International Journal of Engineering & Technology, 7 (4.39) (2018) 686-689

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Marine Breakwater Simulator using 3D Printing and Stereo Vision

Sunjin Yu[1], Kyung Sung Kim[2*]

[1]*School of Digital Media Engineering, Tongmyong University,428, Sinseon-ro, Nam-gu, Busan 48520,Republic of Korea*
[*2]*School of Naval Architecture and Ocean Engineering, Tongmyong University, 428, Sinseon-ro, Nam-gu, Busan 48520,Republic of Korea*
**Corresponding author Email: keiuskim@tu.ac.kr*

Abstract

Background/Objectives: Breakwaters are widely used to reduce the risk of waves. In this paper, we propose a marine breakwater simulator using 3D printer and Stereo Camera.
Methods/Statistical analysis: The proposed system can be divided into three parts. First, we create a virtual wave generator to create the breakwater effect. Next, a buoy with 3D printing technology is made to measure the water height. Finally, we use visual sensors to track our buoys.
Findings: We use 3D printing technology to create custom buoys and use them in simulators. Therefore, customized buoys can be 3D printed to match the simulator situation. The custom buoy is designed to be easily tracked from the vision sensors. We use color and shape information to track the buoy. First, candidate regions of the buoy are extracted using color information. Next, the shape fitting technique finds the location of the real buoy among the candidate areas of the buoy. Finally, we use the Kalman filter to keep track of the position of the buoy. In this paper, we attempt to shift from the existing marine breakwater research using large equipment or virtual space to the study of measuring the actual height of actual waves. We have improved the function of the ocean breakwater simulator by using computer vision technology.
Improvements/Applications: The proposed wave generation simulator can generate virtual waves and simulate wave danger and wave risk protection by measuring wave height using 3D printing and vision technology.

Keywords: *3D Printing, Stereo Vision, Breakwater, Simulator, Kalman Filter.*

1. Introduction

Typhoons and convection can cause high waves on the coasts and cause disasters in residential and commercial facilities. Breakwaters play an important role in reducing the risk of high waves on the coast. Marine breakwaters are used to minimize the effects of rough and high waves on the coast. At present, the landscape of the coastal area changes according to the height of the breakwater, and various complaints such as tourists and residents are raised. In order to reduce the damage of hurricane waves caused by typhoons or worsening weather and to avoid damaging the landscape, it is necessary to set the height of marine breakwater according to the situation[1-4], or to lower the height of marine breakwater for normal coastal scenery. In this paper, we propose a simulator to control the height of marine breakwater along the wave height. For marine breakwater simulators, we use 3D printing technology and computer vision technology. For custom buoy creation, we apply 3D printing technology. Using 3D printing technology, we can create various shapes of buoys. The buoy is used to measure the height of the wave. To measure the height of the waves, we have created floating buoys in water and 3D printing in hollow form. To track the buoy through vision technology, we first extract candidate areas of the buoy with color information[5].Filaments which are easy to extract color are used in the production of buoys using 3D printing. To detect the buoy in the image, shape fitting technique is applied among candidate regions. The position of the buoy in the image can be determined through the shape fitting step. To track the location of the buoy in real time we use the Kalman filter [6,7].Vision-based object detection and tracking technology can track the location of buoys in frames acquired from the camera. For wave height measurement, we use Stereo vision technology, which is one of the representative computer vision fields[8,9].Through the camera calibration step, internal and external parameters of the camera are obtained. Then we use the relationship between two cameras to solve the correspondence problem. Finally, we use triangulation to extract the three-dimensional coordinates of the buoy[8,9].In this way, the verification of the position of the buoy is solved using computer vision techniques. Next, we construct a water tank and a virtual wave generator for a marine breakwater simulator. Various computer vision techniques for buoy tracking have been used. First, a color image processing technique is used to detect the buoys candidate region. Next, we use a tracking technique that uses the Kalman filter for buoy tracking. Finally, stereo vision technology is applied for three-dimensional position measurement of buoys.

2. Background

Various computer vision techniques for buoy tracking have been used. First, a color image processing technique is used to detect the buoy candidate region. Next, we use a tracking technique that uses the Kalman filter for buoy tracking. Finally, stereo vision technology is applied for three-dimensional position measurement of buoys.

2.1. Color Space

In the field of computer vision, there are various color spaces representing colors such as RGB, YCbCr, and HSI. Images obtained from cameras usually represent data on an RGB color space basis. There is a conversion equation between color spaces to extract characteristics of a specific color distribution. The conversion from RGB color space to HSI color space[5] is as follows.

$$H = \begin{Bmatrix} \theta & if\ B \leq G \\ 360 - \theta & if\ B \geq G \end{Bmatrix}, \quad \theta = COS^{-1}\left\{\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{\frac{1}{2}}}\right\} \tag{1}$$

2.2. Kalman Filter

To track the position of the buoy in the image, we use a Kalman filter. Kalman filter which is one of the representative tracking algorithms solves the problem of linear filtering of discrete data using a recursive method. The Kalman filter is used to refine the state from the error after estimating the state. The Kalman filter is represented as Table 1[10].

