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Comparative Study of CNN Models for Defect Detection in Food Packets

Neeti Shukla [1], *Asmita A Moghe* [2]

[1] *Research Scholar, Department of Information Technology, University Institute of Technology, RGPV Bhopal. Madhya Pradesh, India*

[2] *Professor, Department of Information Technology, University Institute of Technology, RGPV Bhopal. Madhya Pradesh, India*

Emails: neetishukla09@gmail.com, aamoghe@rgpv.ac.in

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Abstract

Industry 4.0 is the term which promises a new industrial revolution. It is an amalgamation of advanced manufacturing techniques and Internet of Things(IoT) to produce such manufacturing systems which are interconnected, and can communicate, do analysis, and utilize the information to drive further intelligent action back in the physical world. Industrial Internet of Things (IIoT) involve application of IoT in manufacturing and other industrial processes to enhancing the working condition, and improvement of operational efficiency (Foukalas et al.).

This paper reviews the recent work on industry 4.0 for automated defect detection in food packaging industry. This will help to reduce the complexity and improve the speed and accuracy of detection. This paper discusses the challenges and applications of industry 4.0 in general and further proposes a method to compare how various CNN models can be used for detecting the defects in food packaging industry. In this work seven (Alexnet, Resnet50, Resnet101, Densenet, VGG16, VGG19 and Squeezenet) different convolution neural networks are subjected to detecting the defects in food packets. After running the models with a Multi-Label-Classifier the training accuracy after 100 epochs is found as 98.5% and Validation Accuracy as 98.4%.

1. Introduction

Technology plays a big role in our day to day lives, and with the ever-increasing connectivity, it is having an impact on the industrial world as well. Industry 4.0 is not a new kind of technology, neither it is a business ideal, however it is a revamped approach which is motivated by new advancements to attain results that were rarely possible a decade ago. World is seeing this as "Fourth Industrial Revolution". Figure 1 depicts the various Industrial revolutions. First Industrial Revolution was during the period from 1760 –1840 involved invention of steam engines. The construction of railways acted as a stimulant in the revolution which resulted in machines being used in production. Electrification of Industries brought the Second Industrial Revolution in early 20th century. The introduction of assembly line triggered the revolution which resulted in mass production.

Third Industrial Revolution began in 1960s with the introduction of computers which resulted in Digital Revolution. (Foukalas et al.) The production of semiconductor trigged the revolution which brought forth mainframes, personal computers and the internet.

Onset of Fourth Industrial Revolution started in

21st century around 2011 (Alaloul et al.). It was an initiative by the German government which proposed to uplift their economy. The Digital Revolution triggered this revolution further by the extensive use of ubiquitous and mobile internet.

During this revolution, sensors became cheaper, smaller, and powerful. The innovative technologies which are helpful to implement Industry 4.0 are Internet of Things, Artificial Intelligence, Machine Learning, Cyber Physical System (CPS), Big Data and Cloud Computing. The objective of Industry 4.0 is to integrate these technologies for Smart manufacturing.

The goal of this paper is to concentrate on some of the significant challenges in meeting the demands of Industry 4.0 and its implementation areas. Paper is organized as follows: In Section 2, we will examine the various challenges in Industry 4.0. In Section 3, we will discuss the different areas where Industry 4.0 is applied, Section 4 discusses the methodology used for defect detection and also about the data set used for that, Section 5 discusses the results of various CNN models and Section 6 provides the conclusions and further developments.

