

Air-water temperature difference estimation from mirages based on deep learning

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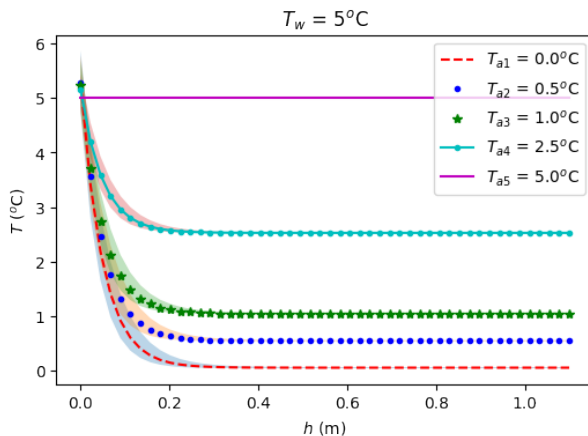
May 15, 2023

Outline

- ① Mirages and their importance
- ② Image generation
- ③ Machine learning
- ④ Testing on generated data
- ⑤ Testing on real-life data

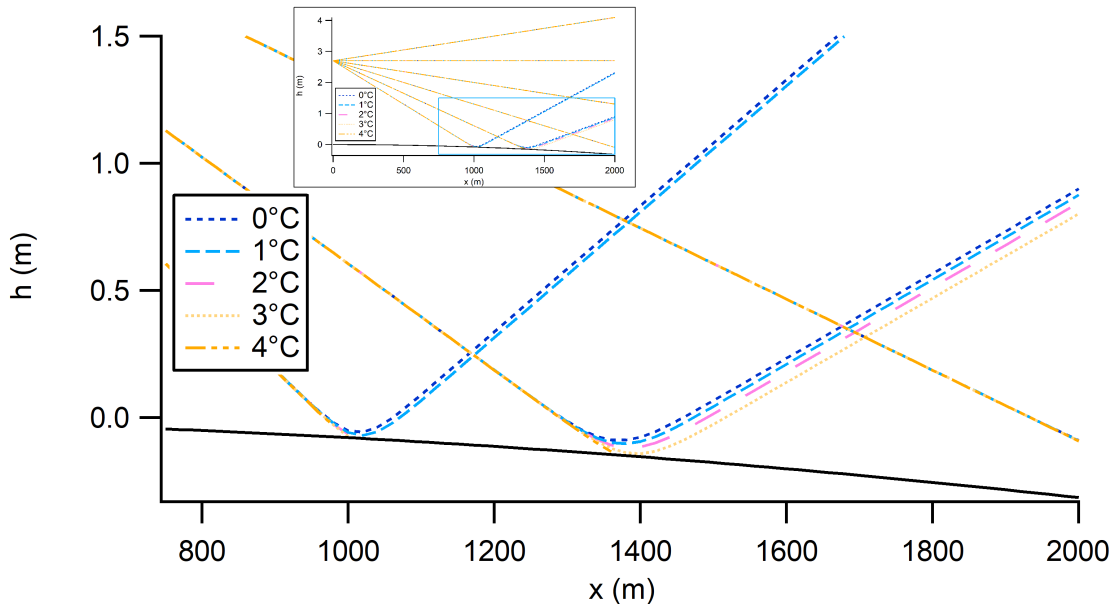
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Mirage formation 1

