Predicting Fading in Free Space Communication Channel Using Deep Learning

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Outlook

1 - Understanding the importance of free space optical communication (FSOC)

2 - How atmospheric turbulence distorts an FSOC channel

3 – Simulating atmospheric turbulence in FSOC

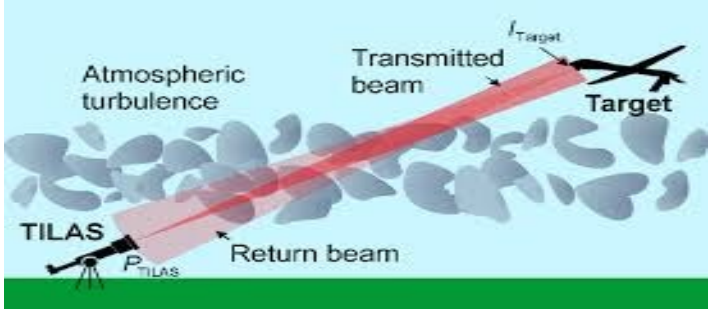
4 - Using the data from the simulation to train our ANN model.

Introduction

Free space communication is used in lots of different places such as: remote controlling, internet connecting, …

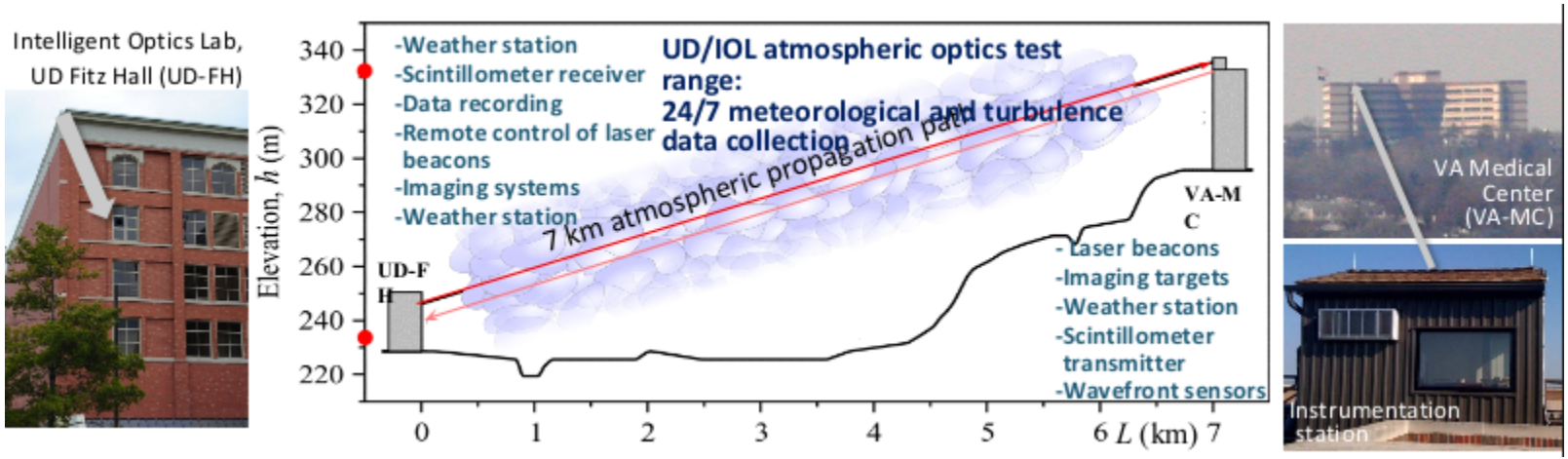
However the earth's atmosphere is not a perfect medium for propagating signals, since the atmosphere can distort the optical signal and cause signal fading.

Thus predicting fading in a signal in advance could be helpful in many situations, for example, we control a drone through free space optical communication channel, knowing when the signal could be faded is important to take an action.



Free Space Optical Communication

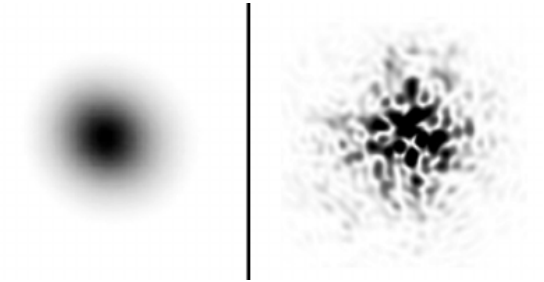
- The laser signal is modulated with data and propagates from the transmitter to the receiver through air.



