Contribution

The Past and Present of AI and Prospects in Manufacture

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AI is now said to be in the third boom. In this article, the author first gives an overview of the history of AI up to the present Deep Learning. Next, Deep Learning, which is currently undergoing rapid development, focusing on the expansion of that area is introduced. Then, the author introduces new issues and hot topics arisen with the significant development of Deep Learning, such as ethical issues, explanations and safety issues. In addition, the problems of human resources for AI development with the expansion of application areas is discussed. Lastly, based on the above, the author will state the prospects of AI in the manufacturing industry.

1. Introduction

AI (Artificial intelligence) has been a topic of discussion in the general public and mass media since around 2015. In 2016, the AI software for the game of Go "AlphaGo," developed by Google DeepMind beat the top human Go player, which became a bit of a sensation at the time[1]. That software uses a technology called deep learning. While the excessive hype of media coverage has calmed down, today, AI is steadily making strides into various industrial sectors with expectation of increasing productivity.

2. History of AI: 3 booms and "winter times"[1]

2.1 What is an AI?

In general, AI is described as a research and technology field with the objective of realizing computer programs with the "ability to recognize the external world, learn from the experience, think with acquired knowledge and behave or have a conversation just as humans do." However, the exact definition of AI is controversial among researchers, because there is no clear answer to the fundamental question of "what is an intelligence?" In addition, "what is an AI?" changes over time, too. For example, in the late 1960s, when adoption of character recognition in commercial use started, automatic recognition for postal codes was called an AI.

Research of AI can be categorized broadly into two directions:

1) Engineering technology development to realize the intelligent processing functions in the computer
2) Research for gaining insight in human intelligent behavior and brain functions by realizing the intelligent processing function in the computer

What the public at large talks about and expects most is the AI of the above 1) Engineering achievement of intelligent functions. Among different areas of AI, deep learning has proven to achieve high accuracy especially in recognition and identification.

2.2 History of AI

(1) Dawn of AI (-1956)

When the world's first computer ENIAC was developed in 1946, research for a "machine to perform human intelligent activities" started. In this period, artificial neuron (mathematical model on transmission of electrical signal of nervous cells) was proposed by W. McCullouch and W. Pitts and a program playing chess was developed by C. Shannon and A. Turing. In 1956, the research area on computers performing intelligent activities was named "Artificial Intelligence" in the "Dartmouth Conference" organized by J. McCarthy and others.

(2) Search/reasoning: The first boom (1957-1960s)

It was an extraordinary accomplishment, during this period, that a computer could deal with even the slightest intelligent activity as it had only been able to do calculations before. At that time, AI was converting objects into explicit symbols, then used logic for search and reasoning. Automatic mathematical theorem proving was one of the research areas. However, in 1969, the "Frame Problem," the largest technical difficulty, was raised by J. McCarthy and J. Hayes. The frame problem describes an issue that a computer cannot deal with all the possibilities that potentially arise in real life since it only has limited information processing capability (actually, current deep learning has not fundamentally resolved the "Frame Problem," yet).

(3) Winter time ① (1970s)

It became clear that the approach of search and reasoning based on the symbols in the 60s was only effective in toy problems (toy problems such as a building block puzzle called Tower of Hanoi) with clear rules and small magnitude but not with real-life problems. One of the reasons was that the AI programs did not have knowledge of the objects and the second reason was that the computers were still not powerful enough to solve large-scale problems within a practical time frame. Therefore, the fervor of research was gradually diminished.

(4) Time of knowledge: The second boom (1980s)

During this period, researchers were focusing on handling real-life problems by incorporating knowledge of the objects into computers. They were called "expert systems" as they were dedicated systems for individual problems. Many commercial expert systems were developed. In Japan, with the leadership of the Ministry of International Trade and Industry (currently, Ministry of Economy, Trade and Industry) the fifth-generation computer development project (ICOT) started in 1982 with different development projects of expert systems and reasoning systems using symbols based on them.

