Recognition of vortex beams using convolutional neural networks

A.P. Bodunov
dimedron2024@gmail.com

Abstract - In this paper, the properties of vortex optical beams are considered, which make it possible to increase the efficiency of their recognition based on the use of neural networks. Modeling of the formation of vortex optical beams and their astigmatic transformation was carried out using the Fourier transform.

I. INTRODUCTION

In the last few decades, laser optical beams with orbital angular momentum (OAM) have become widespread in atmospheric communication systems, allowing for high coding density. The only problem is that due to the existence of such an aspect as atmospheric turbulence, this encoding method is suitable only for small distances between the transmitter and the recipient. Due to the resulting disturbances, the noise of the transmitted information occurs, which is why the recipient cannot perceive the received signal with the necessary accuracy. Therefore, in order to ensure the possibility of transmitting information through optical radiation, it is necessary to create a system that is resistant to emerging noises, capable of receiving and determining the received signal.

A good basis for compiling such systems are convolutional neural networks, which have become widespread in the field of computer vision, a field thanks to the development of which modern electronic computers are able to recognize objects in photographs, provide image search, detect distortions and processed fragments in images, which ultimately allows us to conclude about the originality and truthfulness of the captured image. Also, deep learning algorithms are increasingly being used to solve optical problems. The convenience of this approach is due to the fact that it is obtained faster than iterative methods and, in addition, there is no need for a powerful reference source to get an answer to the task due to the fact that it is possible to use for these needs the image generated on the receiver by a signal beam.

The main purpose of this work is to develop a software package for generating images of vortex optical beams with a view to their subsequent application for training a convolutional neural network for recognizing the orders of vortex optical beams entering the input of a formed convolutional neural network that performs visual image analysis.

II. MODELLING

To start creating the convolutional neural network we need to model optical vortex beams with the mathematical interpretation (Fig. 1). To increase the accuracy of the network it is necessary to make images differ between each other, so the decision to use astigmatic transformation was made (Fig. 2). But still there is no opportunity to use them separately from the beams images we created without the transformation because of the reduced accuracy of half-integer orders detection, therefore there is the need to merge them (Fig. 3). The final formulas for astigmatic and non-astigmatic images of vortex beams are shown at (1) and (2). Also, it is needed to make the network resistant to noise, so the images in the training data set have to be noised manually (Fig. 4).

As a result, a trained convolutional neural network with the provided data set is able to determine the orders of vortex optical beams with an accuracy of 94%.

III. CONCLUSION

In this paper, the properties of vortex optical beams are considered, their formation is simulated, and the mechanism of formation of a training data set for training a convolutional neural network is demonstrated. The characteristics formed in a convolutional neural network during training and the dynamics of their changes occurring with each epoch are presented.