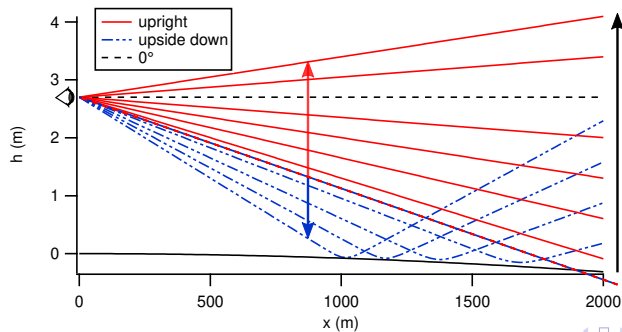
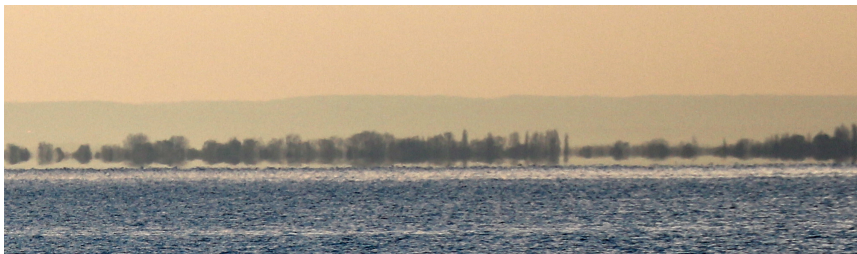


- Mirages occur when the ground or water body is warmer than the ambient air
- The higher the air temperature, the lower its index of refraction

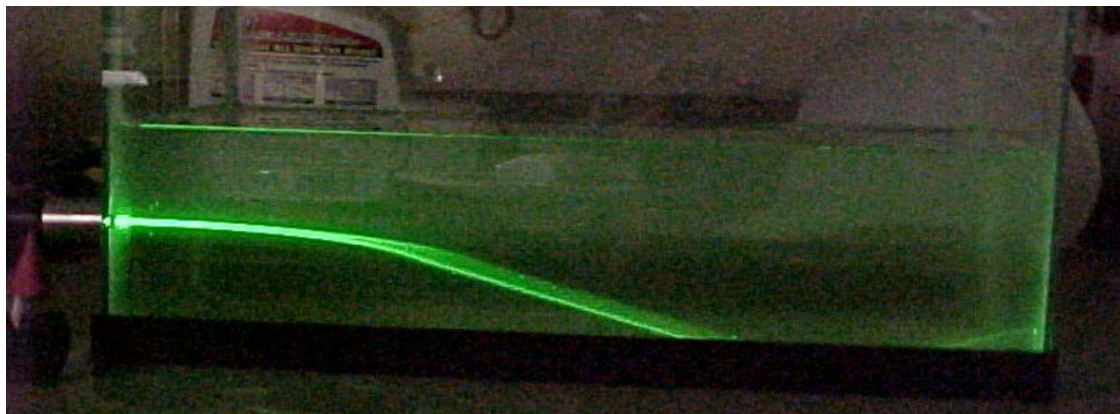
Mirage formation 2



Mirage formation 3



Light bending in sugar solution



- The solution is layered so that the higher concentration parts sink lower
- The higher the concentration, the higher its index of refraction

Mirages in current human life

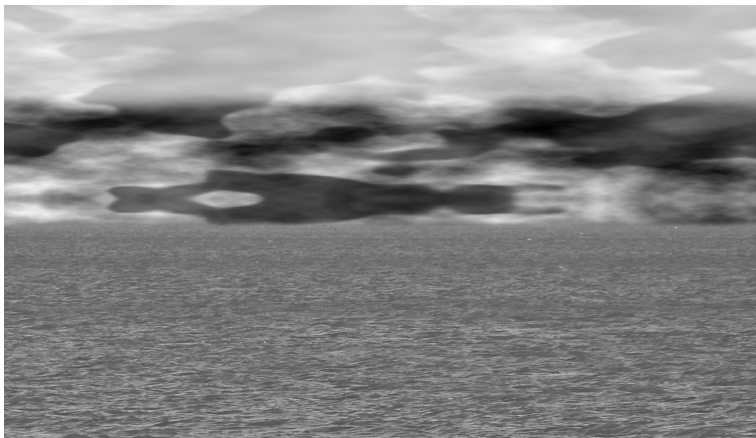


Figure: JASON EDWARDS / GETTY IMAGES

- Immediate decision making for self-driving cars and automated navigation systems
- Decide, whether rovers depicted water or mirages on planet Mars

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Problem: no annotated images available



- Wrong learning results

Artificial lake landscapes 1

Variable image properties:

