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Deep Learning Algorithms for Internet of Things Development: Classification and Selection

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***Abstract*:** *The new era of industrial revolution 4.0 has driven the rapid development of smart devices from the advanced technologies of sensors, processors, memories, energy sources etc. In contrast, the development of the technologies has driven the revolution in return as well [1].*

One of the prominent technologies from the Industry 4.0 is Internet of Things (IoTs) [37]. The connected sensory devices have been developed for physical observations and measurement [2]. Devices related to IoTs technology was predicted that would replace up to 50 billion devices by 2020 [2]. From the growth, it followed with high data quantity. Since IoTs devices use high and multi-connection to communicate and data-transferring between them. The data they communicate includes with the data they senses from physical world and analyzed data from each device. The continuously increasing data leads the large amounts of data which is commonly called in this era "Big Data" [3]. The characteristic of the big data is the large data sets which are from high-volume, high-variety and high-velocity information [4]. The complexity made difficulty to traditional data processing systems to handle effectively [5]. From the problem, the key solution is to develop intelligent processing systems to manage and analyze the big data [2]. This leads smart devices development which has been from main two sides of technological development; hardware and software. On the hardware side, smarter processers, higher memory capacity and portable technology has been developed. The development has been to support the complex logic patterns from artificial intelligence (AI).

A significant problem of smart devices development was the compatibility between hardware (smart devices), software (types of logical patterns) and aims of use (application) [2]. The incompatibility effect to the lost from time and budget consume, and the lost of opportunity to develop new innovation and applicable/marketable products. From the aforementioned problem, this research aims to classify types of deep learning algorithm (a part of AI logical patterns) to the types of machines and their missions/roles. This research use the mixed methods of content analysis and quantitative data collection from experts to discover the results. The main contribution of this research is to develop a validity and reliability guideline from systematic and scientific approach for AI related developers to select proper concepts of deep learning algorithm based on their applications and hardware.

Keywords: *Deep Learning, Machine Learning, Artificial Intelligent, Algorithms, Internet of Things, Smart Devices*

1. Introduction

From the rapidly increasing number of smart devices based on Internet of Things technology and Industry 4.0 trend. There have been various algorithms developed to handle with the smart processors and big data. The development provided choices of application, however, the volume is also an obstacle on selection difficulty. From Mahdavincejad et al (2017), data science is a solution for this problem, since it is the combination of data mining, machine learning, data analysis and data management methods [2]. This research adopted the view of data science to analyze the capability and compatibility based on data sources of application, since specific data types are from different data sources, the logical patterns selection should be match to data characteristics for more effective results, according to Mahdavincejad et al (2017). The objective of this research is to answer the

following question: What are the taxonomies of deep learning algorithms for the different types of Internet of Things application.

2. Internet of Things

The definitions of internet of things are various and changed over time, since technologies which is the drivers of this term has been changing. According to Atzori et al (2010) Internet of Things has been developed from the main 3 technological paradigms: Internet, Sensors and Knowledge [36], Atzori et al (2016) described the evolution of IoTs as from the main 3 technologies (RFID&Sensors, Webservice&Internet and Social&Cloud&ICnetworks) [37]. Global organizations developed the terms from their standards which Gubbi et al (2014) concluded to "interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative application, achieved by seamless large scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing" [36]. From data collection from Google since 2004, the trend of Internet of Things is raising rapidly since 2010 (at the same time of deep learning trend) while other trends of wireless sensor network and ubiquitous computing trends has been stable since 2008 [36].

3. Types of Machine Learning Algorithms

Mahdavincejad et al (2017) analyzed approximately 70 articles based on IoTs analysis. From their analysis, the machine learning algorithms were categorized to 8 major groups; classification, regression, combining models, clustering, feature extraction, neural network, time series and sequential data, anatomy detection .The categorization based on structural similarities, types of their data administration ability, capability on data process quantity.

4. Machine Learning Classification

The concept of machine learning classification has been adopted and developed from the concept of statistical classification [17]. To classify data the pattern of recognition has been recognized, the classification can be classified to 2 main group from its approach; generative approach and discriminative approach [18].

Generative model is the concept focusing on providing primary data before classification, while Discriminative model based on output concentration without primary data. The concept of discriminative approach has been interesting to the experts in 2010s because its characteristic on using quantity of data instead of provided process and criteria [19]. From the concept of mathematical probability, generative model is represent from the P(X,Y) formula and discriminative model is from (P(Y|X=x) [18].

