Chapter 2

The Design of Mechanisms Via Artificial Intelligence

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Abstract

The engineering design is a very comprehensive term and required a number of different disciplines work together. There are many examples of engineering design studies and design of mechanisms is one of them. The design of mechanisms is one of the focused areas by mechanical engineering field and it includes kinematic synthesis, kinematic analysis, kinetics, dynamics, force and optimization of the mechanisms. The mechanisms can be complex; hence, additional help is needed in solution process. At that point, artificial intelligence (AI) of computer science is a really helpful for the mechanical engineers. Artificial intelligence field was found in 1956 and it is applicable to significant parts of the mechanism design. However, mechanical engineers cannot really apply artificial intelligence principles to mechanism design and as a result, design of mechanisms via AI became an interdisciplinary engineering studies between mechanical engineering and computer engineering. In this chapter of the book, mechanism design with artificial intelligence is focused and some sample applications are shown.

1. Introduction

The field of mechanical engineering includes a number of different disciplines such as heat transfer, material science, fluid mechanics or control. In addition to all of these disciplines, one of the main focus disciplines of mechanical engineering is the mechanisms. The mechanism design in mechanical engineering includes kinematics and kinetics investigation and optimization. In early mechanism design studies, optimization was not a part of the mechanism design; however, since mathematical computations can be done by computers easily, the optimization has started to be a main

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part of the mechanism design as well. Overall, the mechanism design includes forward and inverse kinematic analysis, kinematic synthesis, dynamics, force investigations and optimization based on optimization criteria.

The computer science (or computer engineering) is the study field of automation, information and computation theory, design and implementation of hardware and software. The artificial intelligence (AI) is the part of the computer science refers receiving, synthesizing/analyzing and inferring information which is given by the machines. The academic field of artificial intelligence was founded in the Dartmouth Conference in 1956 [1]. Although it was found in 1956, it is widely used in different areas such as social intelligence, philosophy of mind, robotics, mechanical engineering, electrical engineering or software development.

In this chapter of the book, combination of mechanism design of mechanical engineering and artificial intelligence of computer science is focused. Since artificial intelligence is a cross-disciplinary field, this chapter focuses how artificial intelligence experts and mechanism designers help each other to solve mechanism design problems. Especially in academia, researchers in computer science and mechanical engineering work together to design needed machines for humanity.

2. Mechanism Design in Mechanical Engineering

As mentioned earlier, the mechanism design is one of the main study areas in mechanical engineering field and it has a long history. For instance, Leonardo da Vinci designed some mechanisms in 15th century or Franz Reulaeux, who is one of the artist-engineer in 19th century, has significant works on mechanism design [2]. One of the famous Leonardo da Vinci drawing of mechanisms is lifting water mechanism and it is shown in Fig. 1. As seen in Fig. 1, the lifting machine design only includes some basic drawings of the mechanism from different views of the machine and some notes about it.

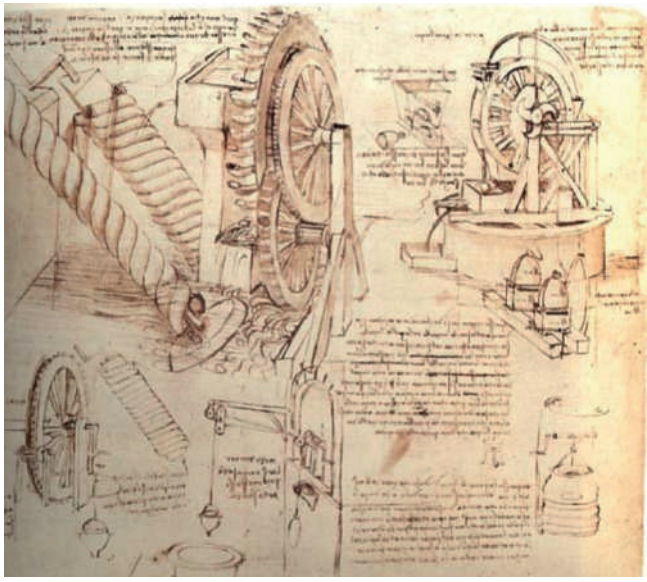

Figure 1. Leonardo da Vinci, Drawing and Illustrations, 1481 [15]