- Place of horizon
- Water shade
- Water structure
- Sky shade and contrast
- Hills shade and contrast
- Trees shade and contrast



Artificial lake landscapes 2



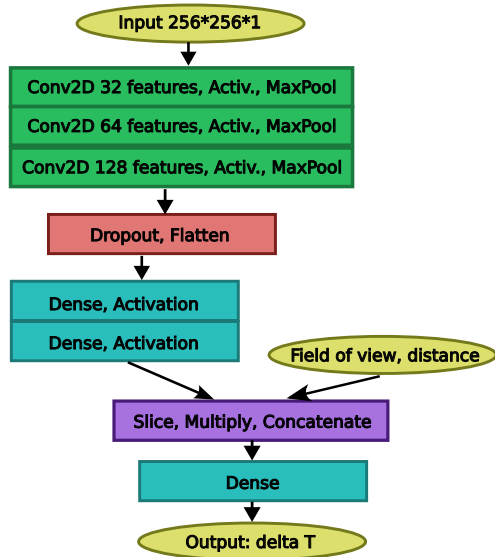
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Algorithm and framework selection

- Supervised learning
- TensorFlow
- Keras
- Convolution neural network
- Input image is 256*256 grayscale
- Input parameter is camera field of view and distance
- Annotation is temperature difference used for landscape generation

Algorithm and framework selection

- Regression network
- Around 1M trainable parameters
- A green block contains 3 layers:
 - 3*3 convolution
 - Exponential linear unit activation
 - Max pooling with decimation
- The dropout layer drops 20 percent of its input randomly
- The final concatenate also gets the product of the field of view and the CNN output



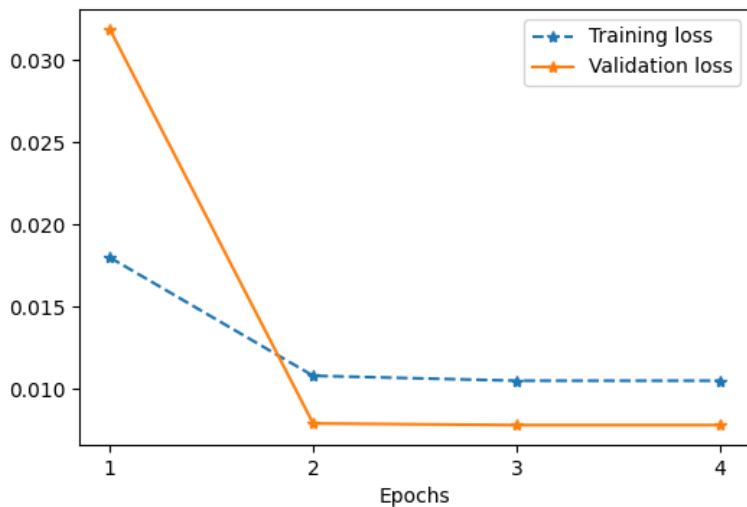
Network settings

Parameter	Value
Batch size	32
Training set size	1,024,000
Validation set size	128,000
Initial learning rate	0.001
Decay rate	0.05
Optimizer	Adam
Loss	mean squared error
Epochs	30

Training on GPU server of Wigner Scientific Computing Laboratory

- Ubuntu Linux
- Two AMD EPYC 7302 CPUs
- Eight NVIDIA A2 GPU
- Disk based image cache for subsequent epochs