The principal player of the second boom was the expert system. However, research of artificial neurons, which was one of the areas that opened the field of artificial intelligence research also made good progress with the introduction of Multi-Layer Perceptron. Character recognition through neural network also developed in the late 1980s to the 1990s. This was the period when the foundation of the current deep learning was built.

The former approach of knowledge processing based on the symbols represented by the expert system is called "symbolism" and the latter approach of computing mechanism based on the multi-layer perceptron and the numerical values of neural network is called "connectionism." Both of these contrasting approaches led their respective times.

(5) Winter time ② (1990s-2000s)

The boom of the expert system gradually dwindled down due to its limitation of describing knowledge base and complexity of maintaining and updating extensive data. On the other hand, in Japan, the internet was connected for the first time in 1984 and the www (World-wide web) and communication environment drastically evolved in the 1990s. As massive information crossed over the web, research of data mining (technology to discover (mining) useful knowledge from a large amount of data) and image/information retrieval was very heavily conducted. In addition, statistical machine learning based on mathematical and statistical theories such as probability/statistics and mathematical optimization developed.

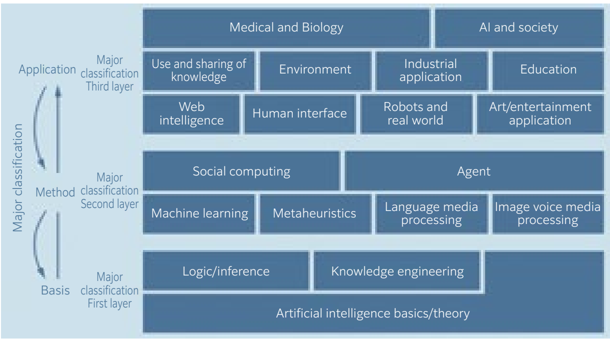
(6) Period of data and learning: The third boom (2013-present)

The period from 2013 to present is called the time of "Learning" by deep learning based on big data. Deep learning is being achieved from the integration of connectionism that has been inherited from the continuing research and mathematical foundation of statistical machine learning being developed in the 1990s and 2000s, as well as availability of storage with the capability of storing and processing massive data and high-speed computing capability leveraged by a GPU (Graphic Processing Unit).

2.3 Overview of AI field

Fig. 1 is an extract of the Overview of AI research for beginners and interdisciplinary researchers "AI Map β 2.0"[2] which was published in June 2020 by the Japanese Society for Artificial Intelligence. The website of the Japanese Society for Artificial Intelligence shows 4 detailed maps from different perspectives, so please review them if you are interested.

The first layer in **Fig. 1**, foundation, shows that AI is built on the broad foundational scientific studies such as mathematics, logic, cognitive science, brain science and psychology. Then, AI's own foundation includes logic, inference and knowledge engineering. In the second layer, on top of the first layer, machine learning including deep learning as the foundational technology related more tightly with applications, language and image/voice media processing are found. The research areas located in the upper side within the second layer are the foundational areas closer to applications. Then the most upper layer, the third layer is the application area and shows robots and real world, medical/biology, education, etc. however, the application fields of AI is, recently, drastically expanding.



(Source: The Japanese Society for Artificial Intelligence "AI Map β 2.0 (June, 2020)"[2]
This figure is an English translation of the Japanese version of AI Map β 2.0.)

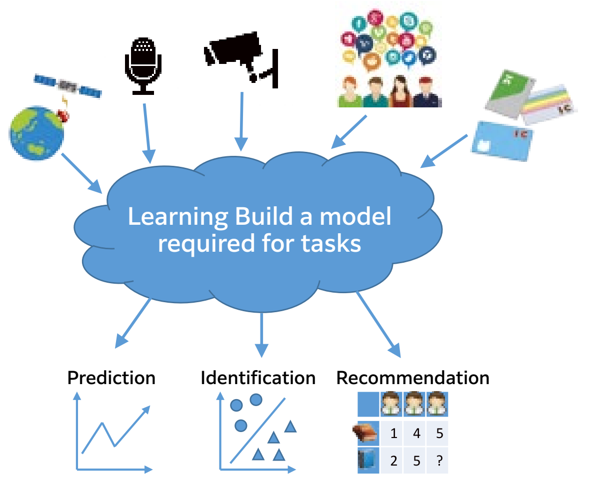
Fig. 1 Development from basic research to methods and applications

