On the Effect of Atmospheric Turbulence in the Feature Space of Deep Face Recognition

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Problem Statement

How does optical atmospheric turbulence *break* the performance of deep face recognition?

Contributions

- Extensively evaluate Face Recognition model behavior under various levels of atmospheric turbulence and Gaussian blur.
- Demonstrate state-of-the-art methods performs poorly under atmospheric turbulence.
- Identify **feature defection** as a cause of poor quality assessment and lower recognition performance under atmospheric turbulence.
- Outline paths of future work for creating models robust to atmospheric turbulence.

Atmospheric Turbulence

What is Atmospheric Turbulence?

Turbulent air flow and air temperature deltas create spatially and temporally varying refractive indexes in the atmosphere. For an imaging system, this creates degraded image quality due to variable point spread functions. This effect, called atmospheric turbulence, can be described as:

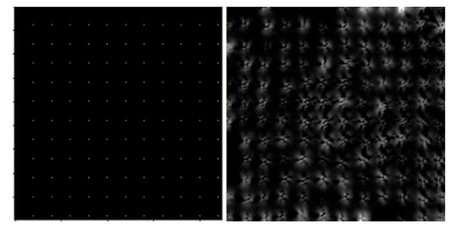
$$o = B(\mathrm{MTF}, x, y, t) \otimes (G(\xi(p, T, \lambda), \theta, \ldots, x, y, t) \otimes z) + \epsilon$$

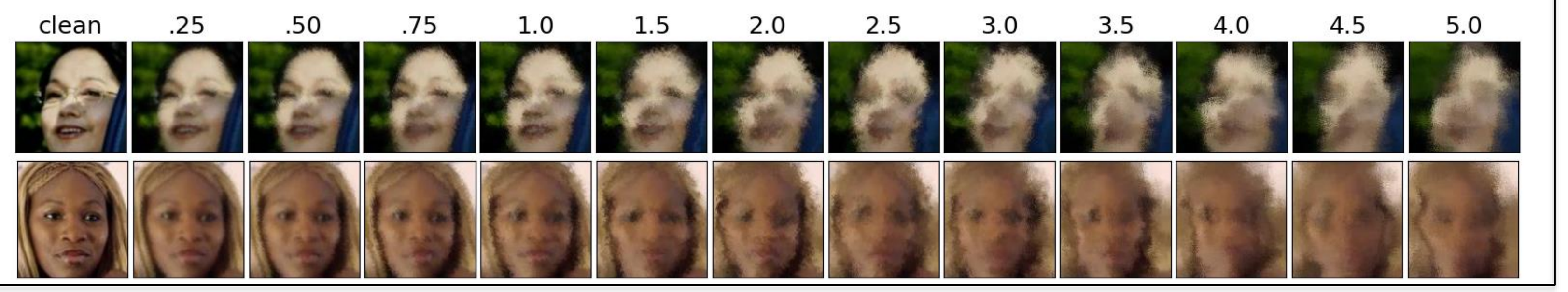
where (x, y) are spatial parameters, t is a temporal parameter, $(p, T, \lambda, \theta, \xi)$ are physical parameters, and z is an unobserved clean image. Several of these parameters are unobservable, and operators B, G are non-linear and random. Accounting for this perturbation in computer vision tasks is an open problem.

Simulated Atmospherics

To obtain sufficient data for experiments we use state-of-the-art atmospherics simulation software on the LFW, AGEDB, and CFP datasets. For each dataset we simulate 20 levels of turbulence between 0.25 (weak) and 5.0 (severe).

