Convolutional Neural Networks for Super High Momentum Spectrometer Optics Pattern Recognition

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***Abstract*—Our Research focused on developing algorithms for the recognition and prediction of specific tune patterns in spectrometer optics data from Experimantal Hall C at Jefferson Laboratory. The main goal was to create a machine learning model capable of recognizing optics patterns that would otherwise be tedious for humans to classify, in a mere matter of seconds with reasonably high accuracy. Specifically, we utilised the Keras deep learning Application Programming Interface(API) to build a Convolutional Neural Network(CNN). The CNN was trained on a dataset of 186 simulated optics patterns and a Cross-Entropy function was implemented to assess the model's accuracy throughout the training process. The model was able to reach an average accuracy close to 100% and an average loss of approximately 0.4. The machine learning model's ability to predict output was then tested against a set of 60 new images and achieved an average accuracy of 83%.**

I. Introduction

Since the inception of Artificial Intelligence in the mid 20th century, there has been rapid progress towards the creation of systems capable of matching or even surpassing human ability. As a result, Machine Learning (ML) a subset of artificial intelligence, emerged. In ML computer systems learn to perform tasks without bein explicit instructions, they learn purely from a set of data. The concept of computers learning directly from data has led to many algorithms modelled after the way humans learn. In particular, Neural Networks were inspired by the wiring of the human brain, imitating the interconnectedness of the neurons. See Fig.2 [1]

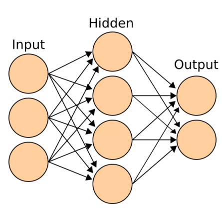

Fig. 1. Example of a figure caption.

In our research, we used a specific type of Neural Network known as a Convolutional Neural Network to interpret and analyse imgaes. All CNNs follow a basic list of steps in order to learn patterns from data.

- Receive input data
- Make a prediction
- Assess the prediction by comparing it to the desired output
- Adjust its internal structure to give more accurate predictions the next time

A simple illustration of neural network architecture is shown in Fig. 2 (Give reference of picture here.)

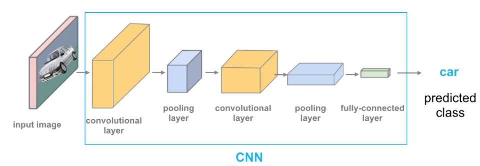

Fig. 2. Example of a figure caption.

[Here you would show a figure from the reference [1], whcih shows a dancing cartoon translated to "dancing" output]

II. Methodology

Discuss your research methodology. Did you employ qualitative or quantitative research methods? Did you administer a questionnaire or interview people? Any field research conducted? How did you collect data? Did you utilize other libraries or archives? And so on. For example, see next paragraph:

In this research, we analyze a total of 185 distinct simulated optics patterns from the Super High Momentum Spectrometer (SHMS) at Hall C of Jefferson Lab. There were six different optics correlations (xfp_vs_yfp, xpfp_vs_ypfp, etc. you will see this when you do the final project . . .make sure to use mathfonts when writing these, labels, so they look nicer, for example, x_{fp} vs. y_{fp}), each pattern had 31 optics images with varying optics tunes [Q1, Q2, Q3], corresponding to the spectrometer quadrupole magnets, summarized in Table I:

Each of the six 2D SHMS optics pattern correlations were trained separately, using 31 different optics tunes per correlation plot for a total of 185 images. The optics patters for testing the network consisted of only varying Q2 from

Quadrupole Magnet	Range	Stepsize
$Q1$	[min, max]	stp1
$Q2$	[min, max]	stp2
$Q3$	[min, max]	stp3

TABLE I
CAPTION OF TABLE.

0.945 to 1.055 in steps of 0.01, while keeping Q1 and Q3 tunes fixed at unity. To test the neural network after it had been trained, a set of 10 images were used for each 2D optics correlation, where Q1 and Q3 tunes were kept fixed at unity while Q2 was varied from 0.955 to 1.055 in steps of 0.01 for a total of 10 Q2 tunes.

IMPORTANT: Keep explaining what you did, or how was the data collected (I CAN HELP WITH THIS SINCE I WROTE THE CODES TO EXTRACT THE DATA IMAGES) (See paragraph below, where I expalined roughly what I actually did. You can write this part as it is, and then put a citation that you got this information through me. For example: [3] Private communication. C. Yero. August 2021. (see references.bib in the current directory for bibliography format)

III. Data Analysis Procedure

This is generally the longest part of the paper. It's where the author supports the thesis and builds the argument. It contains most of the citations and analysis. This section should focus on a rational development of the thesis with clear reasoning and solid argumentation at all points. A clear focus, avoiding meaningless digressions, provides the essential unity that characterizes a strong education paper. An example of how to start is in the next paragraph.