3. Present status of AI: period of big data and learning[1)]

3.1 What is machine learning?

Machine learning refers to the overall technologies to have computers acquire learning ability. Learning is, simply put, the ability to handle various tasks well based on past experience and data. For example, becoming proficient at catching a ball by predicting the trajectory after playing catch many times. Therefore, machine learning is a technology for inference and prediction by studying principles from experience and observation. Machine learning is broadly used today, in medical diagnosis, recommendation systems, spam filters, prediction of financial markets, classification of DNA sequences, pattern recognition such as voice recognition and character recognition, games such as shogi (Japanese chess) and most recently, automated driving **(Fig. 2)**.

Today, the mainstream machine learning acquired functions to conduct tasks such as identification and prediction from data. If the desired output is y for the input x, then machine learning acquires the mapping function $c{:}x \longmapsto y$ from the training data. Since acquiring a true mapping function from the limited amount of training data is impossible, in practice, parameters of such function are adjusted to obtain the desired output by, for example, limiting the form of function or placing certain assumptions. This parameter adjustment of functions is called "learning." Parameter adjustment for the training data which was used to acquire functions is relatively easy if the degree of freedom of function is increased; however, for new unknown data, this adjustment does not work well and is likely to fall into overfitting. One of the challenges of machine learning is how to reduce overfitting and increase generalization performance for unknown data and various technologies are being developed.



(Source: Introduction to learning how to use AI through Python[1)])

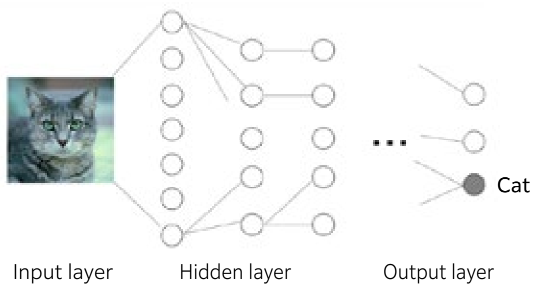
Fig. 2 Machine learning used in various applications

3.2 What is deep learning?

Deep learning is a general name for a neural network with many layers. Originally, the neural network was a model of transmission of electrical signals of neural cells. However, today it is used as a type of machine learning to learn mapping functions corresponding to various tasks. **Fig. 3** is an example of a typical neural network of a task to identify an animal in an image. In the learning stage, many images of various animals are used and the weight between neurons in the hidden layer is adjusted so that only the neuron in the output layer corresponding to cats (gray dot) responds strongly when an image of a cat is input. Conventionally, learning of a neural network with a deep hidden layer was difficult, however, with the recent evolution of various mathematical optimization techniques and development of computers, learning of the network in deeper layers is now possible.

With deeper layers, various expressions can be acquired inside the network. Before deep learning, experts in different fields had to design input features well, however, with deep learning, it is possible for the network to learn features even when raw data is directly input into the neural network. This technology of learning features of the object problems from data is called "feature learning." When training data can be massively collected, this high feature learning ability can be maximized, so deep learning currently shows extraordinary accuracy in identifying images and voices.

In addition, **Fig. 3** depicts a simple overlay of networks of full connectivity, however, various network structures have been recently created by configuring neurons with various functions and exploring different connectivity of networks. For example, there are Convolutional Neural Networks (CNN) which leverage space information such as images and Recurrent Neural Networks (RNN) which learn change in temporal sequence.