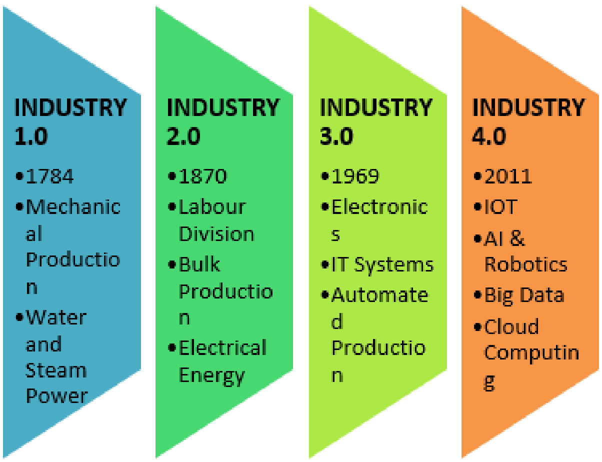

FIGURE 1. Industrial Revolutions

2. Challenges in Industry 4.0

Deployment of Industry 4.0 is not an easy task. It poses challenges (shown in Figure 2) like Energy efficiency Data integration, Security and Privacy, Lack of standardization, Legacy installations and Lack of skills. These are discussed as below:

2.1. Energy Efficiency:

Since most of the Industrial IOT applications are required to run on batteries for many years hence

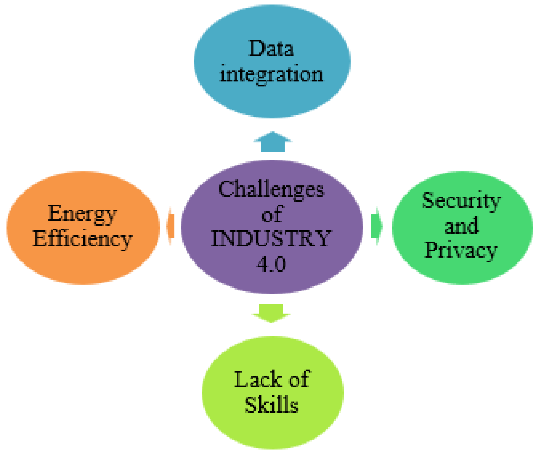

FIGURE 2. Challenges in Industry 4.0

such sensors need to be designed which use lesser power and in turn will not need batteries to be replaced for their entire lifecycle. The demand for energy efficient designs will hence increase (Sisinni et al.). For Wireless sensor networks lot of energy efficient designs have been proposed in the recent past (Rault, Bouabdallah, Challal, et al.), but these designs cannot be directly applied to Industrial IOT.

The sensor nodes in IIOT(Industrial IoT) applications utilize their energy to perform operations like data acquisition, processing, and communication. The type of monitoring decides the acquisition technique. The energy required for communication is the highest. In data processing techniques, intermediate nodes are selected to strengthen the data stream coming from source nodes and going to the sink node. The data sensed is forwarded either in queried form or continuous form. This process can consume significant energy. BatNET wireless communication technology is used to monitor the energy consumption of IIoT devices. (Campo et al.)

Green networking is one of the important techniques in IIOT to minimize the power requirement and the cost of operation. The whole process will therefore reduce the pollution and will work towards environment conservation. In LPWAN IOT technique, operational power can be reduced using different energy efficient design methods (Saifullah et al.), (3GPP) .

There are various other ways to improve the energy efficiency such as the use of SDN paradigm in which devices of IIOT communicate with each other and create API that tests and validates any application (Lins and Oliveira). Based on economy, socio-technology, and environment a model was conceptualized to check the impact on industrial sustainable energy by use of Causal Loop Diagram. (Hidayatno, Destyanto, Hulu, et al.)

To improve energy efficiency in smart factories, authors in (Mohamed, Al-Jaroodi, et al.) proposed two solutions as: 1) creating a three-layer model, consisting of the Cloud Manufacturing Services Layer, the Fog Manufacturing Services Layer, and the Manufacturing CPS Services Layer, to support the development, integration, and implementation of Industry 4.0 applications. 2) using the three service layers (Cloud, Fog, and CPS Manufacturing Services Layer) and a blockchain-based, service-oriented middleware to establish Industry 4.0 (Mohamed, Al-Jaroodi, et al.)