5. Deep Learning

Deep learning is a type of machine learning based on the concept of feature learning [28]. The origin of deep learning can be track back to the concept of artificial intelligent. Artificial intelligent or AI is a concept on providing intelligent to machine which also called "Machine Intelligent"[29]. The main natural functions that have been developed for the machine intelligent are learning and problem solving since the traditional computer and machine was developed for common task of calculation[29]. An inspiration for AI concept was from the idea of developing robot or machine to have the natural intelligent of human [30]. Since this concept elevate human as the role model for intelligent, the target of this concept called "General Intelligent" [30]. From the target, the concept of AI combines of intelligent, creativity, and skills [30].

Machine learning is a technique for AI development based on computer science which applications from the significant ability of computer on statistical calculation. Machine learning has been developed for specific tasks on predictive analysis [31].

Deep learning is a method of machine learning based on concept of feature learning [32]. Neuron system of creatures' brains is an inspiration for this concept [30]. According to Kim (2016), deep learning is a form of

machine learning that enables computer to learn from experience and understand the world in term of hierarchy concept. Kim (2016) described that to learn complicated concepts of the real-world hierarchy of layer from experience(information) is important [33]. The processes within the layers are non-linear [34]. From the character , Chinetha (2016) provided basic definition of deep learning "a class of machine learning techniques that exploit many layers of non-linear information processing for supervised or unsupervised feature extraction and transformation, and for pattern analysis and classification"[34].

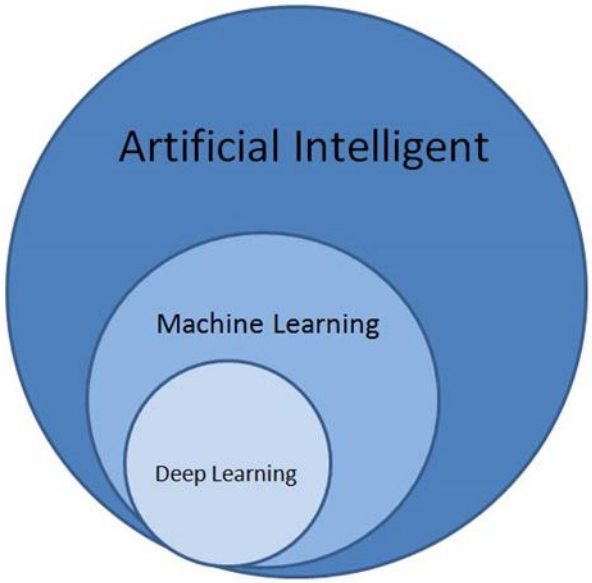

Fig 1. Relationship between Artificial Intelligent, Machine Learning and Deep Learning

6. Deep Learning Process

From the concept of deep learning, there are main three types of learning : supervised, semi-supervised and unsupervised [20][21][22].

Supervised learning is from the concept that data has to be labeled and the process has to be guided [23]. Limitations of this learning are (1) it need example of data and process, (2) it is inelastic (stick to samples and rules). Beside of classification, this learning type can apply regression to provide an example from the quantity of its output as well [23]. Unsupervised learning is in contrast of supervised learning. Its concept is from unlabeled data, without example from labeled input, there is no specific process for the algorithm [24]. Instead of classification and regression, unsupervised learning use clustering as a method to analyze its output [24]. The disadvantage of this learning is the accuracy of the results since it analyzes for desired results, not with low intention on input and process [24].

Supervised and unsupervised learning are the two main concepts for deep learning development, however, there are other concept that has not been fit to those types of learning [25]. For example, semi-supervised learning. Semi-supervised learning is a type of supervised learning which added the technique of unsupervised learning. This type of learning has been developed from the occurrences in the real-world that all input is impossible to be labeled and results are hard to be accurate without any guideline [25]. From the contrast of the advantage and disadvantage between supervised and unsupervised learning, the new learning technique from both of them has been developed [25]. From this combination, some experts claimed that semi-supervised technique is the most accurate technique in some cases [25]. In the real world, this technique is an effective (a great practical value) technique since labeling all input is time and budget consume, and accurate labels need skilled agents to interpret and transcribe [25]. Since semi-supervised learning is from the mixed techniques there are different views of application e.g. for classification performance by best technique selection, for transductive

learning (learn from example for discovering/predicting result from unlabeled data), for inductive learning (to mapping between the two technique), for exam learning concept (labeled data is an example from question and unlabeled data is the data to analyze answer) [25].