(Source: Introduction to learning how to use AI through Python[1)])

Fig. 3 Typical pattern of image recognition by deep learning

3.3 Development of deep learning

Deep learning started to attract attention when it broke the record of the conventional classification performance with a significant margin at international competitions of image recognition in 2012 and 2013. **Fig. 4** shows the championship records of ImageNet Large Scale Visual Recognition Challenge (ILSVRC)[3] held from 2010 to 2017. ILSVRC is a large-scale problem of classifying around 14 million images into 20,000 classes. Until 2011, a method combining the conventional image processing and machine learning was winning, however, since the appearance of deep learning in 2012, classification errors have been drastically decreased year over year. A classification error of a human being for classification by visual identification is said to be around 5 %. Deep learning has been exceeding the average human classification since 2015.

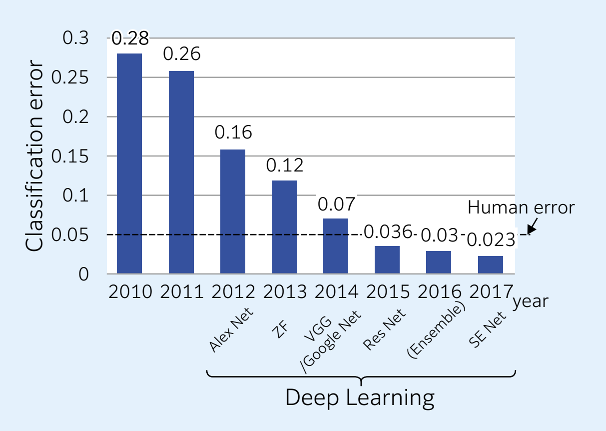


Fig. 4 Championship Record of ImageNet Large Scale Visual Recognition Challenge (ILSVRC)

Deep learning initially attracted attention in the field of image recognition. Then from 2014 to 2016, its application range expanded into "action" from "recognition," such as general game playing, AI go and automated driving through Deep Q-Network (DQN), which combines deep learning with Reinforcement Learning. In 2016, when "AlphaGo" developed by Google DeepMind beat the go champion, that news grabbed headlines. From 2016 to 2018, natural language processing (field of processing languages) also made significant progress thanks to deep learning. Conventional automated translation that used statistical model with bilingual corpus was replaced with deep learning, which drastically improved translation accuracy.

In addition, the invention of the network called Generative Adversarial Network (GAN), with which two networks learn from each other, enabled "generation" and "imitation" and its application range has been recently expanding to creative fields such as art. A famous example is the successful generation of a masterpiece of the famous Dutch artist of the 17th century, Rembrandt, by learning his painting style through "The Next Rembrandt"[4], a project led by Microsoft. In Japan, the singing voice of Hibari Misora, who passed away 30 years ago, was recreated and featured on a TV program, NHK's Kohaku Utagassen[5] in 2019 and a new manga (comic book) production of Osamu Tezuka (also passed away over 30 years ago), "Phaedo" was published as a result of collaboration between AI and human artists in February 2020, through a project called "TEZUKA 2020."[6] [7]

4. Future of AI: a thought on the outlook in the manufacturing industry from the front line of research

4.1 Issue of ethics

The evolution of AI, especially that of deep learning is tremendous as we have seen in Chapter 3. Those technologies are put into practice in many industrial fields. In order to prevent unforeseen circumstances, discussions on the ethical aspect of R&D and utilization of AI are taking place throughout the world.

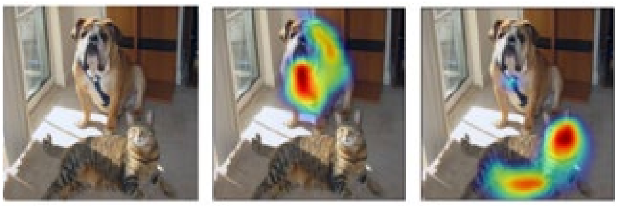
In Japan, the Ethics Committee was established in the Japanese Society for Artificial Intelligence in 2014 and the "Japanese Society for Artificial Intelligence Ethical Guidelines" was released in 2017.[8] It lists 9 articles, namely, 1. Contribution to humanity, 2. Abidance of laws and regulations, 3. Respect for the privacy of others, 4. Fairness, 5. Security, 6. Act with integrity, 7. Accountability and Social Responsibility, 8. Communication with society and self-development, and 9. Abidance of ethics guidelines by AI. In addition, "AI R&D Guidelines"[9] was released in July, 2017 by the Ministry of Internal Affairs and Communications for developers, "Social Principles of Human-Centric AI"[10] was released in March, 2019 by the Cabinet Office for users and policy makers, and "AI Utilization Guidelines" [11] was released in August, 2019 by the Ministry of Internal Affairs and Communications for all parties including consumers.

