to the cost, time, and security advantages it provides. It is aimed to take the edge AI technology level in the

FIVE-ML simulation system further from its current situation in the future, so that it is planned to benefit from the benefits offered by this technology such as gaining the cost advantage and increasing the security level at a higher level. The advantages offered by digital twin technology are brilliant, but the disadvantages will be eliminated with edge AI. Thus, the level of maturity of the technology will increase even more and the number of applications in this field will increase.

Author contribution

The author is responsible for designing the study, establishing research methods, applying and concluding theoretical theories.

Declaration of ethical code

The author of this article declares that the materials and methods used in this study do not require ethical committee approval and/or legal-specific permission.

Conflicts of interest

The author declares that there is no conflict of interest.

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