Table 1: Summary of Kalman Filter

Kalman Filter	Control	Measurement
Update	$x_t = A_t x_{t-1} + B_t u_t + \varepsilon_t$	$z_t = C_t x_t + \delta_t$
Mean	$\bar{\mu}_t = A_t \mu_{t-1} + B_t u_t$	$u_t = \bar{\mu}_t + K_t(z_t - C_t\bar{\mu}_t)$
Covariance	$\bar{\Sigma}_t = A_t \Sigma_{t-1} A_t^T + R_t$	$\Sigma_t = (I - K_t C_t)\bar{\Sigma}_t$
Kalmangain	-	$K_t = \bar{\Sigma}_t C_t^T (C_t \bar{\Sigma}_t C_t^T + Q_t)^{-1}$

2.3. Stereo Vision

Stereo vision is a field of computer vision that acquires 3D information through image information obtained from two cameras. A calibration step, which is a step of acquiring internal and external information of the camera, is required prior to acquiring three-dimensional information. The internal parameters of the camera are composed of five parameters. The external parameters of the camera consist of 6 parameters including 3 parameters for rotation and 3 parameters for translation. A total of 11 camera parameters can be acquired through the calibration step[8]. The 11 camera parameters are shown as in (2),(3).

$$\mathbf{K} = \begin{bmatrix} \alpha_x & s & x_0 \\ 0 & \alpha_y & y_0 \\ 0 & 0 & 1 \end{bmatrix}, \tag{2}$$

α_x *is the scale factor in the x − coordinate direction*
α_y *is the scale factor in the y − coordinate direction*
s *is the skew*
$(x_0, y_0)^T$ *are the coordinates of the principal point*

$$\mathbf{R} = \begin{bmatrix} r_{11} & r_{12} & r_{11} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}, \ \mathbf{T} = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix}, \tag{3}$$

R *is the rotation matrix*
T *is the translation vector*

The direct analogue of the DLT method[8] is employed for linear triangulation. In each image we have a measurement **x=PX**, **x'=P'X**, and combined equations are applied into a from **AX=0,** which is an equation linear in **X** . Due to a cross product, the first the homogeneous scale factor would be eliminated. It gives three equations for each image point, of which two are linearly independent. For example for the first image, **x** × (**PX**)=**0** and writing this out gives

$$\begin{aligned} x(\mathbf{p}^{3T}\mathbf{X}) - (\mathbf{p}^{1T}\mathbf{X}) &= \mathbf{0} \\ y(\mathbf{p}^{3T}\mathbf{X}) - (\mathbf{p}^{2T}\mathbf{X}) &= \mathbf{0} \\ x(\mathbf{p}^{2T}\mathbf{X}) - y(\mathbf{p}^{1T}\mathbf{X}) &= \mathbf{0} \end{aligned} \tag{4}$$

, where superscription iT denotes row elements of **P**. These equations are linear in the components of **X**.

An equation of the form **AX=0**can then be composed, with

$$\mathrm{A} = \begin{bmatrix} x\mathbf{p}^{3T} - \mathbf{p}^{1T} \\ y\mathbf{p}^{3T} - \mathbf{p}^{2T} \\ x'\mathbf{p}'^{3T} - \mathbf{p}'^{1T} \\ y'\mathbf{p}'^{3T} - \mathbf{p}'^{2T} \end{bmatrix} \tag{5}$$

,where two equations have been included from each image, giving a total of four equations in four homogeneous unknowns. This is a redundant set of equations, since the solution is determined only up to scale. Matrix A was solved by SVD.

3. Proposed System

3.1. Customized Buoy by 3D Printing

Because buoys can be freely produced in size and shape according to the experimental environment, we use 3D printing technology to make buoys. We have confirmed the shape and size through various experiments. In this paper, we use buoys of spherical shape among various types of buoys. The buoys are made in a grid shape so that the manufactured buoys can float on the water. Figure 1 shows customized buoy by 3D printing.

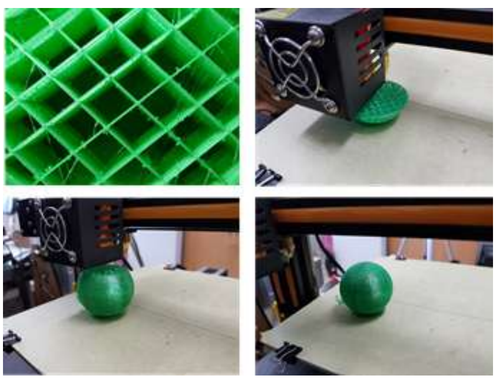

Figure 1: Customized Buoy by 3D Printing

3.2. Extraction and Decision Step in 2D

In order to extract the position of a buoy in an input image from a camera, first, a RGB image is converted into a HSV image and the buoy position candidate region is detected. With HSV conversion, we can extract colors in specific areas. From the images converted to HSV, we detect only the green region. Because we use buoys using green filaments, we extract the green region, but we can change the color to extract according to the experimental environment. After HSV conversion, image binarization and labeling are performed and the extraction step proceeds. Figure 2shows Buoy Candidate Region Extraction Step Procedure in 2D Space.