Among those guidelines, technical research on fairness has recently been picking up steam. In 2018, AI conducted the hiring process, after learning past resumes and the successful/unsuccessful results of applicants. As a result, AI rejected female applicants for engineering positions through the review process, as the engineering positions are mainly occupied by male workers. This happened because the training data was biased. Therefore, research on technologies to fairly handle the socially sensitive attributes are now being conducted.

4.2 Issue of explainability

Importance of the ability to explain the "basis of decision" is increasing as AI is being introduced in various fields. Current mainstream deep learning consists of several millions and tens of millions of parameters making it impossible for human beings to explore the basis of decision by manually analyzing the model that AI used for learning. Explainability is one of the challenges critical for introduction of AI, as a lack of explanation for the decision-making process can often be a barrier of introduction.

The research area to add explainability to AI is called XAI (eXplainable AI) and it is very active in the field of image recognition[12]. For example, **Fig. 5** (a) shows a dog and a cat and **Fig. 5** (b) highlights the area when a "dog" is focused on in the trained deep learning model. Accordingly, **Fig. 5** (c) highlights the area when a "cat" is focused on. In principle, gradation is applied on the image based on the calculation of the gradient of output response when input pixels are slightly manipulated.



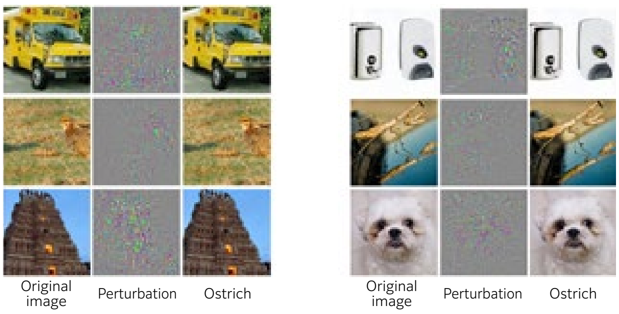
(a) Original image (b) Focused area for dog (c) Focused area for cat

(Source: International Journal of Computer Vision[13])

Fig. 5 Visualization example of attractive areas in deep learning with Grad-CAM

4.3 Issue of security

In 2013, it was pointed out that the identified result of the trained deep learning model could intentionally be altered. This leads to the risk of misinterpretation of traffic signs and "impersonation" in face recognition. This is called an Adversarial example, Adversarial attack and Adversarial perturbation. For example, **Fig. 6** shows that when a special perturbation (in the middle) is added to the image input to the trained deep learning model (left side), all the images (right side) are identified as an "ostrich" even if they look the same as the input images. Defense technologies against adversarial attacks are also being researched/suggested, however, they are only symptomatic treatment for each case, not fundamental solutions. It is expected that fundamental defense technologies will be developed.



(Source: Cornell University arXiv[14])

Fig. 6 Example of adversarial attack

4.4 Limitation of current AI

In 2016, an automated driving vehicle had an accident colliding with a trailer. It was explained that AI could not recognize the trailer as the sunlight reflected on its white body. In addition, from 2008 to 2015, a service to estimate the outbreak of influenza from search words was provided, however, it overestimated the actual outbreak by more than 50 %. These problems were caused by the fundamental issue that the current machine learning is based on the inductive approach where laws are obtained from past data. It works well for the "interpolated" cases closer to the past data, but not at all for the "extrapolated" cases not present in the past data.