Atmospheric Turbulence

The laser beam can be distorted due to atmospheric turbulence.

This atmospheric turbulence causes a fluctuation in the refractive index. The amount turbulence is quantified by C_n^2

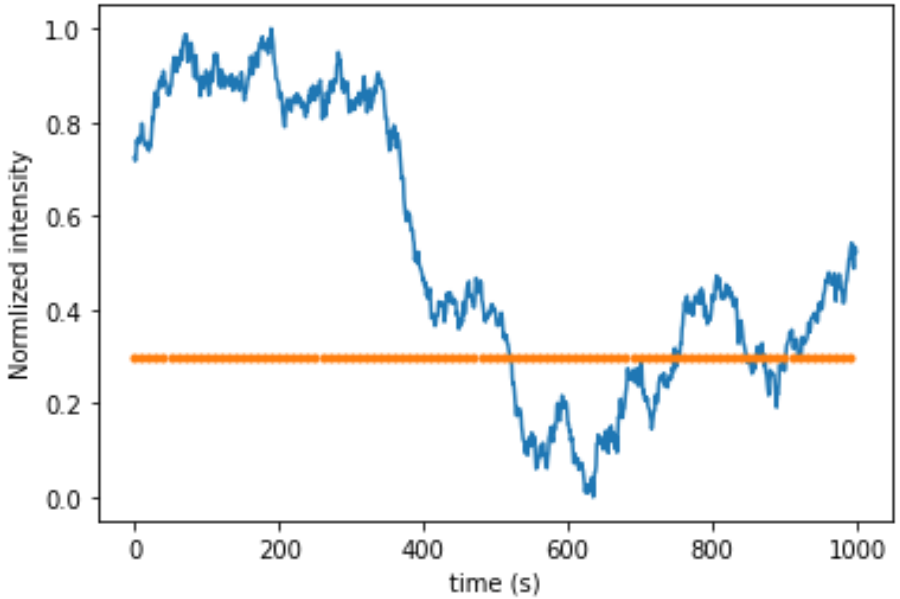


The effect of atmospheric turbulence on the laser beam, on the left a laser beam without atmospheric turbulence, on the right the laser beam affected by atmospheric turbulence[2]

An experiment done at Kennedy Space Center in Florida. A laser beam is sent from 1 km distance. You can see there are some high intensity spots dots due to the atmospheric turbulence.

Fading in Optical Communication Channels

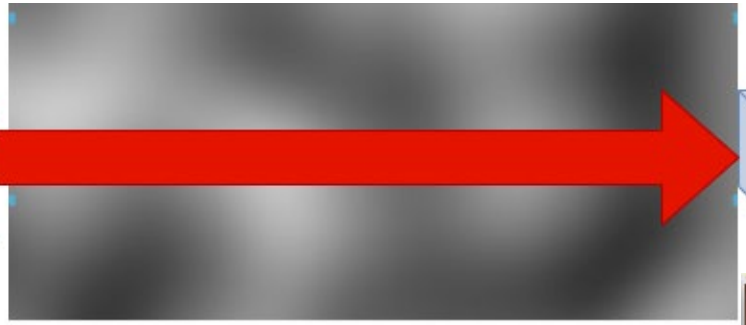
Due to atmospheric turbulence, the strength in the signal is fluctuating.
If the signal's strength gets below some threshold we cannot receive the data.



Simulation Process

Intelligent Optics Lab,
UD Fitz Hall (UD-FH)

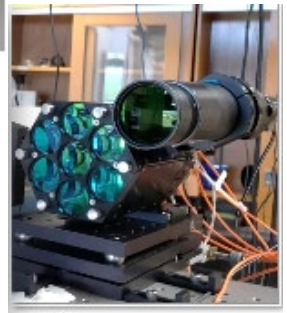
Sender (Laser)



Power in the bucket sensor

Atmospheric truculence (7 Km)