2.2. Data integration challenges:

Data integration is one of the main challenges of Industry 4.0. It has complex & varied data from different sensors and actuators. Also, frequency at which data is being generated by multiple devices also differs. Device interferences also need to be handled for ensuring that they remain operational. In near future the digital ecosystem that is well designed will need faultless data sharing that is between the physical systems and the machines by varied manufacturers. Due to shortage of interoperability between the IIOT devices the cost for integration and deployment will add to the complexity. Then the run towards having seamless interoperability will further increase the complexity linked with life span of specific industrial equipment. This will also need expensive retrofitting or the replacement for working with latest technology. The challenges involved with the device diversities in IIOT can also be addressed in three dimensions: Software flexibility, multimode radios and cross technology communications (Ascorti et al.). The multimode radios offer diverse IIOT devices for talking with each other. This software flexibility also offers supports for the cloud services, multiple protocols, and connectivity frameworks. Very recently, the cross-technology communication (Kim, He, et al.) without the additional hardware assistance needs to be studied for the communication that has been occurring across Bluetooth devices, WiFi and ZigBee. These approaches also are specific to technology and therefore there is future research required for enabling the cross-technology communications between IIOT devices.

2.3. Security and Privacy:

Since Industry 4.0 is mainly concerned with interconnection of various devices so security becomes a crucial element of Industry 4.0. These connected devices interact with the real world. The two most important security concerns of Industry 4.0 are Information security and Data privacy protection. Privacy Protection is a wide concept and when it comes to IIoT there is a threefold guarantee (Ziegeldorf, Morchon, Wehrle, et al.) firstly for awareness for the privacy risk imposed by the services and things, secondly individual control that is over processing and collection of information and the third one is control and awareness of the dissemination subsequent to any of the outside entities.

Some of the biggest challenges with the privacy can be seen in two procedures: Data anonymization procedure and data collection procedure. Normally, the collection of data also involves collectible data and the access control for these data during collection from smart things. The data anonymization ensures data anonymity via concealment and protection using cryptography of the data relations. Because of the restrictions that come with storage and collection of privacy preservation, private information can also be ensured simultaneously. However, the challenge in data anonymization lies in preserving privacy due to the diversity of things and the adoption of various cryptographic schemes. Another challenge is the sharing of collected information with multiple IIoT devices and the computation for encrypted data in the anonymization process. Thus security required in areas like Healthcare Industries (where data integrity is highly essential), Food Industries (where information that can harm the reputation of the company should be kept confidential), in power grids (where collapse of a power grid can result in a huge impact), national transportation (since it forms veins of the nation and making them secure is very crucial) etc is a major concern.

2.4. Lack of skills :

The technologies associated with Industry 4.0 are new, so there is limitation of skilled workers in related technologies. Workers should have vast and diverse knowledge. We can also designate four significant elements that distinguish the industry 4.0 from the industrial revolutions as Operations, information, sensors and Data. Combining these four elements means the elimination of unskilled labor forces.As the robots and machine take charge, the unqualified workforce is also replaced. The qualification and category of labor forces and the number of people working for the industry will dramatically change. From the time when first industrial revolution took place, there has been a requirement for the labor force that is well qualified at different points of time. During fourth industrial revolution it had become inevitable that some professions had to change while others ended. The professions that are going to shine might be enlisted as digital market experts, digital HR experts, interface design, data management professionals and data analysts. (Al-Fuqaha et al.) While observing historical procedures it was noticed that each of the innovations had been changing and has led to emergence of new professions while some professions were lost. At the same time new job description, new profession, new initiatives, and new sectors with novel business opportunities also came up in the fourth industrial revolution. (Tomas)

Section 3 discusses different areas of Application of Industry 4.0.

3. Applications of industry 4.0

The key application areas of Industry 4.0 are discussed below.

