1D CNN Empowered Speckle-based non-line-of-sight Communication using Hermite-Gaussian modes

Purnesh Singh Badavath†, Vijay Kumar*
Department of Physics, National Institute of Technology Warangal, Telangana, India-506004.
*Author e-mail address: †bpurneshsingh@gmail.com; *vijay@nitw.ac.in*

Abstract: The experimental proof-of-concept for 1-D CNN empowered speckle-based non-line-of-sight communication using Hermite-Gaussian modes is presented and achieved an average classification accuracy >96%. © 2022 The Author(s)

1. Introduction

Structured light modes made a great impact on free space and fiber optical communication by increasing spectral efficiency. Hermite-Gaussian (HG_{pq}) modes orthogonality property makes them more vital for communication applications. One-to-one communication channels have already been employed at larger distances using structured light modes for high classification accuracy [1,2]. Speckle-based communication is proven to be alignment-free and has high classification accuracy than regular orbital angular momentum (OAM) modes and non-OAM modes [3, 4]. Speckle-based optical communication links are been explored effectively using artificial intelligence based demultiplexing [5]. In this paper we present the experimental analysis and results of speckle-based one-to-three non-line-of-sight (NLoS) optical communication link using HG_{pq} modes. We have broadcasted the information to three different receivers (CMOS cameras), which are placed in the Fraunhofer region. A wavelet scattering network has been used to extract the scattering coefficients from the captured HG_{pq} intensity speckle images and fed to 1D Convolutional Neural Network for classification of HG_{pq} modes. Because of the speckle-based communication, the proposed method of demultiplexing is independent of beam wandering and beam rotation.

2. Experimental Set-up

A HeNe laser (3mW) is used to illuminate the SLM's active area, which is projected with the blazed hologram to generate the required HG_{pq} modes. We have used $p = q = 1$ to 8 modes to generate the respective far-field speckle patterns using rotating ground glass as shown in Fig 1. Ground glass has been used to diffract the modal information at a wider angle, which resembles the information broadcast in multiple directions. We have achieved information broadcasting up to 30° in the plane of the beam. The far-field speckle patterns of the respective HG_{pq} modes are captured at three different positions (C1, C2, C3) using a CMOS camera. For each mode 500 intensity speckle images of image size, 1200×1920 pixels are captured using a CMOS camera. All the CMOS camera is kept at a radial distance of 26cm. One of the CMOS cameras is kept on axis (C2), which is 26cm away from the ground glass and the other two CMOS cameras (C1 and C3) are kept at an angle of 15° away from the propagated beam axis and 26cm away from the ground glass plane as shown in Fig 1.

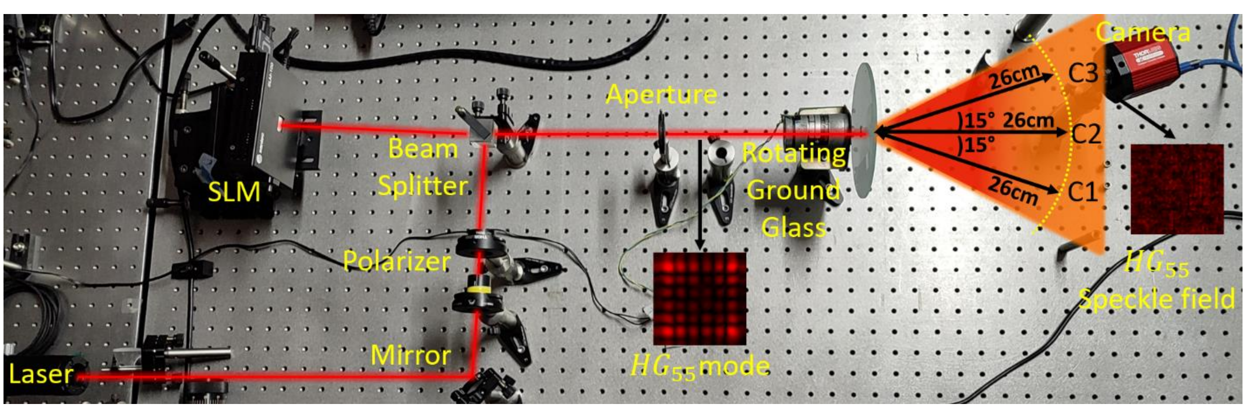

Fig. 1 Experimental set-up for 1D CNN Empowered Speckle-based non-line-of-sight Communication using Hermite-Gaussian modes.

