

# UGAN: Underwater Image Restoration using Generative Adversarial Networks

Cameron Fabbri  
Information Directorate  
Air Force Research Laboratory  
Rome, NY, USA.  
cameron.fabbri@us.af.mil

Md Jahidul Muslim  
UMN

Junaed Sattar  
UMN

**Abstract**—Autonomous underwater robots often rely on visual input for decision making due to its non-intrusive and passive nature. However, due to many factors such as light refraction, particles in the water, and color distortion, images are often times very noisy. This paper propose a method using Generative Adversarial Networks (GANs) to denoise underwater images, and show that these images provide both increased accuracy for an underwater tracking algorithm, as well as a more visually appealing image. Furthermore, we show how recently proposed methods are able to generate a dataset for the purpose of underwater image reconstruction.

## I. INTRODUCTION

TODO - talk about having to go back to the same location if you want to get good/bad pairs of the "same" image. Vision is a commonly used sensor in autonomous underwater robots due to its non-intrusive, passive, and energy efficient nature. The monitoring of coral reefs [1], deep ocean exploration [2], and mapping of the seabed are all tasks suitable for autonomous robots because they provide safety by taking the risk instead of a human. Despite the advantages vision provides, many underwater environments can be quite noisy due to light refraction and particles present in the water. Because red wavelengths are quickly absorbed by water, images tend to have a green or blue hue to them. As you go deeper, this worsens as more and more red wavelengths are being absorbed. This extremely non-linear distortion has many factors such as the amount of light present (overcast vs sunny or depth), particles in the water, time of day, and the camera being used. This may cause difficulty in tasks such as segmentation, tracking, or classification due to their indirect or direct use of color.

As color and illumination begin to change with the depth, vision based algorithms must be very generalizable in order to work within the depth ranges a robot may operate in. Because of the high cost and difficulty of acquiring a variety of underwater data, as well as the high amount of noise introduced, many algorithms may perform poorly in these different domains. Figure 1 shows the high variability that may occur in underwater environments. A step towards a solution to this issue is to be able to restore the images such that they appear to be above water, i.e., with colors corrected and particles removed. By performing a many to one mapping of these domains from underwater to not underwater (what the image would look like in the air), algorithms that have



Fig. 1. Underwater images showing the vast diversity of noise that can occur, including different hues of green and blue, as well as particles in the water.

difficulty performing across multiple forms of noise may be able to focus only one clean domain.

Deep neural networks have been shown to be powerful non-linear function approximators, especially in the field of vision. Often times, these networks require large amounts of data, either labeled or paired with ground truth. For the problem of automatically colorizing grayscale images, paired training data is essentially free due to the fact that any color image can be converted to black and white. However, underwater images distorted by either color or some other visual effect lack ground truth. We use the recently proposed CycleGAN [3], which learns to translate an image from domain  $X$  to domain  $Y$ , as a way to generate a paired dataset. By letting  $X$  be a set of undistorted underwater images, and  $Y$  be a set of distorted underwater images, we can generate an image that appears to be underwater while retaining ground truth.

## II. RELATED WORK

While there have been many very successful recent approaches towards automatic colorization [4], [5], most are focused on the task of grayscale to color. The work of [6] used an energy minimization formulation using a Markov Random Field. MORE RELATED BLAH. Many use physics based models to directly model the light source and such. Most similar to our line of work is the recently proposed WaterGAN [7], which uses GANs for color correction of underwater images.

As ground truth pairs do not exist for underwater images, their first step is to structure a generator to create realistic underwater images. Their generator model can be broken down into three stages: 1) Attenuation, which accounts for range-dependent attenuation of light. 2) Scattering, which models the haze effect caused by photons scattering back towards the image sensor. 3) Vignetting, which produces a shading effect on the image corners that can be caused by certain camera lenses. Opposed to our work, they use a GAN for generating the underwater images and Euclidean loss for color correction, whereas we use a GAN for both. Furthermore, they require depth information during the training of WaterGAN, whereas we only require two separate image domains.

Recent work in generative models, specifically GANs, have shown great success in areas such as inpainting [8], style transfer [9], and image-to-image translation [10], [3]. This is highly due to their ability to provide a more meaningful loss than simply the Euclidean distance, which has been shown to produce blurry results. In our work, we structure the problem as paired image-to-image translation, using Generative Adversarial Networks (GANs) as our generative model. Much like the work of [10], we use image pairs from two domains as input and ground truth.

### III. METHOD

#### A. Dataset Generation

Here we describe our dataset generation process. Depth, lighting conditions, camera model, and location are all factors that affect the amount of distortion an underwater image undergoes. Under certain conditions, it is possible that an underwater image may have very little distortion, or none at all. We let  $I^C$  be an underwater image with no distortion, and  $I^D$  be the same image with distortion. Our goal is to learn the function  $f : I^D \rightarrow I^C$ . Because of the difficulty of collecting underwater data, more often than not only  $I^D$  or  $I^C$  exist, but never both.