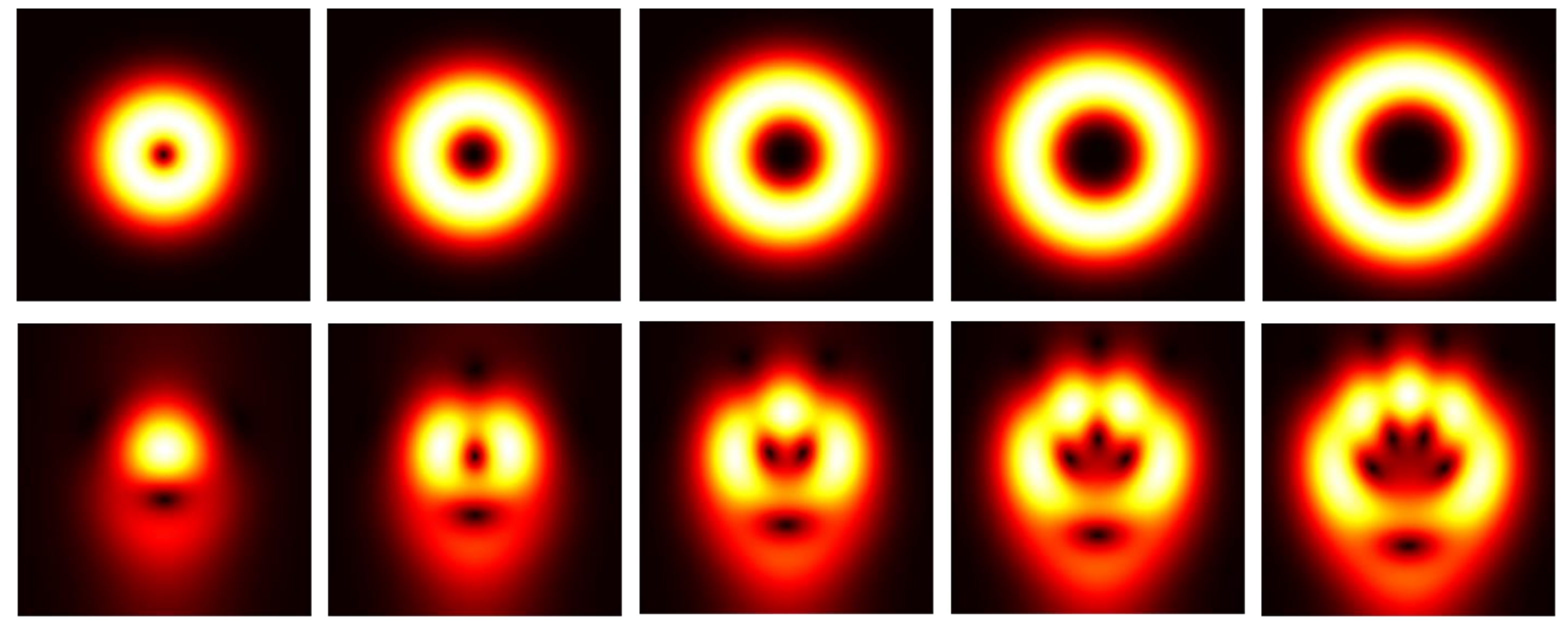

Fig. 1 – Generated images without astigmatic transformation

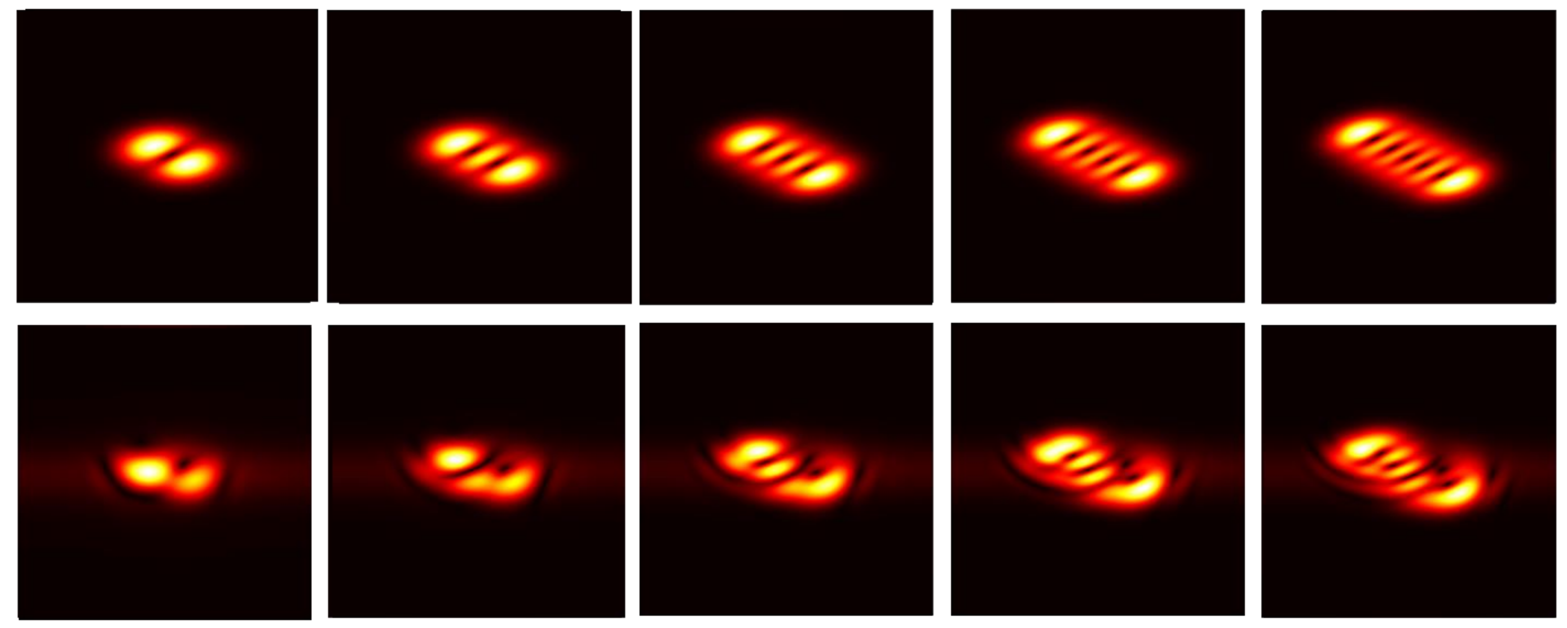

Fig. 2 – Generated images with astigmatic transformation

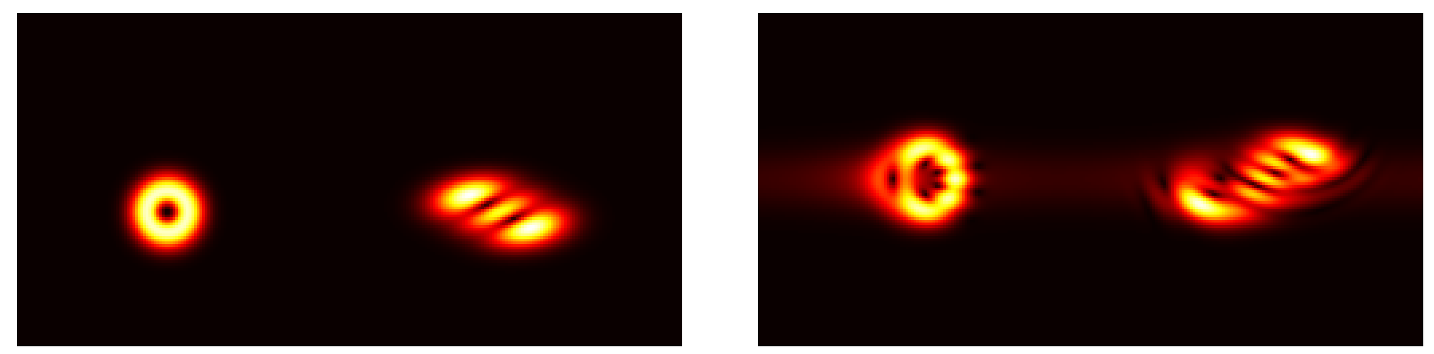