3-wavelength scanning laser beacon for long-range atmospheric sensing



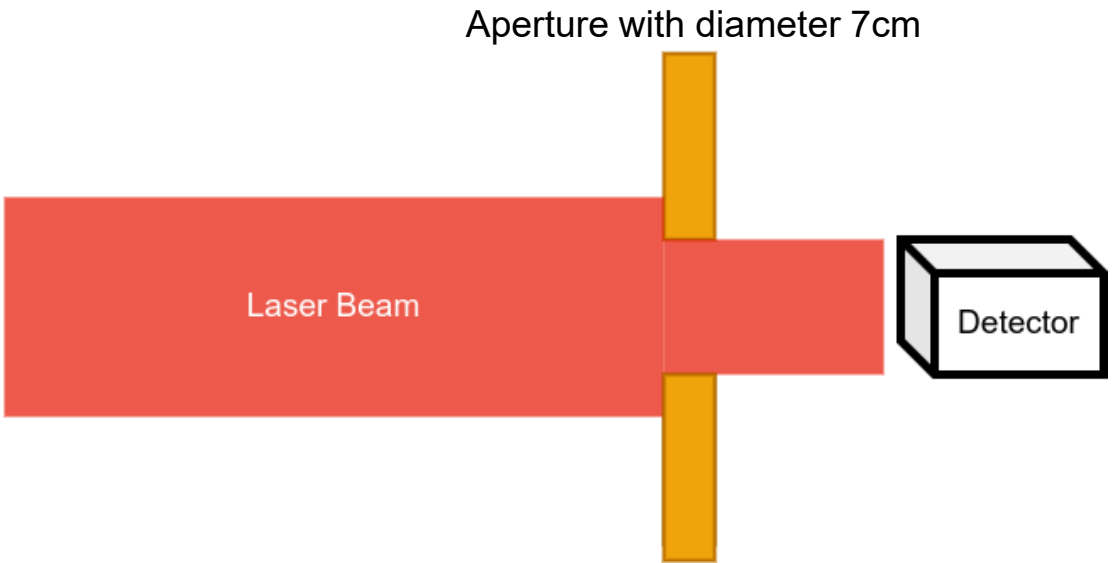
Multi-aperture power-in-the-bucket sensors

The beam enters a small aperture (the bucket) and is focused by a lens onto the detector.

Beam Quality Measurement

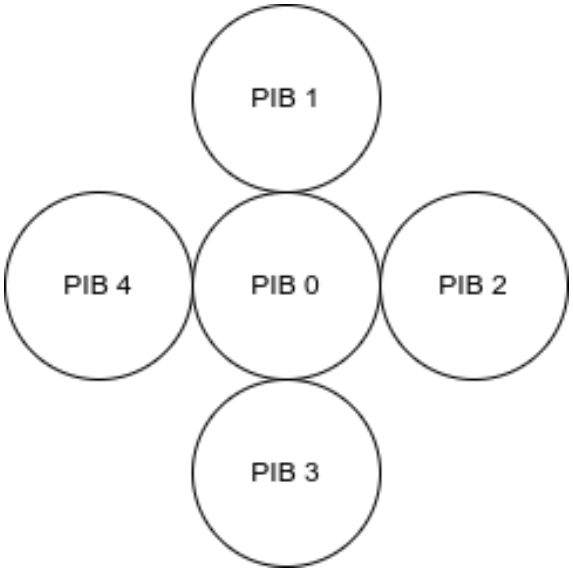
- Power in the bucket (PIB) can be used to determine the quality of our beam (signal). We can measure PIB.

  Simply PIB is the intensity of the beam that propagates through the aperture.