We use the recently proposed CycleGAN [3] to generate  $I^D$  from  $I^C$ , which gives us a paired dataset of images. Given two datasets  $X$  and  $Y$ , where  $I^C \in X$  and  $I^D \in Y$ , CycleGAN learns a mapping  $F : X \rightarrow Y$ . Figure 2 shows paired samples generated from CycleGAN. From this paired dataset we train a generator  $G$  to learn the function  $f : I^D \rightarrow I^C$ . It should be noted that during our data generation process, CycleGAN simultaneously learns a mapping  $G : Y \rightarrow X$ , which is similar to  $f$ . In section IV we show a comparison with our method.

#### B. Adversarial Networks

GANs [11] are a class of generative models based on game theory in which a generator network competes against an adversary. Given an image  $I^D$ , the generator is trained to produce an image to try and fool the discriminator, which is trained to distinguish between distorted and non-distorted underwater images. In the original GAN formulation, the goal is to solve the minimax problem:



Fig. 2. Paired samples of ground truth and distorted images generated by CycleGAN. Top row: Ground truth. Bottom row: Generated samples.

$$\min_G \max_D \mathbb{E}_{I^C \sim p_{train}(I^C)} [\log D(I^C)] + \mathbb{E}_{I^D \sim p_{gen}(I^D)} [\log(1 - D(G(I^D)))] \quad (1)$$

In this formulation, the discriminator is hypothesized as a classifier with a sigmoid cross entropy loss function, which in practice may lead to issues such as the vanish gradient and mode collapse. There have been many recent works which hypothesize a different loss function for the discriminator [12], [13], [14], [15]. In our work, we adopt the Wasserstein GAN with gradient penalty (WGAN-GP) [14], which instead of clipping network weights like in [13], enforces the Lipschitz constraint by constraining the gradient norm of the discriminator's output with respect to its input. Following [14], the new objective then becomes

$$L = \mathbb{E}_{I^D \sim p_{gen}(I^D)} [D(I^D)] - \mathbb{E}_{I^C \sim p_{train}(I^C)} [D(I^C)] + \lambda \mathbb{E}_{\hat{x} \sim \mathbb{P}_{\hat{x}}} [(||\nabla_{\hat{x}} D(\hat{x})||_2 - 1)^2] \quad (2)$$

#### C. Image Gradient Difference Loss

#### D. Network and Training Details

L1 weight 100, batch size 32, wgan loss, learning rate 1e-4, IG weight 1.0 and 0.0, 100 epochs Following WGAN-GP, the discriminator is updated  $n$  times for every update of the generator, where  $n = 5$ .

### IV. EXPERIMENTS

Here I want to show a number of things. First talk about the datasets used, Imagenet and the diving videos. Second, show some general results. Explain how our network is able to do three very important things: 1) Restore an image to its natural colors with varying amounts of distortion, i.e. blue hue, green hue, aka not just one type of color distortion. 2) The network does not just subtract a certain hue from the entire image. Show how in the clownfish image, part of the image has good colors, while part of it doesn't. Our network is able to leave correct colors. Third, show that even images taken towards the water's surface, either above or below, are able to be restored correctly.