In addition, there is a new type of learning in machine learning called "Reinforcement Learning". Reinforcement learning (RL) is a viewpoint of learning developed from the concept of behaviorist psychology. RL is focusing on maximum sum of expected reward which is from rewarding when machines do the expected actions, and probably punishing on the unexpected actions [27]. This technique is advantage on lower time consumes from hand coding and mechanical adjusting for machines based on provided target [27]. RL performance is from the balance of exploration and exploitation as it takes time and meets risk in the beginning of exploration. However, when they explore right directions, it is the harvesting time [26].

7. Types of Deep Learning Algorithms

According to Mahdavincejad et al (2017), deep learning algorithms developed from the concept of artificial neural network (ANN) of machine learning algorithms. The concept of neural network has been developed from the idea of creature (biological) brain system [8]. In animal (including human) brain, there are groups of nervous system where nerves work and link together like the internet network [7]. Difference from the traditional computer system, creature brain system analyzes input without solid pattern guidelines. Natural processing system is more flexible from the processing of network nodes in non-liner function. The output is from the sum of all layers [8]. The advantage of ANN is to solve the problem based on experience and possible scenarios as human brain [8]. From the advantage benefit of ANN is to understand what human communicate by learning and thinking like human [8].

Bonnardot (2018) illustrated the ANN on an example of house price analysis. From the example, common information to house price calculation are house size, number of bedroom, location and district wealth. In common calculation, the four information are calculated together for the output of house price. However, deep learning alternatively added layer(s) between the input and output for more possible dimensions. Bonnardot provided the dimensions of family size, popularity and school quality for the added layer [10]. The additional layer effect to the more suitable house price based on human's justification from their experience and background.

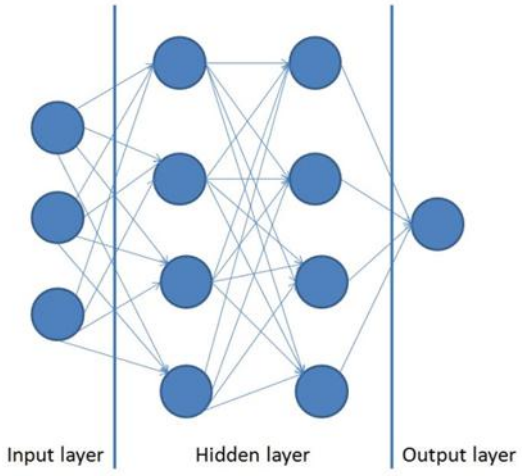

Fig 2. Model of Artificial Neural Network (ANN)

There are other algorithms developed from ANN concept, for example, convolutional neutral network (CNN). This algorithm focuses on image processing for recognition and classification [10]. Giant hi-tech companies such as Google, Baidu and Facebook applied the CNN consented to develop their image processing

systems for their search engines and social network systems [10][11]. CNN applied the concept of ANN by adding layer for processing. However, difference from ANN which focuses on the network of information, CNN focus on the network of the appearance based on colors and pixels of image data [10].

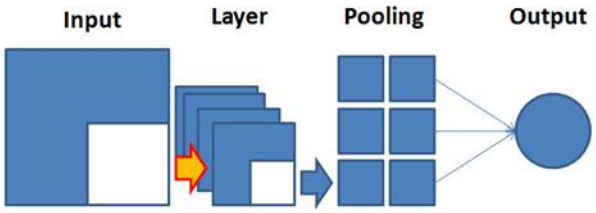

Fig 3. Model of Convolutional Neutral Network (CNN).

For sound processing, recurrent neural networks (RNN) has been developed based on the uncertainty of data [10]. This concept applied well with human speech which is not constant [10]. The concept of this algorithms is to separate each data in to a sequence which the sequence contain a list of possible data. RNN uses the previous processes to develop the sequences, this concept is strong on prediction on possibility which is same as what human do when they communicate with each other [10].