Early studies in mechanism design includes only drawing mechanism links and some basic calculations. The graphical methods were used in kinematic analysis and synthesis of the mechanisms until 1954. The first analytical approach of kinematic analysis of the four-bar mechanism is introduced by F. Freudenstein in 1954 [3] and; therefore, Ferdinand Freudenstein of Columbia University is known as "Father of Modern Kinematics". Since that time, a number of academic researches on kinematic analysis and synthesis has done by researchers by using this analytical approach.

In the mechanism design, first, kinematic analysis and synthesis are carried out. Then, kinetic analysis of the mechanism is investigated if it is a design requirement. Lastly, optimization investigation is done based on optimization criteria. The optimization criteria depend on design goal such as it can be minimizing force, optimizing link length or optimizing mechanism weight. Overall, these steps are required steps for complete the mechanism design. Multi-objective function can be an option for the optimization if there is more than one design goal.

3. Artificial Intelligence in Computer Science

Artificial intelligence is a very comprehensive term in computer science field because it refers machine learning, deep learning, artificial neural networks or reinforcement learning etc. All of these terms relate each other and

relation of these terms are shown in Fig.2. The artificial intelligence methods are widely used in different applications such as computer vision, speech recognition, natural language processing, face recognition, robotics and autonomous vehicle control, consumer services, control of logistic systems chains, economics, psychological study of human behavior, neuroscience, medical diagnosis systems for patients, organizational behavior, the study of educational practices, the study of evolution etc.

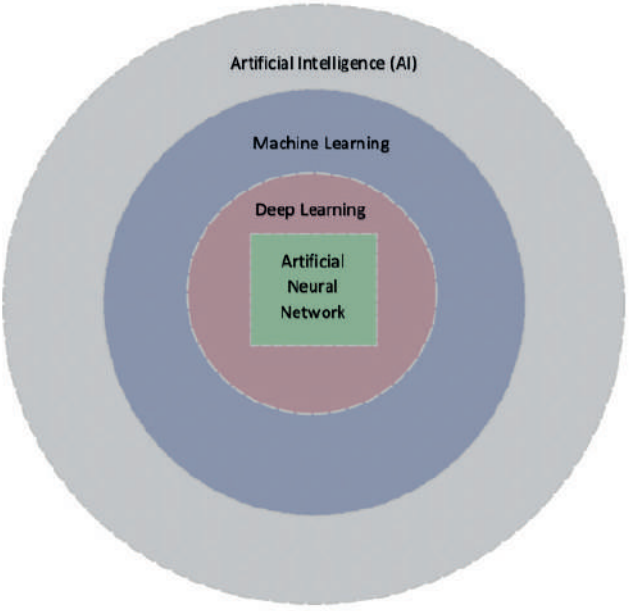

Figure 2. Artificial intelligence, machine learning, deep learning and artificial neural networks

Artificial neural network is the main architecture of the artificial intelligence and working principle of it is inspired by human brain. Working principles of neural network architecture is developed by researches in computer science based on neuron organization in human brain. There are many different training algorithms and training is the most important part of the neural network learning [4]. Indeed, artificial neural network is a kind of the optimization because weights of the network corrected during training. In the mechanism design, the artificial neural networks can create a model, predict unknown parameters, make classification based on data. Especially, complex mechanism designs can be done easily by using artificial neural networks methods.

4. Combination of Mechanism Design and Artificial Intelligence

Since computers are widely used and advanced software for computation is developed, the complex mechanism design process has become popular in 21st century. Instead of optimization or after optimization part of the mechanism design, the artificial intelligence methods are used for prediction of unknown design situations such as finding 3-position synthesis of mechanism and predict other 300-position synthesis via artificial intelligence methods. In fact, 300-position synthesis of the mechanism is almost impossible to calculate via traditional kinematic analysis methods but it is possible via artificial intelligence methods. Deep learning is one of the used artificial neural network methods in mechanism design [5]. There are a number of deep learning studies for mechanism design and some of them are mentioned in 4.1. By using deep learning methods, different predictions can be investigated.