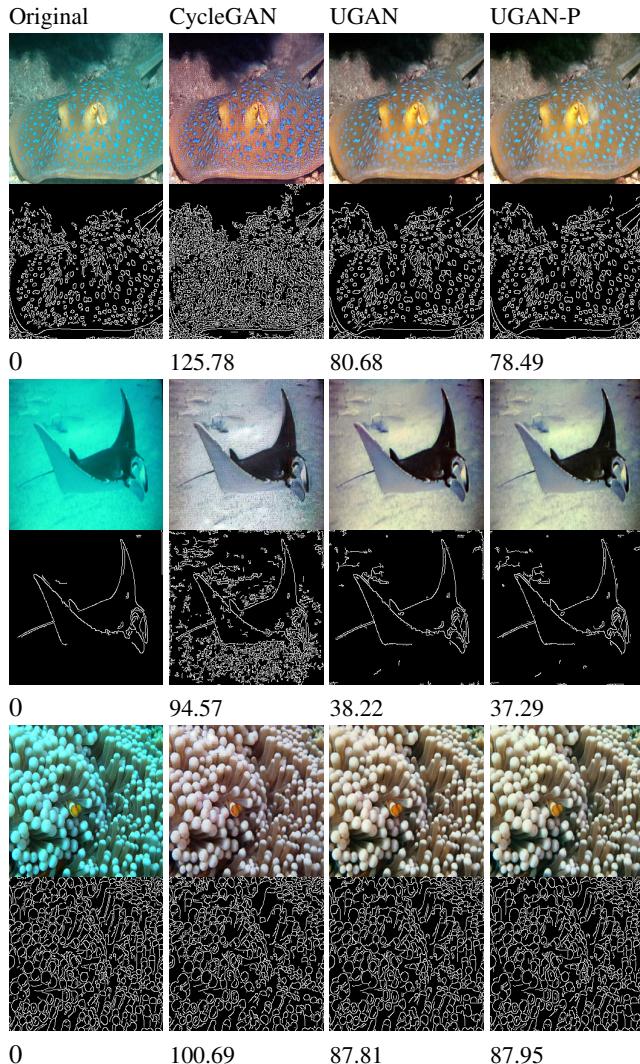


Fig. 3. Running the Canny Edge Detector on sample images. Both variants of UGAN contain less noise than CycleGAN, and are closer in the image space to the original. For each pair, the top row is the input image, and bottom row is the result of the edge detector.

Third mention that since CycleGAN has a cycle consistent nature, compare their results. Then from there go into how ours are better by showing results from Canny Edge Detector.

## V. CONCLUSION

## ACKNOWLEDGMENT

## REFERENCES

- [1] F. Shkurti, A. Xu, M. Meghjani, J. C. G. Higuera, Y. Girdhar, P. Giguere, B. B. Dey, J. Li, A. Kalmbach, C. Prahalas, *et al.*, “Multi-domain monitoring of marine environments using a heterogeneous robot team,” in *Intelligent Robots and Systems (IROS), 2012 IEEE/RSJ International Conference on*, pp. 1747–1753, IEEE, 2012.
- [2] L. Whitcomb, D. R. Yoerger, H. Singh, and J. Howland, “Advances in underwater robot vehicles for deep ocean exploration: Navigation, control, and survey operations,” in *Robotics Research*, pp. 439–448, Springer, 2000.
- [3] J.-Y. Zhu, T. Park, P. Isola, and A. A. Efros, “Unpaired image-to-image translation using cycle-consistent adversarial networks,” *arXiv preprint arXiv:1703.10593*, 2017.

- [4] R. Zhang, P. Isola, and A. A. Efros, “Colorful image colorization,” in *European Conference on Computer Vision*, pp. 649–666, Springer, 2016.
- [5] S. Iizuka, E. Simo-Serra, and H. Ishikawa, “Let there be color!: joint end-to-end learning of global and local image priors for automatic image colorization with simultaneous classification,” *ACM Transactions on Graphics (TOG)*, vol. 35, no. 4, p. 110, 2016.
- [6] L. A. Torres-Méndez and G. Dudek, “Color correction of underwater images for aquatic robot inspection,” in *EMMCVPR*, pp. 60–73, Springer, 2005.
- [7] J. Li, K. A. Skinner, R. M. Eustice, and M. Johnson-Roberson, “Watergan: Unsupervised generative network to enable real-time color correction of monocular underwater images,” *arXiv preprint arXiv:1702.07392*, 2017.
- [8] D. Pathak, P. Krahenbuhl, J. Donahue, T. Darrell, and A. A. Efros, “Context encoders: Feature learning by inpainting,” in *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pp. 2536–2544, 2016.
- [9] L. A. Gatys, A. S. Ecker, and M. Bethge, “Image style transfer using convolutional neural networks,” in *The IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2016.
- [10] P. Isola, J.-Y. Zhu, T. Zhou, and A. A. Efros, “Image-to-image translation with conditional adversarial networks,” *arXiv preprint arXiv:1611.07004*, 2016.
- [11] I. Goodfellow, J. Pouget-Abadie, M. Mirza, B. Xu, D. Warde-Farley, S. Ozair, A. Courville, and Y. Bengio, “Generative adversarial nets,” in *Advances in neural information processing systems*, pp. 2672–2680, 2014.
- [12] X. Mao, Q. Li, H. Xie, R. Y. Lau, Z. Wang, and S. P. Smolley, “Least squares generative adversarial networks,” *arXiv preprint ArXiv:1611.04076*, 2016.
- [13] M. Arjovsky, S. Chintala, and L. Bottou, “Wasserstein gan,” *arXiv preprint arXiv:1701.07875*, 2017.
- [14] I. Gulrajani, F. Ahmed, M. Arjovsky, V. Dumoulin, and A. Courville, “Improved training of wasserstein gans,” *arXiv preprint arXiv:1704.00028*, 2017.
- [15] J. Zhao, M. Mathieu, and Y. LeCun, “Energy-based generative adversarial network,” *arXiv preprint arXiv:1609.03126*, 2016.