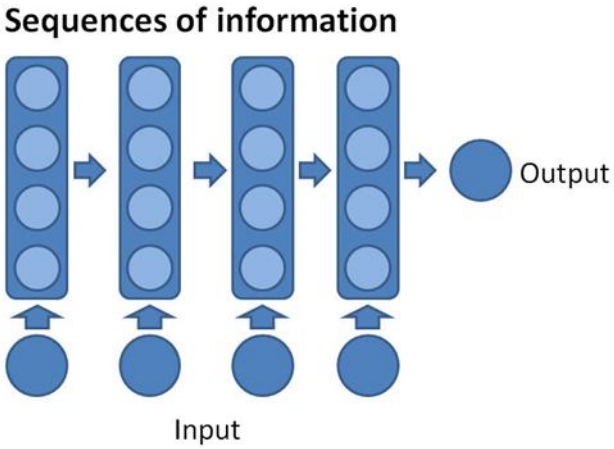

Fig 4. Model of Recurrent Neural Networks (RNN)

From the three types of deep learning above, it can be seen that they use all the stored data to analyze the result. However, creatures also have another concept of analyze called “dimensionality reduction”[10]. Since creature’s brain cannot handle with massive data compared to computer [12]. Biological brain use the technique of retrenchment by removing irrelevant data from their processing system to reduce processing load. The concept has been develop to the autoencoders algorithm, however it has been applied in the different way of what creature brain does [10]. Autoencoders has been applied to the field of data mining called anomaly detection, the algorithm has been widely use in financial transactions to detect frauds or in industrial field to detect production errors [13][14]. The process of anomaly detection is to continuously receive data, when data is stored enough the patterns of data will be shown as a standard for the set of data [13][14]. When there is distorted data diverged from the common pattern of the standard, it will be detected as the focusing data [13][14]. Autoencoders applied the concept of anomaly detection to understand what is the representation of the data pattern (called encoding) and what is the anomalous items [15][16]. Autoencoders has applied to the field of noise canceling, health monitoring, and also be an alternative algorithms for face detection [15][16].

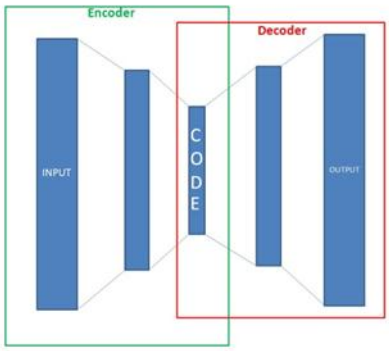

Fig 5. Model of Autoencoders

The character of deep learning is multi-layers with non-linear information processing. The advantage of this concept is to handle the received data with all of the possible dimensions from the stored data [10].

8. Main Applications of Deep Learning Algorithms

Most papers categorized the applications of deep learning algorithms into 5 main groups: Audio Applications, Language Applications, Object Recognition Applications, Information Retrieval Applications, Multimodal Applications.

9. Choices of Processing Hardware

According to Claesson and Hansson's research (2017). Deep learning algorithms are developed based on big data processing of the real world, which needs capacities on continuous long time process with high amount of data. In nowadays, there are 2 main types of processor; Central Processing Unit (CPU) and Graphic Processing Unit (GPU) [6].

CPU has been developed for computer for the task of calculation, nowadays CPU has multi-core to perform different tasks parallel for faster calculation [6]. Compared to CPU, GPU has multiple cores, in top GPU nowadays they can be up to thousands cores [6]. In sequential operations GPU is much slower than GPU, however, the position will be inverse on the task of parallel operations [6].

10. Research design

This research used content analysis as the first phase of mixed methods to explore the relationship between concepts of deep learning and their related variables. The questionnaire was developed for quantitative collecting data from the three organizations members of IEEE Thailand, ACM Thailand and ISOC Thailand. The results from the second phase were reviewed and analyzed by the experts of the three organizations for the conclusion.

11. Results

From the exploration the link of types of process, algorithms, processors, fields of application hardware and smart devices are shown in the table below