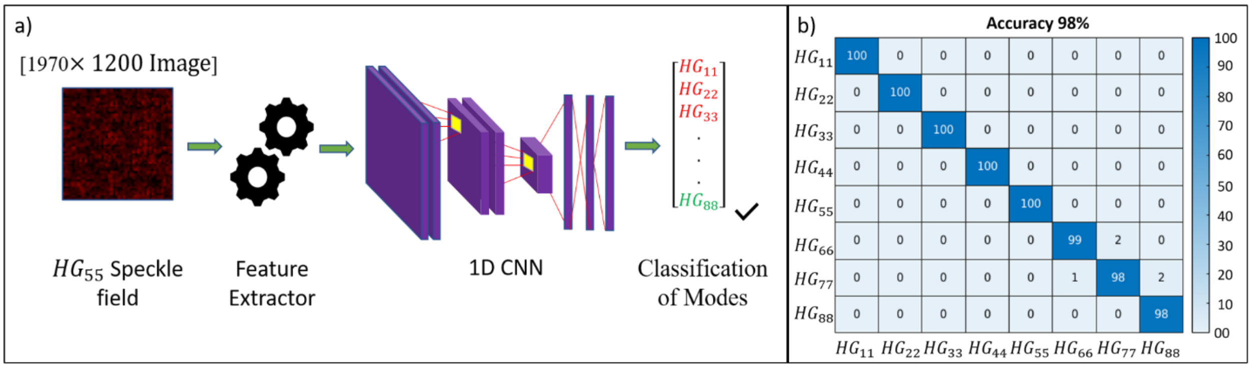

Fig 2 a). Data flow in 1D CNN empowered machine learning model. b). Confusion matrix showing classification accuracy of 98% for C2 channel.

3. Speckle-based Classification of Hermite-Gaussian modes using 1D CNN

AI-based demultiplexing is been effective and efficient considering its advantage over traditional demultiplexing techniques. A wavelet scattering network has been used to extract scattering coefficients. Extracted scattering coefficients from wavelet scattering help the neural network to train and learn at a much faster rate. Wavelet scattering coefficients represent features of the input signal over time and frequency domain that have less variance and are independent of spatial changes. Such features preserve the crucial information and discard spatial deformations of the image like rotation and translation [6]. Generated scattering coefficients represent low variance real values. A scattering network has been built with 2 filter banks, in which 8 and 1 number of filters have been used per octave. The generated scattering coefficients have been fed to 1D CNN. The schematic diagram of the data processing for classification has been explained in fig 2a.

1D CNN has an enormous advantage over other traditional neural networks in performance and training time. The architecture of 1D CNN consists of two 1D convolutional layers. The filter size in both layers is 3 pixels. The number of filters in both the convolutional layers is 32 and 64 respectively. Filters in the convolutional layers stride over the data map the activations and update the weights and biases in the network. Followed by a ReLu layer, Normalization layer and 1D Global averaging layer. 1D global averaging pooling layer transforms the output of the normalization layers by the means of subsampling or mapping the highest value over a small set of normalized values, 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 0.0001. In the captured intensity speckle images, 80% of the images are used to train the network, and the rest 20% of the images are used to test the trained network.

4. Results and Discussions

The captured intensity speckle images have a size of 1200×1920 pixels, in which we have cropped the center area of size 512×512 pixels and processed it for training and testing of the network. The network has achieved a classification accuracy of 93%, 99%, and 98% for the channels C1, C2, and C3 respectively. Fig 2b shows confusion matrix for C2.

This paper provides the proof of concept of speckle-based non-line-of-sight information broadcast using HG_{pq} modes. The classification accuracy of the proposed communication channel can be improved further by enhancing the architecture of the neural network. Depending upon the grit size of the ground glass and the power of the laser used, the information broadcasting area can be increased.

5. Acknowledgment

V. K. acknowledges SERB funding (SRG/2021/001375) and we acknowledge Prof. Nirmal K. V, University of Hyderabad for allowing us to use his lab facility.

6. References

[1] T. Doster et al., "*Machine learning approach to OAM beam demultiplexing via convolutional neural networks*," Appl Opt **56**, 3386 (2017).
[2] L. R. Hofer et al., "*Hermite–Gaussian mode detection via convolution neural networks*," JOSA A **36**, 936 (2019).
[3] V. Raskatla et al., "*Speckle-Based Deep Learning Approach for OAM Modes Classification*", JOSA A **39**, (2022).
[4] V. Raskatla and V. Kumar, "Deep Learning Assisted Classification of Noisy Laguerre Gaussian Modes," in Front. Opt. Laser Sci. 2021, (OSA, Washington, DC, 2021).
[5] V. Raskatla et al., "*Convolutional Networks for Speckle-Based Orbital Angular Momentum Modes Classification*", Optical Engineering **61**, (2022).
[6] W.-H. Lai et al., "*Application of Wavelet Scattering and Machine Learning on Structural Health Diagnosis for Quadcopter*," Applied Sciences **11**, 10297 (2021).