3.1. Healthcare Industry:

In the healthcare sector, Industry 4.0 will accomplish various functions which will solve a number of problems related to healthcare with interdisciplinary approach. Some of these functions of Industry 4.0 (Javaid, Haleem, et al.) include:

1. Increase in production of medical equipment's with flexibility in design and manufacturing.
2. Analysis of patient easier and accurate.
3. Improvement of quality of service and saving time and cost.
4. Use of sensor-based smart components to track new diseases and to control complex surgeries.
5. Centrally manage patient data in the hospital
6. Improve patient comfort with smart IOT devices.
7. Services to the patients to be controlled digitally.
8. Use of robots for complicated cases and surgeries.

The above revolutions in the field of medicine will change patient management and their treatment system.

3.2. Mining industry:

With use of several sensors for gas leak, temperature etc, detection of gas leaks in mines or detection of certain ores/minerals can be achieved. These sensors form a network comprising of gas sensors to detect oxygen or combustible/poisonous gases. There could also be sensors or devices to detect internal structural condition of mine or strata monitoring device, rock mass detection device etc. forming a network of devices. RFID tags are used on mines and there could also be presence of other wireless networking modules. Proper integration of these devices will help establish a good disaster warning system and help in ensuring safety of mines. (Sishi and Telukdarie)

3.3. Manufacturing industry :

The wide concept of smart manufacturing is to maximize the production and its transactions with the help of modern information and manufacturing technologies. Smart manufacturing mainly involves how different device, equipment, supply chain, the work force and platform for work are interconnected and integrated. It refers to a sophisticated principle during which distinctive production resources are then converted into smart manufacturing objects (SMOs) that are ready to sense, interconnect and move with one another mechanically and adaptively to implement the logic.

In IoT-enabled production environments, intelligent perception is achieved through human-to-human, human-to-machine, and machine-to-machine connections. Smart manufacturing offers benefits such as reduced operational costs, increased worker efficiency, improved workplace safety, optimized resource utilization and waste reduction, and full automation (Alcácer, Cruz-Machado, et al.).

3.4. Transportation and logistics :

The use of connected devices, deployed sensors, and GPS allows for simple monitoring of equipment, engines, and tracks. Data obtained from these devices can be analyzed to get information about maintenance, status, performance, and optimal scheduling. Optimal scheduling leads to improved customer service through reduced cancellations and delays and reduced fuel consumption. Safety of both passengers and machine may be enhanced with equipment being properly maintained and will also lead to reduction in maintenance cost. (Barreto, Amaral, Pereira, et al.).

3.5. Smart Firefighting:

Smart fire fighting is a combination of prevention of fire, protection from fire through engineering techniques and emergency fire services. The prevention from fire can be achieved with the help of improving the information collection method incorporated with IoT techniques. The goal of Smart Fire Fighting is as under:

- Saving lives and limiting wounds to building inhabitants and network individuals
- Improving fireman word related wellbeing and security
- Enhancing the general operational proficiency of the fire administration and the adequacy of fire counteraction and security
- Minimizing property misfortune from fire
- Minimizing business interference and loss of mission progression because of fire.

3.6. Smart Packaging:

The primary objective of packaging is to guard a product against any harm resulting from its exposure and usage in the external surroundings. Additionally, it acts as a powerful marketing tool to communicate with the consumer. Product packaging comes in various shapes and sizes and acts as a user-friendly interface, offering the consumer ease of use and convenience. The main functions of product packaging can be classified into four categories: protection, communication, convenience, and containment. For instance, packaging used for food products typically serves the following purposes:

- To protect the product from breaks, leaks and getting contaminated.
- To convey important information of the product like its nutritive content and instructions for cooking
- To provide convenience like microwave packaged food.
- To allow easy handling and transport by containing the product.