Types of Learning Process	Algorithms	Processors	Main Fields of Application	Required Hardware	Example of Smart Devices
Supervised	ANN	GPU	Information Retrieval Applications, Object Recognition Applications	Controller Board, , Large and Diverse Data Storage System, InputSensors	Cloud Computing, Smart Network, Smart Router, Smart Server, Robot
	CNN	GPU	Multimodal Applications, Object Recognition Applications	Camera, Image Sensor, Microphone, Speaker, Input devices	AI Image Recognition and Video Analysis, Smart Speaker, Smart Protein Detector (for drug discovery), Game
	RNN	GPU	Audio Applications, Language Applications	Microphone, Speaker, Actuator, Interactive Display, Activity Detection and Recognition Sensor	Robot, Smart Speaker, Smart Music Composer, Smart Assistant, Smart Classroom, Smart Monitor, Smart Camera, Smart Business Analysis, Smart Protein Detector (for drug discovery), Smart Fitness Device, Smart medical care
	Autoencoders	GPU	Information Retrieval Applications, Object Recognition Applications	Controller Board, Large and Diverse Data Storage System, Camera	Fraud detection, Production Error Detection, Noise Canceling, Health Monitoring, Face Detection
Unsupervised	ANN	GPU	Information Retrieval Applications, Object Recognition Applications	Controller Board, , Large and Diverse Data Storage System, InputSensors	Cloud Computing, Smart Network, Smart Router, Smart Server, Robot
	CNN	GPU	Multimodal Applications, Object Recognition Applications	Camera, Image Sensor, Microphone, Speaker, Input devices	AI Image Recognition and Video Analysis, Smart Speaker, Smart Protein Detector (for drug discovery), Game
	RNN	GPU	Audio Applications, Language Applications	Microphone, Speaker, Actuator, Interactive Display, Activity Detection and Recognition Sensor	Robot, Smart Speaker, Smart Music Composer, Smart Assistant, Smart Classroom, Smart Monitor, Smart Camera, Smart Business Analysis, Smart Protein Detector (for drug discovery), Smart Fitness Device, Smart medical care
	Autoencoders	GPU	Information Retrieval Applications, Object Recognition Applications	Controller Board, Large and Diverse Data Storage System, Camera	
Semi-supervised	ANN	GPU	Information Retrieval Applications, Object Recognition Applications	Controller Board, , Large and Diverse Data Storage System, InputSensors	Cloud Computing, Smart Network, Smart Router, Smart Server, Robot
	CNN	GPU	Multimodal Applications, Object Recognition Applications	Camera, Image Sensor, Microphone, Speaker, Input devices	AI Image Recognition and Video Analysis, Smart Speaker, Smart Protein Detector (for drug discovery), Game
	RNN	GPU	Audio Applications, Language Applications	Microphone, Speaker, Actuator, Interactive Display, Activity Detection and Recognition Sensor	Robot, Smart Speaker, Smart Music Composer, Smart Assistant, Smart Classroom, Smart Monitor, Smart Camera, Smart Business Analysis, Smart Protein Detector (for drug discovery), Smart Fitness Device, Smart medical care
	Autoencoders	GPU	Information Retrieval Applications, Object Recognition Applications	Controller Board, Large and Diverse Data Storage System, Camera	Fraud detection, Production Error Detection, Noise Canceling, Health Monitoring, Face Detection

Fig 6. Table of the relationship between types of process, algorithms, processors, fields of application hardware and smart devices

12. Conclusion, Limitation and Future Research

From the results, it can be seen that each algorithm has its own predominant ability, however, some filed of application are overlapped with the different domains of algorithms. In this case, it need to focus on the objective and structure of the project before selection. Another interesting point is processor, even CPU has dominated electronic devices for more than 7 decades, however the trend of smart devices based on deep learning is on GPU side. This matches to the assumption of Schmidhuber (2015) on that the neutral networks in 21st century required GPU since there are more complexity and deeper in networks' layers, the strength in parallel processing of GPU can reduce processing time multifold [37].

The limitation of this research is on the limit on the algorithms of deep learning, since this research selected on main four algorithms while there has been number of algorithms developed in the past decades. On the view of main algorithms, there is a new trend of artificial intelligent called generative adversarial networks (GANs). GANs is the technique of contesting between two neural networks in zero-sum game framework [40]. It was counted in the 10 Breakthrough technologies in 2018 from MIT [38] and assumed as the most interesting AI technologies in the past two decades from experts [39].

Additional limitation of this research is the part of hardware which this research focusing on processor part. The other hardware such as memory, sensors, network modules and energy sources are also important parts to develop efficient smart IoTs devices. It the part of processor there is a new type of processor developed for deep learning tasks called tensor processing unit, developed by Google [41]. This AI accelerator application-specific

integrated circuit (ASIC) was not selected to this research on the most effective processors; this research compared only CPU and GPU. Besides of TPU, there is another widespread processor called Advanced RISC Machine (ARM). It is a part of CPU family based on reduced instruction set computer (RISC) architecture [42]. ARM is popular in mobile device market from its advantage on small size (from fewer transistor and instruction set format), low complexity, and low power consumption [42].

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