PSF before and after Atmospherics



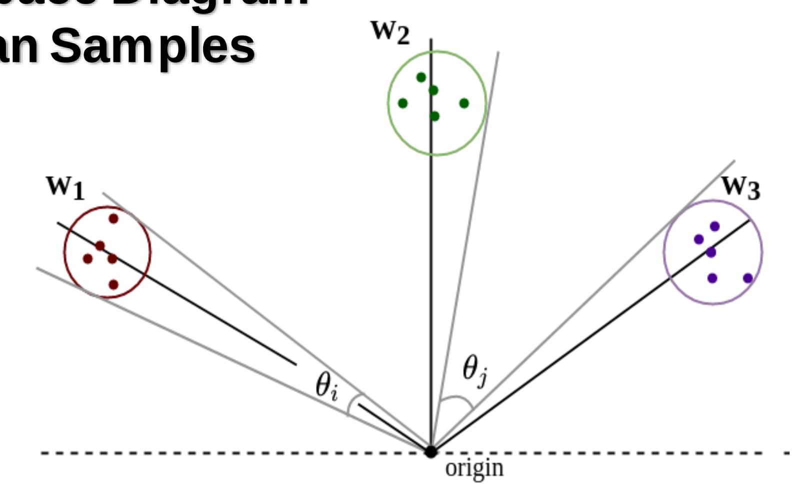


Feature Space of Deep Face Recognition

- In open-set face recognition, performance is dependent on inter-class separation and intra-class compactness in deep feature space.
- In feature space, magnitude is known to be highly correlated with recognition performance.
- **We study how feature space is affected by the presence of atmospherics.**

Feature Space Diagram of Clean Samples

θ_i: intra-class distance
θ_j: inter-class distance

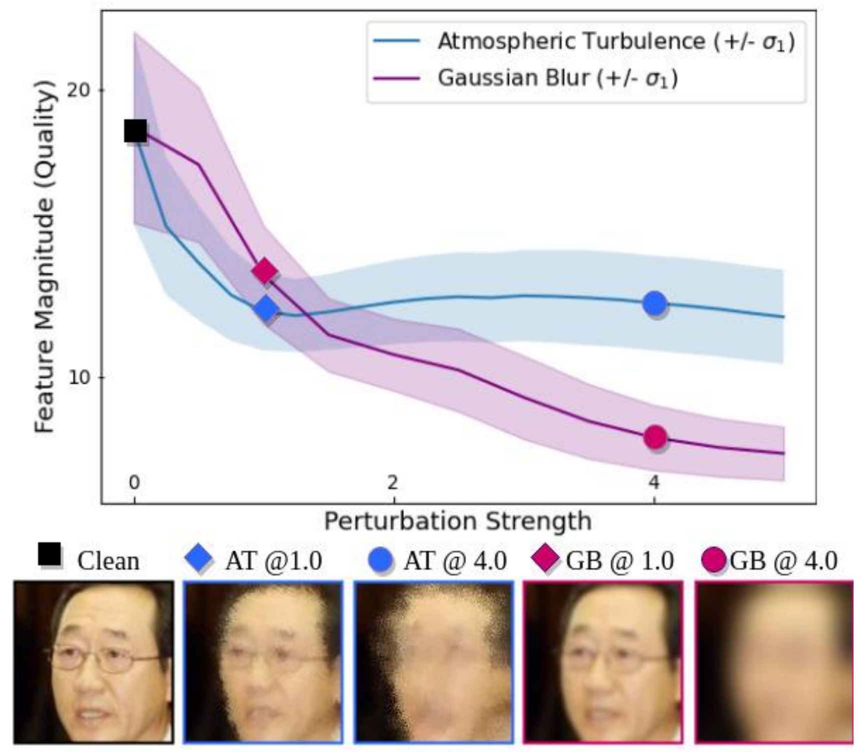


$\mathbf{w_1}, \mathbf{w_2}, \mathbf{w_3}$: separate class centers

Clean samples have large feature magnitudes (i.e., far from origin)