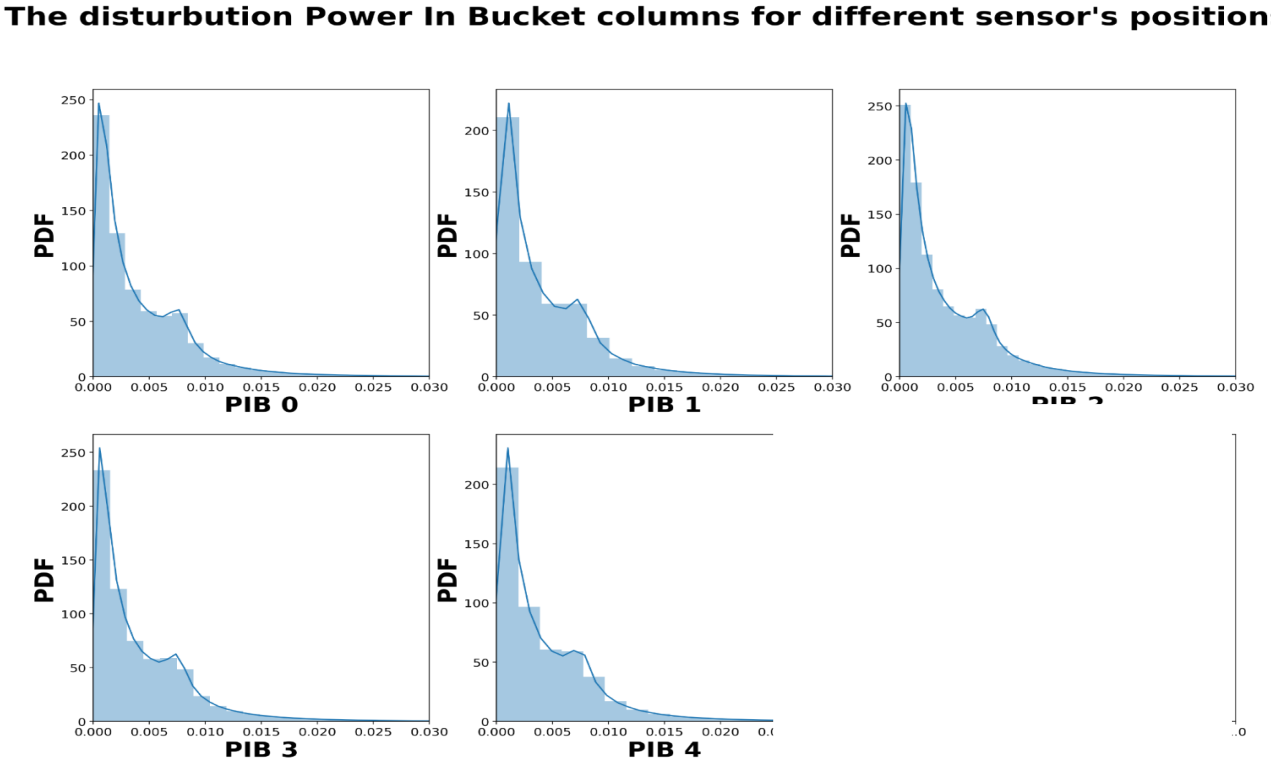
Dataset

- We get from the simulation the data set of PIB for 5 different laser positions as shown in the figure.
- Strength of atmospheric turbulence (C_n^2) is varied to calculate PIB.
- 400s time period with 4 ms timestep.



PIB (Power in the bucket distribution for different position)

The distribution of power in the bucket should has a Log-normal distribution[1].In our dataset we have 5 positions to measure PIB.



Using Artificial Neural Network to predict PIB

This model takes one value from Cn2 data as an input and predicts the PIB as the output .

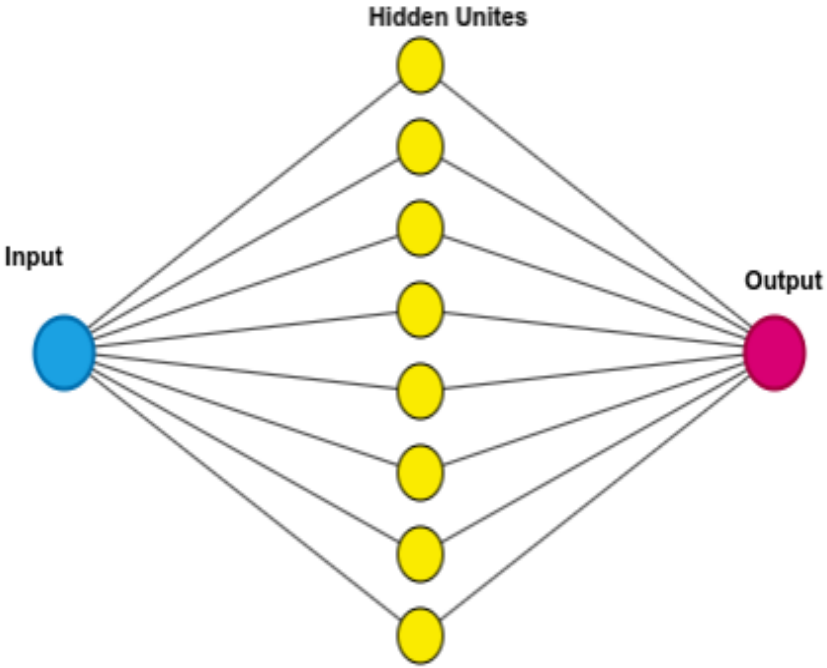
The input data is standardized

One hidden layer with 8 Units and ReLU as an activation function and the weight initialized by Weight initialization .