As per the studies of United Nations, almost 1/3rd of the human food goes waste or is lost every year. This happens because of bad practices of harvesting, as well as the condition of transportation and storage is also not up to the mark. This enormous wastage of food puts a lot of burden financially on the food industry, and therefore availability of an efficient packaging system is of real importance specifically for perishable goods. A good package ensures that the food can withstand longer periods of transportation and storage and gives it increased shelf life. From an industrial point of view designing a smart packaging system is quite challenging. (Schaefer et al.)

Considerable work has been done in the field of defect detection techniques in food packaging. Initially, there was a manual method to detect the defect in packaging. These methods were not so efficient and require a huge amount of manpower. Lot of work has been done by the researchers to make the process automatic. Various algorithms have been proposed to make this process easy and efficient. During the period of last few years researchers contributed to develop various algorithms. Researchers became successful in applying artificial intelligence in the field of defect detection in packaging. With the help of artificial intelligence and neural network the defect detection in packaging becomes cost effective and time efficient (Katyal et al.) (Huang et al.) (I Yang et al.). Also, the use of Internet of things may help the industries to detect the faulty packets automatically.

4. Methodology

In the proposed methodology the food packet images are classified through seven different CNN models. These models are Alexnet, Resnet50, Resnet101, Densenet, VGG16, VGG19 and Squeezenet .The figure 4 shown below describes how the works and a prototype of the same is implemented.

The use of a CNN (Convolutional Neural Network) model aims to improve image training by using a more sophisticated network. The CNN model consists of multiple hidden layers that allow for better feature extraction, resulting in improved training accuracy (Dutta et al.). In model training, six different models of CNN (Alexnet, Resnet50, Resnet101, Densenet, VGG16, VGG19 and Squeezenet) were trained on datasets. All training was done using the Python programming with the PyTorch and FastAI libraries.

A dataset with 50 different classes of food packages was prepared. It contains product images in multi dimensions such as front, top, left, right and so on. 20% of images from the data set were subjected to defects manually (scratch defects, flare defects and broken packages) and labeled as defected packages and non-defected packages. Further subdivision is done to class and sub class labels. There are various class and subclass labels in the image dataset. An image in a dataset can belong to some class and those classes are shown by the image are marked as 1 and the remaining classes are marked as 0. The aim is to detect packaging defects such as scratch defects, glare, and broken packages.(Figure-3)

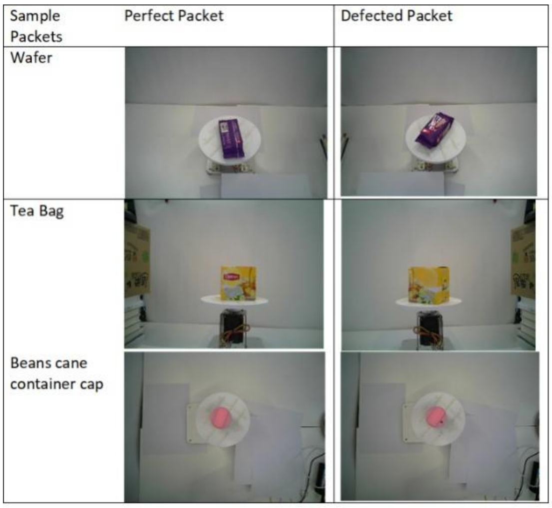

FIGURE 3. **Sample Data Set**

PyTorch is used for this image classification problem. In this scenario, each label is considered as a separate class, and binary classification is performed on each class to train a Multi-Label Classifier. The images and labels are divided into a training dataset and a validation dataset randomly in a 70:30 ratio. With 152 different labels to classify, a custom data loader is necessary to load all the labels related to a given image into a numpy array. The model's performance is evaluated based on the label predictions that are correct for each image. The total number of correct label predictions is calculated for each image and then divided by the number of labels [29].