Model Behavior Under Atmospherics

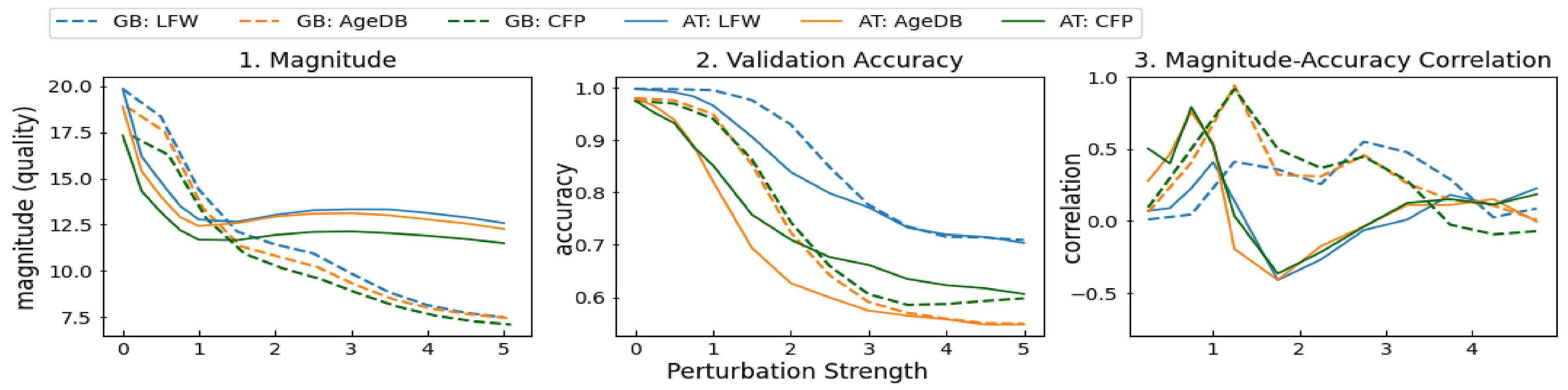
Feature Magnitude under Increasing Perturbations



We perturb the validation sets with varying levels of Gaussian blur to compare to the effect of atmospherics:

- Magnitude decreases monotonically under Gaussian blur perturbations
- Magnitude *is* ***non-monotonic*** *under atmospherics*, increasing from strengths 1-4.
- This suggests atmospheric turbulence is a uniquely challenging perturbation for face recognition.

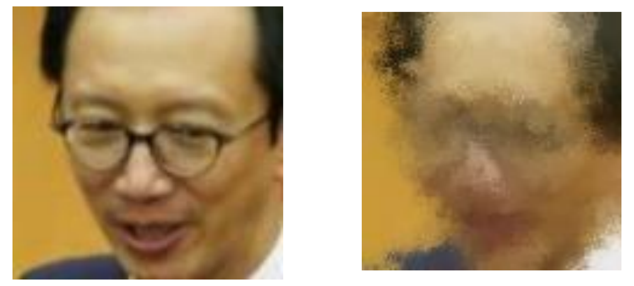
Accuracy and Quality Assessment Correlation



- **Significant impact on error rate (e.g., on LFW: 0.017% to 30.86%)**
- **Accuracy and Quality Assessment (i.e., magnitude) are poorly correlated**