The Neural Network used in this research consists of 5 layers in total (See Fig.**??**). The input and output layers, represent the raw input image and output model prediction, respectively, and intermediate hidden layers, *convolutional*, *pooling*, and *activation* layers, each with a specific image analysis task as described in the subsections below.

A. Convolutional Layer

Briefly describe what the convolutional layer does, its dimensions, and how many filters used and the filter dimentions. Give reference to the online blog you read, [2]

B. Pooling Layer

Briefly describe what the convolutional layer does, and which specific pooling did you used, e.g., maxpooling?. Give reference to the online blog you read, [2]

C. Activation Layer

Briefly describe what the activation layer does, and which specific activation layer did you used, e.g., softmax. Maybe you can put the formula of softmax, and introduce mention how the loss is calculated. If you have not talked about what the the loss, then also give a brief description of what it is (See Ref. []). For the layer description, give reference to the online blog you read, [2], and probably also the article which describes what is softmax. You will need to probably add a new reference to the bibliography to be able to cite the softmax online article, similar to the other citations you have been doing.

**IMPORTANT: Don't worry about putting the details of the math (partial derivatives) that was done to actually carry out the forward/bacpropagation of the neural network. Just focus on explaining the basics of each layer used, and just mention that once the image passed through the layers, the output was compared to the known result, and a backpropagation method was done to minimize the loss by determining the optimum parameters. And mention that an epoch consists of a complete forward/backward propagation. Then, the images were re-analyzed with the updated parameters in subsequent epochs to further optimize the parameters and minimize the loss. ** You'll probably have to also give a brief 1-sentence description of what the loss is in a neural network.

The data with specific [Q1,Q2,Q3] tunes were simulated using the standard Hall C simulation program (`mc-single-arm`) and the raw data output was written to a ROOTfile. A separate ROOT C++ script (`make_2Doptics.C`) was used to form each of the six abovementioned 2D focal plane correlations correlations which were stored in a separate ROOTfile as histogram objects. The 2D histograms were then converted to a 2D pixelated array and stored in binary format (.h5) via a Python code (`save2binary.py`) array to be read by the Neural Network using Python Keras. Each optics image used was 200x200 pixels and was passed thorugh each of the hidden layers of the network described in Section 4 of this article.

IV. Results and Discussion

Summarize results and discuss implications of these results. After spending a great deal of time and energy introducing and arguing the points in the main body of the paper, the conclusion brings everything together and underscores what it all means. A stimulating and informative conclusion leaves the reader informed and well-satisfied. A conclusion that makes sense, when read independently from the rest of the paper, will win praise.

The purpose of this research was to teach a machine to recognize optics patterns that would otherwise be difficult to distinguish by the "human eye". With the help of Keras API, we were able to train and test a CNN by providing simulated optics data from Jefferson Lab, Hall C. Each of the six 2D optics correlation was trained with 31 optics tunes, and were able to reach and plateau at an accuracy of X %, and a loss of Y %, in Z epochs of training. We used 10 test images per each of the six 2D optics correlations, and network was able to correctly predict each the patterns with at least N % accuracy. The results of the training are shown in Fig.**??**

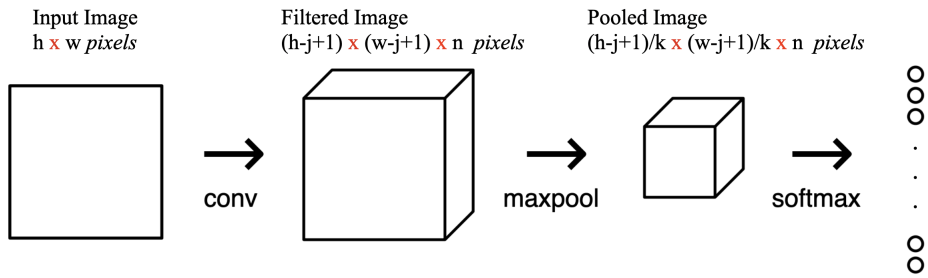

Fig. 3. Description of image

[Here show the plot of Accuracy (and Loss) vs. epochs] to show how the training progresses.

The results of the test images is summarized in Table II

col1	col2	col3	col4
val1	val2	val3	val4
val5	val6	val7	val8

TABLE II
CAPTION OF TABLE.

REFERENCES

[1] V. Zhou. (2019) Machine Learning for Beginners: An Introduction to Neural Networks. (Accessed on 2012-03-20). [Online]. Available: https://victorzhou.com/blog/intro-to-neural-networks/

[2] V. Zhou. (2019) CNNs, Part 1: An Introduction to Convolutional Neural Networks. (Accessed on 2012-03-20). [Online]. Available: https://victorzhou.com/blog/intro-to-cnns-part-1/