5. Results and discussion

In the proposed work a comparative study of various CNN models like Alexnet, Resnet50, Resnet101,

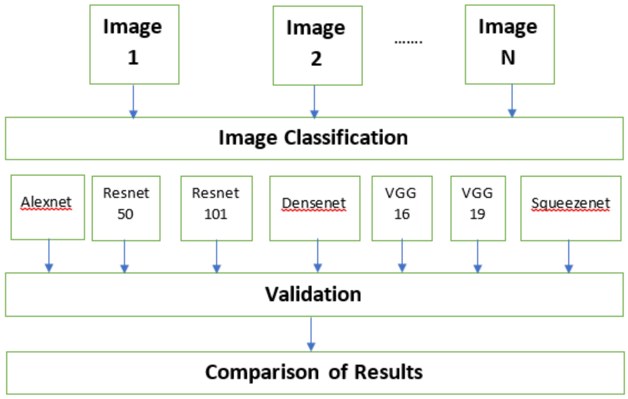

FIGURE 4. **Flow Diagram for proposed methodology**

Densenet, VGG16, VGG19 and Squeezenet is done for defect detection in food packet images. Evaluating the model based on how many correct labels the model is able to predict and then sum the number of correct label predictions for every image and then dividing it by the number of labels. The training of different models is being done by freezing and unfreezing of different layers of that model (Figure-5) . After running the models with a Multi-Label-Classifier the training and validation loss after 100 epochs is shown in figure: 6 and the training accuracy after 100 epochs is found as 98.5% and Validation Accuracy as 98.4% as shown in figure:7

6. Conclusion and Future Scope

The paper explores the different challenges faced in the realization of Industry 4.0 like energy efficiency, data integration, lack of skills, security and privacy are the key challenges. However the challenges like lack of standardization and lack of legacy in smart industries could not be touched upon.

An effort has been made to discuss the various application areas of Industry 4.0 but there are many more where IIOT can be applied and it can work wonders.

One such example can be, if Industry 4.0 would have been effectively applied in the functioning of smart manufacturing, then possibly the impact of stopped production during lockdown period of Covid-19 might not have resulted in slowing down the economy to such an extent because the manufacturing processes would have been self-sustained with very little human interface. Also as the challenges are gradually overcome the applications can realized to their full extent. This put forth a lot of