Identifying *Feature Defection*

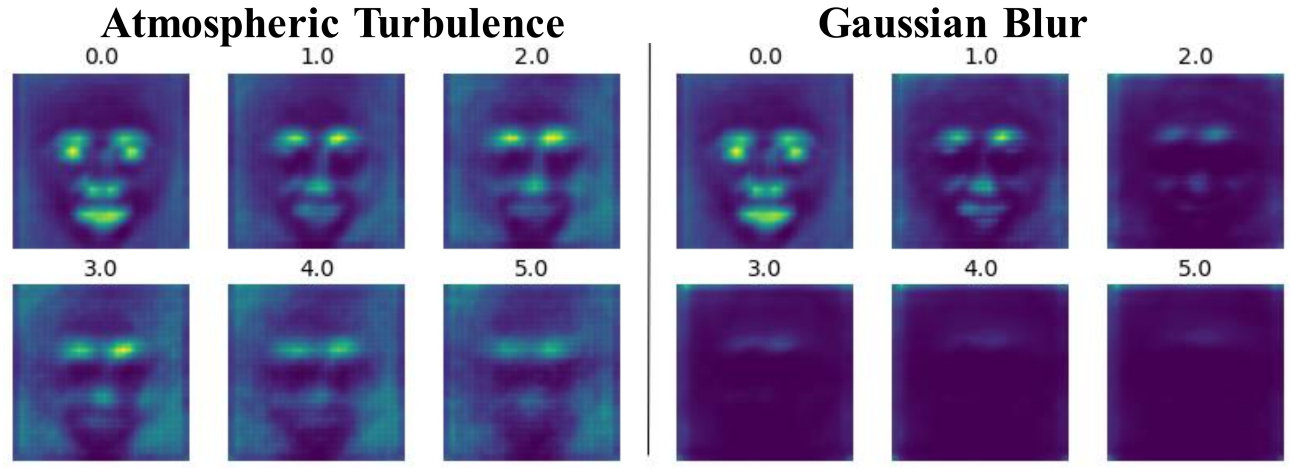
Clean vs. Atmospheric



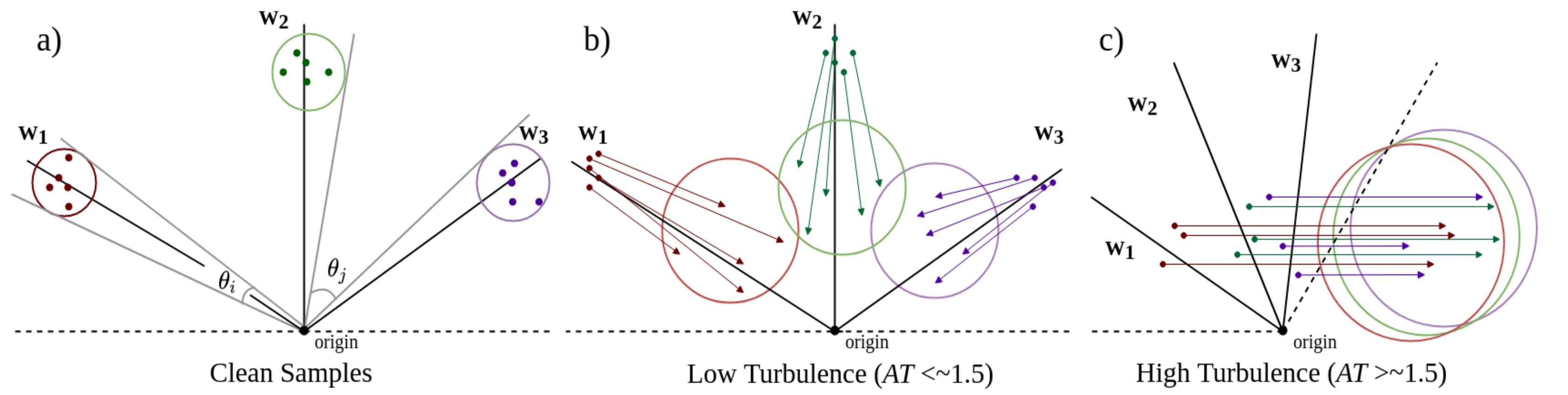
- Perturbed samples have new *'features'* around high-contrast regions (e.g., eyes, mouth, hairline).
- Misinterpreted by the model as salient features for identification.
- Significantly degrades model performance.

Activation Maps

Activation maps are considerably different between atmospheric and Gaussian blur perturbations. *Defected features* cause high activations despite highly degraded images.



Effect of Feature Defection in Feature Space



a) clean samples have high-class separation
b) under low-turbulence features decrease in magnitude
c) under high-turbulence feature space structure is lost

Ongoing & Future Work

Methods for Deep Feature Spaces Robust to Feature Defection

In this work we found atmospheric turbulence creates degrades feature space structure, which is detrimental to Face Recognition performance. We are working on methods for feature spaces that are robust to atmospherics by leveraging atmospheric data for both supervised and self-supervised training.

Validating Simulated Turbulence

A significant limitation of current work on atmospheric turbulence is that both training and testing are on simulated data with no reference to ground truth atmospherics. We are working to validate atmospheric simulators by comparing with images captured through real atmospheric conditions.

Conclusion

We show that Atmospheric turbulence significantly degrades feature space structure of deep face recognition models. Surprisingly, we find feature magnitudes increase under certain levels of atmospheric turbulence. Lastly, we outline paths for future work to overcome discovered challenges.

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