Fig. 3 – Merged images

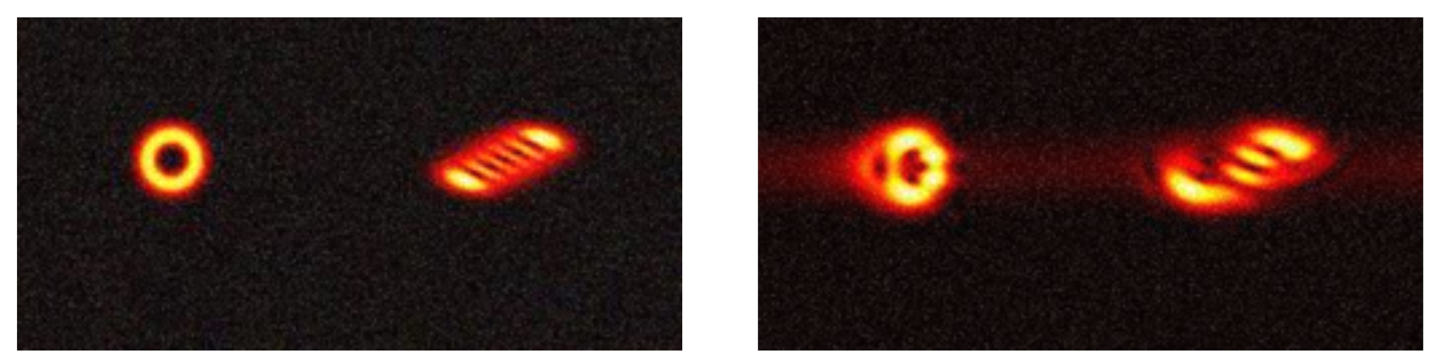

Fig. 4 – Noised images

$$f(x,y) = \exp\left(-\frac{x^2+y^2}{\sigma^2}\right)(x+iy)^m \qquad (1)$$

$$f(x,y) = \exp\left(-\frac{x^2+y^2}{\sigma^2}\right)(x+iy)^m \exp(i\alpha xy) \qquad (2)$$