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Hermite-Gaussian Beams Classification based on 1D Speckle Information using 1D Convolutional Neural Network

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Abstract: Classification of Hermite-Gaussian modes using a randomly picked 1D cross-line array across the 2D speckle pattern of the respective modes is proposed. Less than one-by-thousandth of the image data is utilized for classification.

1. Introduction

Analyzing speckles is been an interesting and emerging topic since the invention of lasers. Applications of speckles have been increasing in biology, surface morphology, communication [1], etc. A recent application of speckles is being used in demultiplexing encoded OAM modes using Convolutional Neural Networks (CNN) based on 2D speckle patterns [2,3]. Here we propose a novel approach for the classification of the Hermite-Gaussian (HG_{nm}) modes using just a 1D cross-line array across the speckle patterns of the corresponding modes. A feature extractor has been used to extract the features from the mapped 1D cross-line array from a 2D speckle pattern, which acts as a signal. A Wavelet scattering network is used to extract the scattering features from 1D cross-line arrays. Extracted features were fed to 1D CNN for training and testing the network. HG_{nm} modes classification accuracy is found to be >88%. In the proposed idea of demultiplexing technique, one-by-thousandth data has been utilized to classify the HG_{nm} beams and still achieved accuracy close to the 2D CNN classification techniques. The proposed classification method makes it feasible for low-end computational resources to achieve high accuracy in less time.

2. Data Generation

A 3mW HeNe laser is illuminated on the active area of the SLM, projected with the blazed hologram to generate the required HG_{nm} modes. An aperture is used to isolate the required mode from the higher order diffracted modes. The required mode is propagated through a rotating ground glass which is placed at the front focal plane of a converging lens and a CMOS camera is kept at the back focal plane to collect the collimated speckles as shown in fig 1(a). The HG_{nm}, $n = m = 1$ to 8 modes are used to generate the respective speckle patterns intensity images. Five hundred intensity speckle images of size 1970×1200 pixels are captured for each mode.

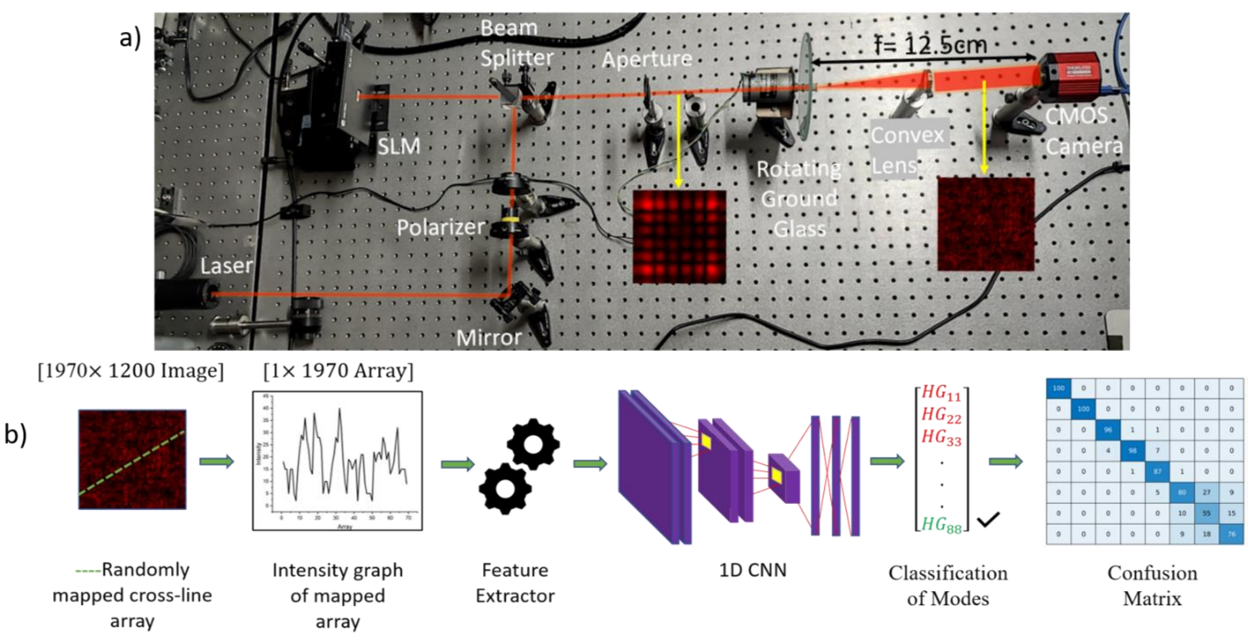

Fig. 1 (a) Experimental set-up for the generation of the speckle patterns corresponding to the HG_{nm} Modes. b) Classification of HG_{nm} Modes based on 1D Speckle Information using 1D Convolutional Neural Network.