Learning process



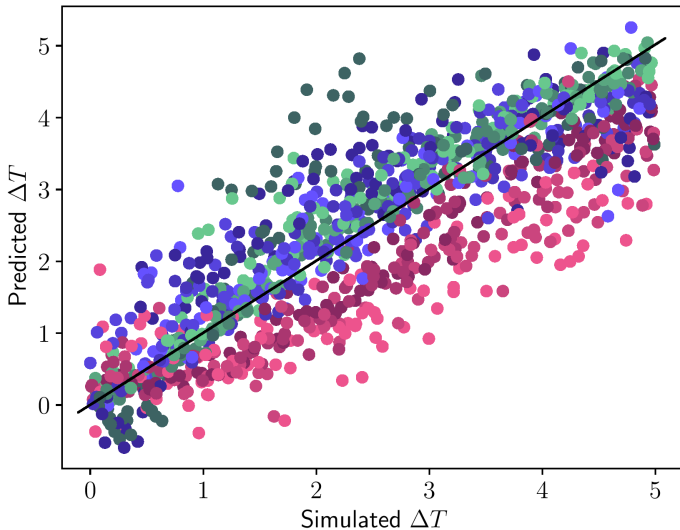
- 1 Mirages and their importance
- 2 Image generation
- 3 Machine learning
- 4 Testing on generated data**
- 5 Testing on real-life data

Correlation

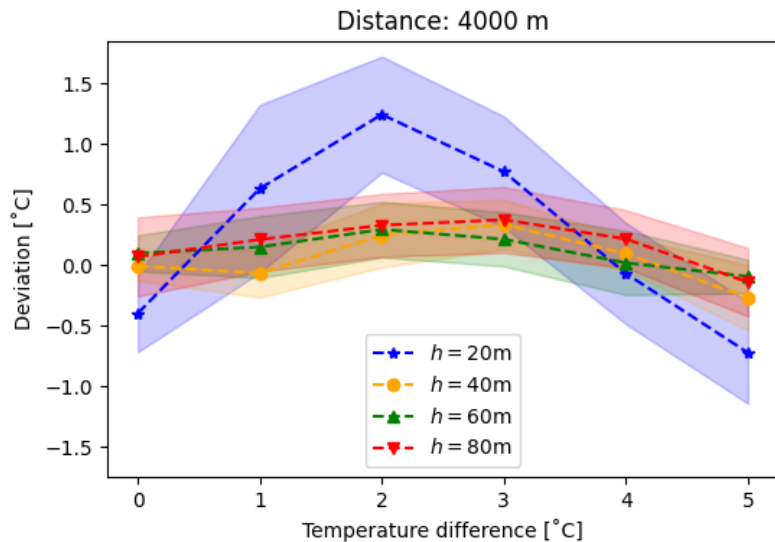
Inference for 1200
artificially created images
with object distances:

- Red: 4000 m
- Green: 8000 m
- Blue: 16000 m
- black line: identity

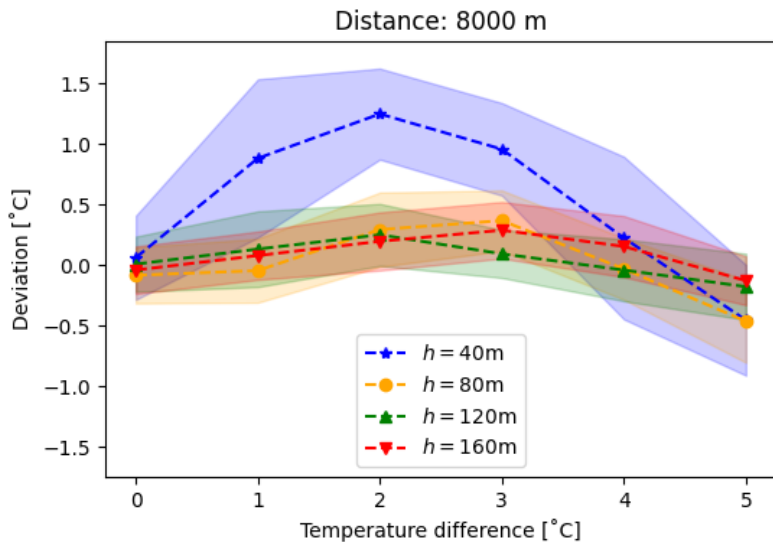
The lighter the dot, the
taller the object.