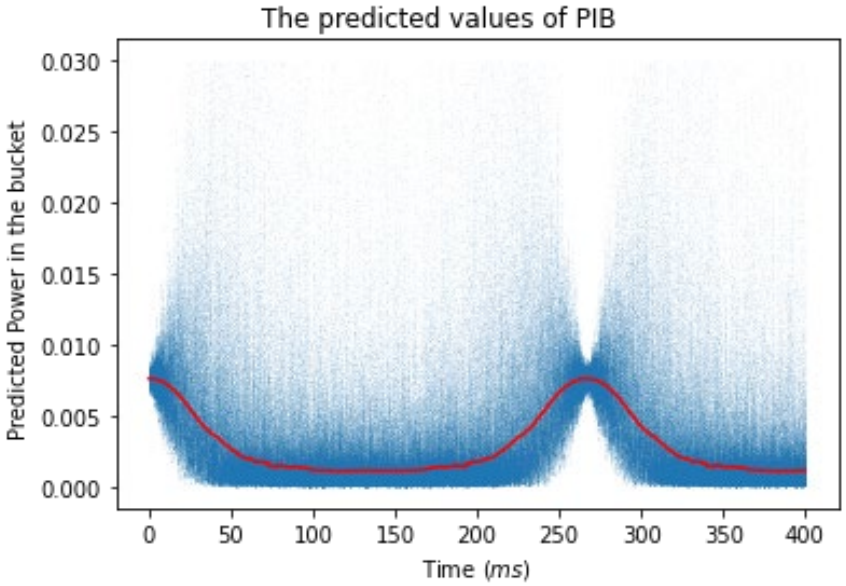
The mean absolute error is used as a loss function .

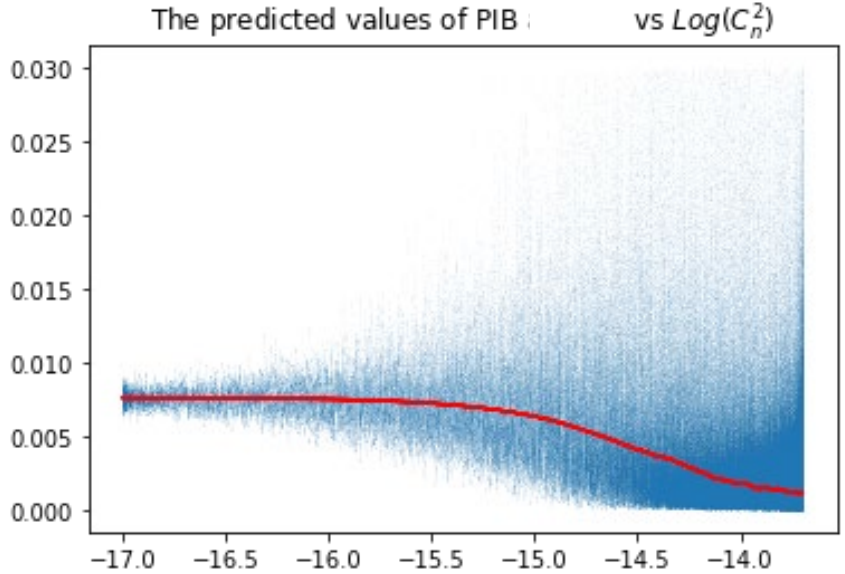
Adam optimizer is used to optimize the model.

