WATER SURFACE RECONSTRUCTION AND TRULY RANDOM NUMBERS GENERATION FROM IMAGES OF WIND-GENERATED GRAVITY WAVES

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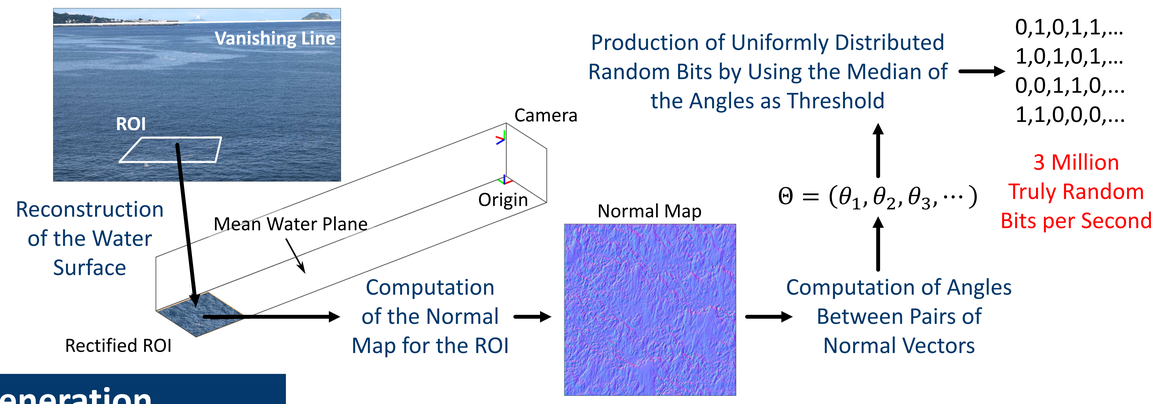
Abstract

We present an image-based approach to generate truly random numbers from the surface of water bodies such as oceanic bays. As a natural phenomenon, wind-generated gravity waves have non-deterministic behavior. We use the randomness of the angular relation between pairs of surface normals to generate uniformly distributed random binary digits and then we build random numbers from those digits. Our approach produces compelling geometric models of water surfaces and generates random numbers with high entropy.

Methodology



Water Surface Estimation

The reflectance function:

$$R(x,y) = R_{btm}(1 - F_\lambda) + R_{sky}\,F_\lambda$$
$$= R_{btm} + \left(R_{sky} - R_{btm}\right)(1 - \vec{n}\cdot\vec{v})^5$$

F_λ: Schlick's approximation for the Fresnel factor
R_{btm}, R_{sky}: reflectance of water bottom and sky
$\vec{v}$, $\vec{n}$: unit vector pointing to the viewer and unit surface normal at (x,y)

The height map at the tth iteration[1]:

$$Z^t(x,y) = Z^{t-1}(x,y) - \frac{f(Z^{t-1}(x,y))}{\frac{df}{dZ(x,y)}(Z^{t-1}(x,y))}$$

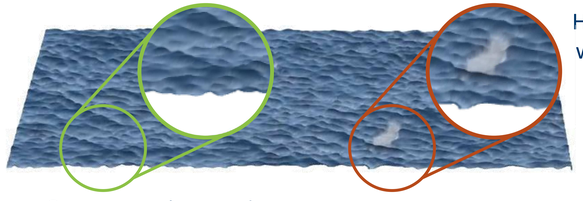
with $Z^0(x,y) = 0$, and f defined with respect to R

Results on Random Numbers Generation

NIST Statistical Test[2]	GCC[3]	VC[4]	MATLAB[5]	RANDOM[6]	Proposed
Frequency	0	0	992	987	998
Frequency within a block	1,000	1,000	987	988	990
Runs	0	58	989	989	987
Longest run of ones	0	0	992	990	991
Binary matrix rank	1,000	1,000	991	991	989
Discrete Fourier transform	1,000	1,000	987	986	983
Non-overlapping template	135/148	126/148	148/148	148/148	147/148
Overlapping template	0	0	986	988	981
Maurer	1,000	1,000	988	975	986
Linear complexity	1,000	1,000	987	985	986
Serial	1,000; 1,000	1,000; 1,000	984; 981	987; 987	994; 995
Approximate entropy	0	0	989	992	989
Cumulative sums	0; 0	0; 0	990; 992	989; 989	998; 998
Random excursions	-/-	265/265	616/616	616/616	827/827

[1] Ping-Sing and Shah, "Shape from shading using linear approximation," Image Vis. Comput., 12(8), pp. 487-498, 1994.
[2] Rukhin et al. "A statistical test suit for random and pseudo-random numbers generators for cryptographic applications", Tech. Rep. NIST SP 800-22 R1a, NIST, April, 2010.
[3] Free Software Foundation, Inc. "The GNU C Library: ISO Random", August 2, 2017. Used with GCC 6.3.1.
[4] Microsoft Corporation, "Visual Studio 2015", July 20, 2015.
[5] The MathWorks Inc. "MATLAB R2016b", September, 2016.
[6] M. Haahr, "RANDOM.ORG", [Online]: https://www.random.org, 1998.

Results on Water Surface Reconstruction



Here, the surface was distorted by foaming scum

Our approach reproduces the hills and the valleys observed in the input image

Reconstruction on a Sunny Day

Reconstruction on a Cloudy Day

Reconstruction on a Wavy Day

Conclusion

The main contributions of this paper include:
(i) a shape from shading solution for water surface reconstruction from single perspective projection images that considers the Fresnel effect observed in nature; and
(ii) an image-based truly random number generator that uses the slope of wind-generated gravity waves as the source of randomness.

Our approach reconstructs the geometry of the water surface under natural illumination conditions. We demonstrated the effectiveness of the proposed technique by using it to reconstruct the surface of water bodies such as oceanic bays, and by using the NIST Test Suite[2] to evaluate the quality of the generated random numbers.

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