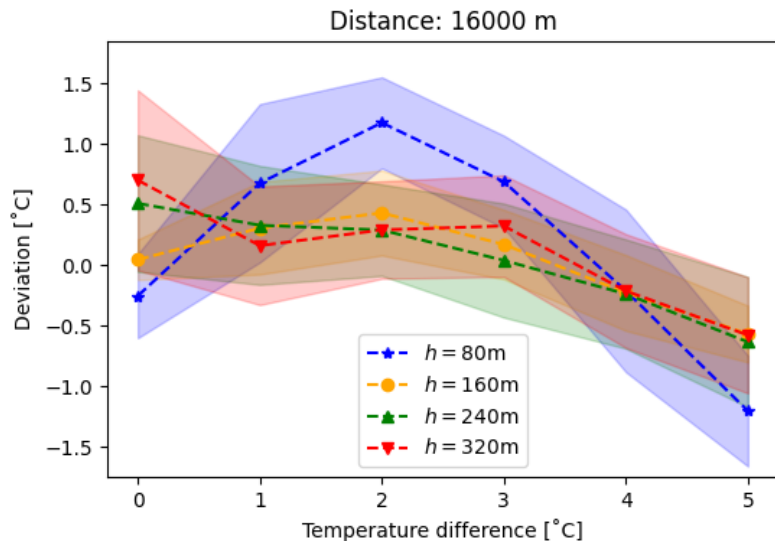
Error and its standard deviation



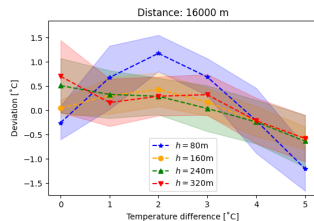
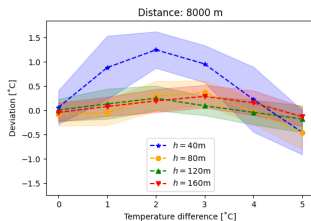
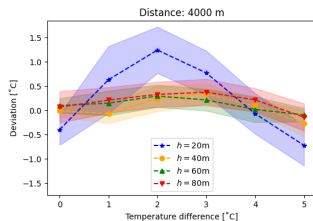
Error and its standard deviation



Error and its standard deviation



Error and its standard deviation



Mainly linear correlation

Sources of error:

- relatively small object height – $h/D \lesssim 1\%$ is problematic
- border of ΔT -domain
- large distance $\sim 16,000$ m – due to limited resolution and Earth's curvature
- small distance $\lesssim 1,000$ m – due to incomplete mirage formation

And now on to some real pictures!

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Measurements were difficult!



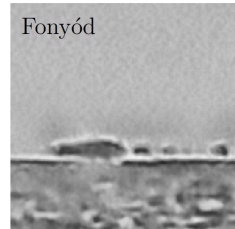
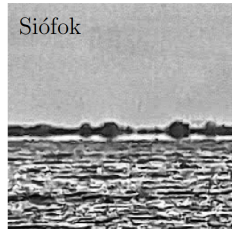
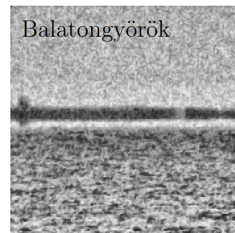
Photos

Modifications:

- converting to black-and-white
- cropping
- increasing contrast

Sources of error:

- lighting, shades
- low resolution
- contrast increasing method
- measurement of temperatures and distance



Measured and predicted temperature values

Depicted place	Distance [km]	T_a [°C]	T_w [°C]	$\Delta T_{Pred.}$ [°C]	ΔT [°C]	Diff. [°C]
Balatonfenyves	16.8	1.0	5.0	0.0	4.0	4.0
Balatongyörök	6.8	3.5	9.0	1.4	5.5	3.9
Siófok	13.5	6-7	11	3.5	4-5	0.5-1.5
Fonyód	20.0	20-21	20	0.7	0.0	-0.7

Summary

Goal: obtain temperature difference between water surface and ambient air from images of mirages

Methods:

- Generating artificial images with mirages
- Convolutional deep neural network
- Supervised learning

Results:

- Inference works well on generated mirage images
- Real-life data is difficult to process
- Lack of measurement data



Photographed by Katalin Horváth

Thank you for your attention!