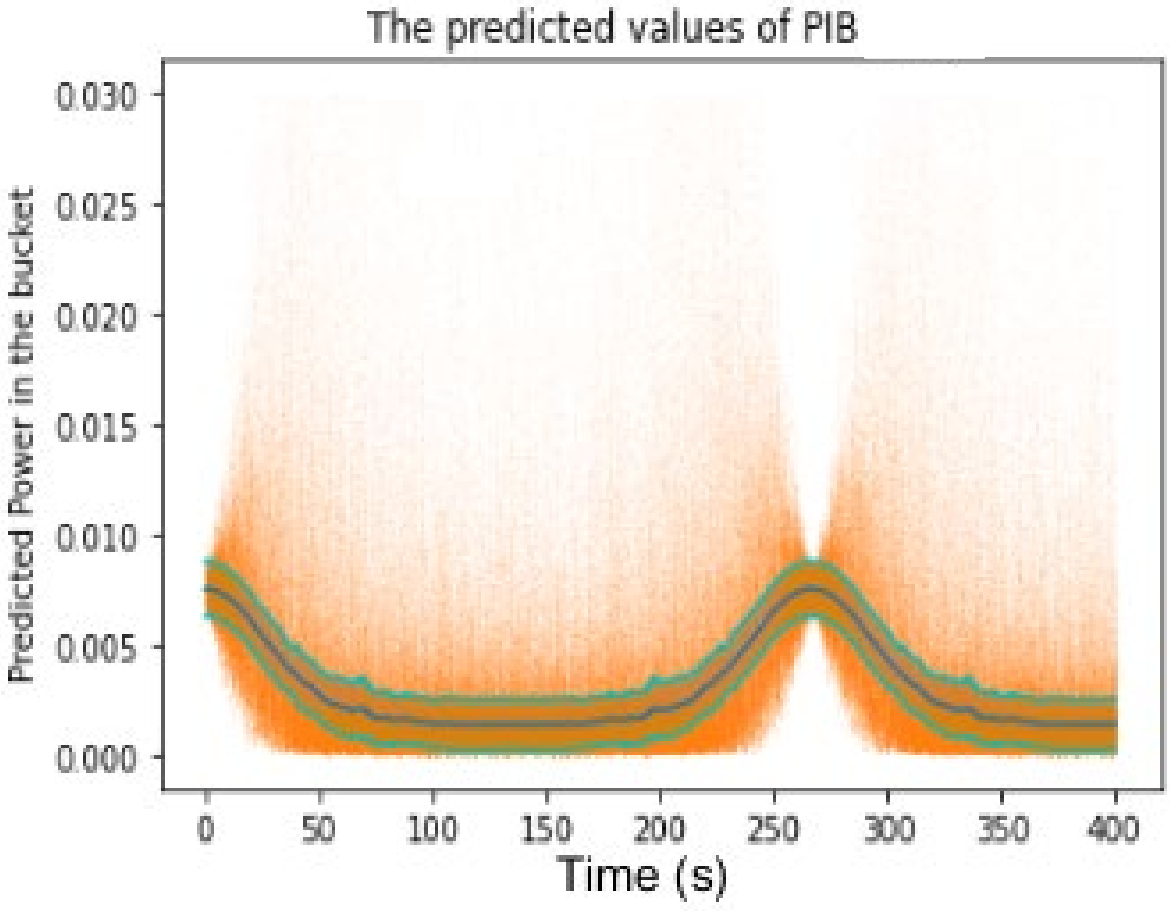
We set the learning rate to 10-3



Result


The predicted values of PIB
Predicted Power in the bucket
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
50
100
150
200
250
300
350
400
Time (ms)


The predicted values of PIB
vs $Log(C_n^2)$
0.030
0.025
0.020
0.015
0.010
0.005
0.000
−17.0
−16.5
−16.0
−15.5
−15.0
−14.5
−14.0


The predicted values of PIB
Predicted Power in the bucket
0.030
0.025
0.020
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0.000
0
50
100
150
200
250
300
350
400
Time (s)

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Conclusion

- Free space communication is used widely for many applications such as delivering internet without needing the huge infrastructure. Also, can be used in controlling drones remotely.

- Atmosphere distorts the signal because of atmospheric turbulence.

- Predicting the PIB is important to be able to predict when the fading in the signal could happen.

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Future research steps

- Include noise in modeling
- Using Sequential Model to predict more time steps
- Include meteo parameters
- Perform an experiment to measure data
- Use the measured data to train the ANN model

Q&A

Thank You!

Reference

[1] Kolosov VV, Kulikov VA, Polnau E. Dependence of the probability density function of laser radiation power on the scintillation index and the size of a receiver aperture. Opt Express. 2022 Jan 17;30(2):3016-3034. doi: 10.1364/OE.444958. PMID: 35209429.

[2] Henniger, Hennes and Wilfert, Otakar (2010) An Introduction to Free-space Optical Communications. Radioengineering, 19 (2), pp. 203-212. Czech Technical University. ISSN 1210-2512.