To test the robustness of the proposed classification technique, a 1D cross-line array of size 1×1970 pixels is mapped across the 2D speckle patterns in random directions and at random positions. For each mode, 400 (80% of data) 1D cross-line arrays have been used to train the 1D CNN network and the remaining 100 (20% of data) 1D cross-line arrays have been used to test the trained network. To increase the efficiency in the training and testing a feature extractor is used. This results in the accurate classification of signals with high precision in machine learning and deep learning network [3]. Scattering coefficients extracted by wavelet scattering transform correspond to multi-resolution data interpretation in the frequency domain and time domain by the 1D cross-line array across speckle images. At each level of the scattering network, the input data goes through convolution, non-linearity, and averaging operations. As wavelet scattering processes the data at different frequencies with different values of scaling factors, it provides us with rich and enhanced data interpretability [4]. Once we get the scattering coefficients for cross-line arrays, we feed them to the 1D CNN network for training and testing as shown in figure 1b.

3. 1D Convolutional Neural Network

Using 1D CNN over conventional 2D CNN gives us advantages in less training time and computational cost [4]. The designed 1D CNN has two 1D convolutional layers with filter size=3 and the number of filters= 32 and 64 respectively. Specified filters with filter size in 1D convolutional layers slide over the 1D cross-line array with a striding factor equal to 1. ReLu layer uses a non-linear activation function to threshold the values convolved from the convolutional layer. The ReLu layer is followed by the Normalization layer, which independently normalizes the input elements by calculating the mean and variance for the possible dimensions for every observation in the ReLu layer. 1D global averaging pooling layer is used for subsampling by giving the average overtime or spatial domain, followed by a fully connected layer for 8 classes, SoftMax layer, and classification layer. The network is trained using the Adam algorithm with a learning rate equal to 0.001.

4. Results and Discussions

We have used eight HG_{nm}, $n = m = 1$ to 8 modes and captured 500 intensity speckle images of each mode. The cross-line array of size 1×1970 size is randomly picked from each image to create a data set of 1D speckles for classification. The 1D CNN network is trained on 80% of the data and 20% is used for testing. For HG_{nm}, $n = m =$ 1 to 8 modes, classification accuracy is found to be <90%. The classification accuracy for lower order HG_{nm}, $n = m = 1$ to 5 modes are >98% and the accuracy drops as the mode order increases. The crosstalk is increasing with the increase in HG_{nm} mode order. The proposed demultiplexing method has also been tested on Laguerre-Gaussian (LG_{pl}) modes and found that the classification accuracy for modes $p = 0$; $l = 1$ *to* 8 is found to be <80%. The 1D CNN network has achieved higher classification accuracy for HG_{nm} than LG_{pl} because of their distinct speckle pattern. Size-dependent classification accuracy study has also been done for both the modes and found that the accuracy drop is much higher in LG_{pl} than in HG_{nm} with the decrease in 1D cross-line array size. The 1D cross-line array is mapped along different directions and different positions to make the proposed demultiplexing technique independent of beam rotation and beam wandering for the tested modes. The classification accuracy can be improved further by preprocessing the raw data, choosing the appropriate feature extracting techniques, increasing the dataset, improving the 1D CNN, etc. and it is under investigation.

In this work, an effective classification of HG_{nm} and LG_{pl} modes have been exhibited just by using 1D cross-line arrays (1×1970) from the corresponding 2D intensity speckle images (1970×1200), which is one-by-thousandth times lesser data than 2D intensity speckle image. It has been proven that the 1D speckle-based demultiplexing technique is not too alignment specific and it is independent of beam wandering and beam rotation. This novel approach can be implemented by using minimal computational resources and by avoiding bulky optical instruments at the receiver end. Further study and research need to be done to improve the classification accuracy using 1D cross-line arrays.

5. References

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