Research of refinement in operation is being pursued but another direction is to incorporate existing theories into machine learning. Collaboration with physics which has a robust theory background is gradually increasing under the names of Theory-guided Data Science and Physics-informed Machine Learning. Our group is also looking into this area, collaborating with experts of meteorology, to forecast the wind in the upper troposphere. We are proposing deep learning for outputting the forecast by decomposing the components based on the equation and the residual components[15] **(Fig. 7)**.

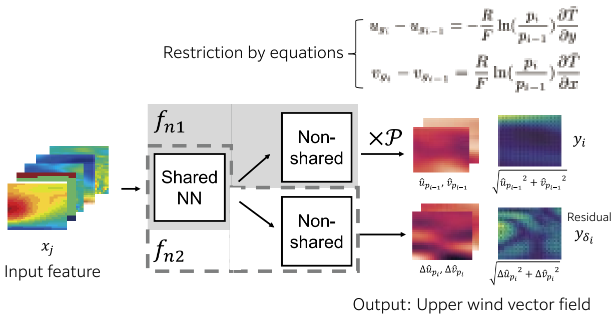


Fig. 7 Deep learning in consideration of physical models[15]

4.5 Issue of AI human resource

Recently, the shortage of human resources that can understand and utilize AI has become a serious issue, as AI is being introduced in various fields. In view of this, the Japanese government established the Strategic Council for AI Technology in 2016 to study and discuss the human resource issues with the Human Resource Development Task Force[16) 17)]. The task force summarized that the development of AI human resource with the following capabilities is critical:

① Problem solving with AI technology

Ability to understand foundational technologies of AI such as machine learning and natural language processing and to indicate a roadmap for problem solving from the AI standpoint

② Implementation of AI technology

Ability to implement AI by programming capability and knowledge of computer science such as algorithm and data structure

③ Utilization of AI technology

Ability to capture the challenges of the respective target fields as the AI problems

Based on the discussion at the Strategic Council for AI Technology, education program for fostering immediately effective players, "Learning AI through the Real Data", was held at Osaka University, where the author belongs, and the University of Tokyo from 2017 to 2019 as a commissioned R&D project of NEDO (New Energy and Industrial Technology Development Organization)[18)]. This course assumes engineers (all fields) with a few years to 10 years of experience after graduation as the audience with objectives of learning AI foundational technologies including machine learning, deep learning and computer vision and putting the knowledge into practice through exercises using real data. This NEDO project has now completed but the lecture of Osaka University still continues having established a non-profit organization[19)].

4.6 Prospects in Manufacturing

Fig. 8 is an extract from "Study Report on Utilization of AI Technology in Manufacturing Area"[20)] by the Ministry of Economy, Trade and Industry published in March, 2018, which summarizes manufacturing areas where AI can be introduced by field and objective/accomplishment. Areas of introduction span not only the manufacturing process but also upper stream and downstream, as well as business management.

Currently, the area that AI fits the most is the application of images where big data can be easily collected. Inspection through image recognition is the most favorable area. AI is also introduced in the area where relatively organized data can be collected such as fault detection and design support. On the other hand, replacement and/or succession support of craftsmen's skills which involves tacit knowledge is still a difficult area even if some advancement can be observed. The issue here is sensing rather than the technical issue of AI.

The current AI is completely based on data. Therefore, it is important to identify and collect/extract "useful data" for utilizing AI. Field knowledge is indispensable and certain know-how is also required for collecting valuable data. When the know-how of data collection is established and useful AI systems are completed, the next important phase seems to be the creation of an ecosystem where "humans and AI collaborate" and complement each other for the operation in the field. Increasing individuals who correctly understand AI's characteristics and "are able to successfully operate AI systems" will be required. The methodology of AI (machine learning) system operation is called "machine learning systems engineering." In 2018, the Special Interest Group on Machine Learning Systems Engineering[21)] was launched within the Japan Society for Software Science and Technology, to promote discussions and know-how sharing.