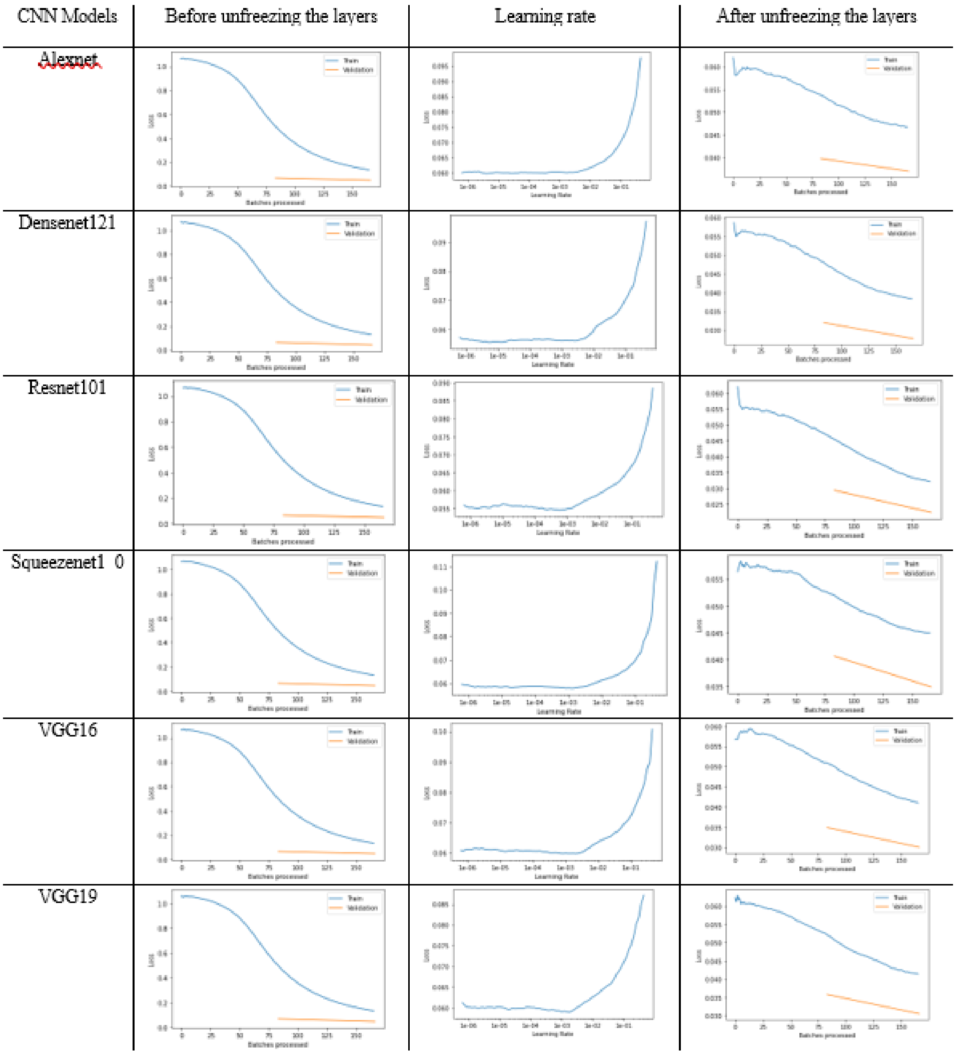

FIGURE 5. Training and validation of data set before freezing and after unfreezing the neural network layers

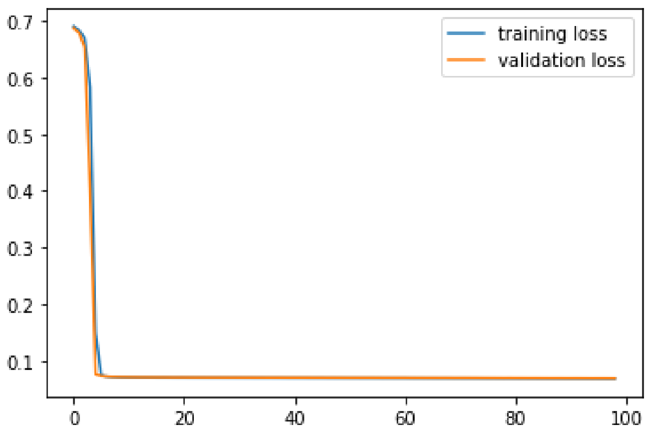

FIGURE 6. Training and validation loss after 100 epoch

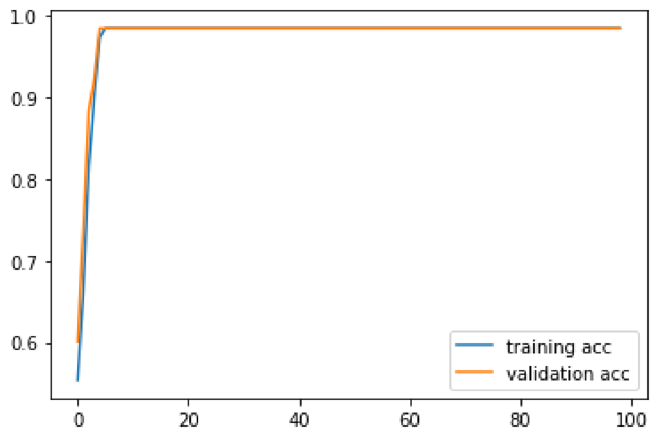

FIGURE 7. Training and validation accuracy after 100 epoch

scope for research in industry 4.0. By looking at the results obtained in the above research work it can be concluded that instead of using prebuilt models of CNN, a new CNN network design will be more appreciable such as Mask R-CNN which will yield better results in object defect detection.

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