At that point, the problem for mechanism designers is how to write algorithms on software or how to apply artificial intelligence methods to mechanism design problems. Since artificial intelligence has a number of methods, algorithms and principles, a mechanism designer cannot be an expert in artificial intelligence study field. Hence, experts in computer science are needed for the mechanism design. For instance, let's assume that a robotic hand is needed to design. For robotic hand design, a researcher from mechanical engineering field is needed to design and optimize physical hand. Another researcher from electrical engineering field is needed to design control part of the physical hand. In addition to people from mechanical and electrical engineering, a researcher from computer engineering field is needed to design artificial intelligence part of the physical hand.

4.1. Examples of the Mechanism Design via Artificial Intelligence

There are a plenty number of studies which use artificial intelligence methods for the mechanism design in mechanical engineering such as artificial neural networks, deep learning principles or reinforcement learning principles. In this part of the chapter, some of the sample examples is introduced:

Reinforcement learning is one of the methods in artificial intelligence area and it is presented as one of the kinematic synthesis solution method by Vermeer etc. [6]. In this article "trial-and-error interactions with a dynamic environment" method of reinforcement learning is reported for kinematic synthesis problem and several mechanisms are investigated to show

reinforcement learning method's efficiency. In this solution approach of reinforcement learning, the prior data is not required and system learns from reward signals received after each experienced data point. As an example, in this article, 300 prescribed positions of the input link are solved for the mechanism kinematic synthesis.

The forward and inverse kinematic analysis of the planar and spatial mechanism can be done by using artificial neural network (ANN) methods. Demang-Jig type crane mechanism kinematic analysis by using artificial neural network method is presented by Yildirim and Uzmay [7]. In this study, a Radial Basis Neural Network (RBNN) is applied to crane mechanism for its kinematic analysis. This crane is a type of double-rocker four-bar mechanism and kinematic parameters are predicted by artificial neural network. According to the results in this study, RBNN can be used for different types of the crane system. Another study presents that solution of forward and inverse kinematics of the 3-DOF planar robotic manipulator by using the Denavit-Hartenberg (D-H) model. [8]. Additionally, the same 3-DOF planar robotic manipulator is solved by using artificial neural network and results show that artificial neural network has faster and acceptable solution with without any error. In this study, Feed Forward neural network is used for inverse and forward kinematic analysis by using MATLAB toolbox.

The following research articles also combine artificial neural networks and the inverse and forward kinematic analysis of the different mechanisms: An inverse kinematic problem of the three degree of freedom manipulator is introduced by Jack etc. [9] and it is solved by using neural networks method. Another kinematic analysis of the series-parallel manipulator (2 (6-UPS)) is introduced by Ghanbari and Rahmani [10] and is solved by using two different neural network methods: Multi-layer perceptron network and radial basis function network. A forward kinematic analysis solution of the 6-3 Stewart Platform Mechanism (SPM) by using backpropagation method of the neural network is presented by Yurt etc [11]. A forward kinematic analysis of the hexapod with screw pairs is solved by Zhukov etc [12] by using neural networks. Another hexa parallel robot forward kinematic problem is introduced by Dehghani etc [13] and solved by using neural network. A neural network-based solution of an inverse kinematic problem of the large degree of freedom manipulator is presented by Dash [14].

The design of mechanism is one of the main study fields in mechanical engineering and the artificial intelligence methods are widely used in the

mechanism design process. However, for the combination of artificial intelligence and mechanism design, researchers in mechanical engineering and computer sciences work together. As a result, engineering design is an interdisciplinary engineering field and the design of mechanism and artificial intelligence combination is one of the examples of interdisciplinary engineering fields.

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