How AI can be utilized in manufacturing

Area | Objective/Accomplishment	Improvement of production process (Automation/improvement → energy saving/cost reduction)		Improvement of quality/service (Increase value to the customers)	Creation of new values (What was impossible becomes possible)
Upper stream of manufacturing	■ Design of production system/ Development of production plan	■ Inventory control ■ Inspection of parts/materials (efficiency improvement)	■ R&D/material design support ■ Inspection of parts/materials (improvement of accuracy)	■ R&D/material design support (AI supporting experts)
Manufacturing process	■ Optimization of traffic line ■ Automation of assembly work/ picking	■ Analysis and implementation of energy saving ■ Improvement of yield/availability	■ Replacement/succession of craftsman's skills(Succession of skills, machining conditions, optimization of manufacturing conditions, management and control of reaction/fermenting process)	■ Manufacturing evolution support (AI supporting experts)
Downstream of manufacturing	■ Image recognition inspection (efficiency improvement) ■ Maintenance/follow-up service	■ Efficiency in packaging process ■ Improvement of logistics → energy saving	■ Image recognition inspection (improvement of accuracy) ■ Maintenance/follow-up service (improvement of service)	■ Provision of new follow-up service
Support activities for manufacturing	■ Development of estimate ■ Facility management	■ Production line management/ maintenance (Maintenance, fault prediction, energy saving)	■ Support for succession of skills/ skills training ■ Production line management (stable operation)	
Business/Management	■ Development of business strategy ■ Demand forecasting	■ Marketing	■ Labor management/human resource management ■ Marketing ■ Customer relation	■ New business/new product development expenses ■ Expansion of business scope

(Source: Ministry of Economy, Trade and Industry "Study Report on Utilization of AI Technology in Manufacturing Area"[20)])

Fig. 8 AI-applicable fields in manufacturing

5. Summary

The public hype of AI in the past seems to have calmed down, however, introduction of AI is steadily advancing. As mentioned in this paper, significant progress of deep learning expanded the utilization of AI, however, at the same time, new issues such as ethics, explainability and security have emerged. On the other hand, the current AI, which is based on training, depends very much on advanced data collection and preprocessing. Therefore, it has significant potential for the Japanese manufacturing industry to use its strength of "front line skills." In order for useful AI systems to become firmly established in society, not as a temporary "boom," we expect to build a system that is operated effectively where AI and humans work together, with correct understanding of AI's strengths and weaknesses.

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2015-Present	Associate Professor, Division of Information and Quantum Sciences, Institute of Scientific and Industrial Research, Osaka University
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[Specialty]

・Machine learning, data mining and its applications
・Knowledge discovery, prediction, fault detection especially from event series data
・Scope of application includes sleep, meteorology, earthquake, fuel cell, etc.

[Affiliated academic societies]

IEEE Computer Society, Japanese Society for Artificial Intelligence, Information Processing Society of Japan, The Japanese Society for Evolutionary Computation and The Institute of Electronics, Information and Communication Engineers

[Awards]

2008	IEEE 8th International Conference on Computer & Information Technology (CIT), Best Paper Award
2011	25th Annual Conference Best Presentation (oral presentation), Japanese Society for Artificial Intelligence
2013	President Award, Osaka University
2013	Encouragement Prize, Research Area, President of Osaka University
2013	Incentive Award in 2012, Japanese Society for Artificial Intelligence
2016	FAN Best Paper, 26th Intelligent System Symposium
2016	The Workshops at the 14th Pacific Rim International Conference on Artificial Intelligence (PRICAI-2016), Best Workshop Paper Award
2017	Incentive Award in 2016, Japanese Society for Artificial Intelligence
2018	Encouragement Prize, Research Area, Artificial Intelligence and Knowledge Processing Research, The Institute of Electronics, Information and Communication Engineers
2018	Elsevier, Knowledge-Based Systems, Outstanding Reviewer
2020	34th Annual Conference Best Presentation (international session oral presentation), Japanese Society for Artificial Intelligence

[Publication]

"Understanding Machine Learning by Python and Real Data - identification/prediction/fault detection," Ohmsha, 2018, etc.