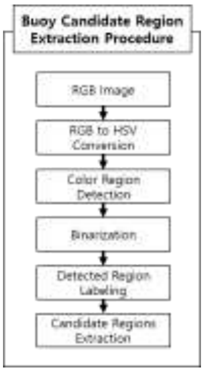

Figure 2: Buoy Candidate Region Extraction Step Procedure in 2D Space

After the buoy candidate region extraction step, we proceed to the decision step. First, the image including the candidate regions is Hough transformed. After applying Hough transform, circular shape detection is performed to find shape of circular shape. Next, the center point is calculated from the detected circular shape. The calculated center point is used as the initial position value in the tracking step. Figure 3 shows Buoy Region Decision Step Procedure in 2D Space.

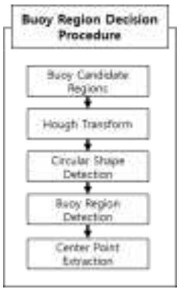

Figure 3: Buoy Region Decision Step Procedure

3.3. Tracking Step in 2D

The extraction of the center point extracted from the extraction and decision step is used as an initial value, and the tracking is started from the next frame. We use Kalman filter which is a representative tracking algorithm for buoy tracking in video. To prevent erroneous tracking, a rectangular area is created based on the extracted center point and is continuously tracked in the next frame. Figure 4 shows Buoy Point Extraction Step Procedure in 2D Space

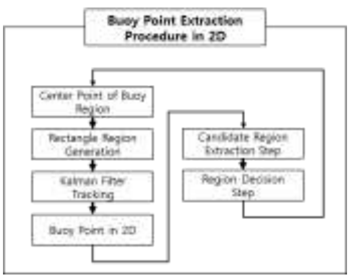

Figure 4: Buoy Point Extraction Step Procedure

3.4. Measuring Step in 3D

In order to measure the height of the wave, we acquire the height information of the buoy by video. Two cameras, called stereo system, are used to acquire 3D information. The 3D information acquisition process can be roughly divided into an offline process for calculating the intrinsic and extrinsic parameters of the cameras in advance and an online process for acquiring the 3D information from the image sequences by calculation. We solve the correspondence problem by receiving two 2D coordinates extracted from each of the two cameras which are acquired by extraction and decision steps. The 3D information of the buoy is then obtained by triangulation. Figure 5 shows Height of Buoy Measuring Step Procedure in 3D Space.

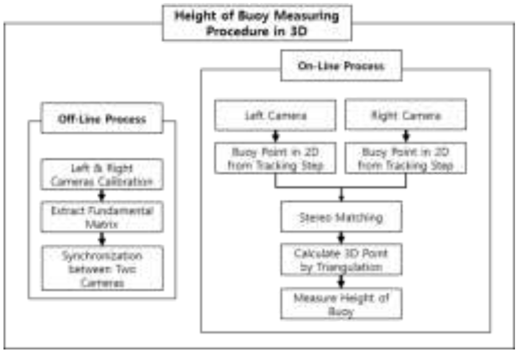

Figure 5: Height of Buoy Measuring Step Procedure

3.5. Breakwater Simulation Tank

To create a virtual wave, we create a wave generator in the tank[11].To generate various wave heights, the wave generator is designed to adjust the vertical movement distance and speed. The altitude of the buoy depends on the artificial wave and the height of the buoy according to the wave height is measured by stereo camera. The Marine Breakwater Simulator is also designed to increase the effectiveness of the breakwater by adjusting the height of the breakwater under the water. Figure 6 shows constructed marine breakwater tank.

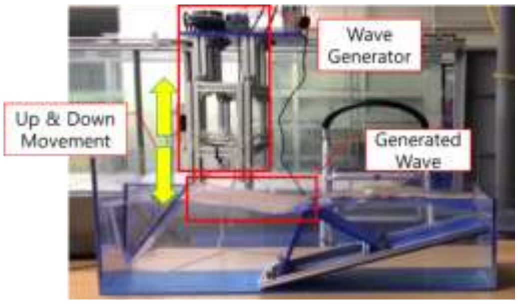

Figure 6: Constructed marine breakwater tank

4. Results and Discussion

3D printing technology has been applied to create various types of buoys. With 3D printing technology, we can also produce buoys of various sizes and we use sphere buoys with a diameter of 50mm.We use a PLA-type 3D printer. The diameter of the used green filament is 1.75 mm and the thickness of the 3D printed layer is 0.1 mm. Stereo vision technology is applied to locate the buoy. We use two cameras with Full HD picture quality in the experiment. In order to find candidates for the buoy area in the image, we convert the RGB image to the HSV image. The green region is found from the HSV converted image and the labeling step is performed after binarization. Next, the circular shape is detected after applying the Hough transform. Finally, the extraction step is completed by finding the center of the circular region. To proceed with the tracking step, we apply the Kalman filter using the center point calculated in the extraction step as the initial value. To apply stereo vision technology, we first extract intrinsic and extrinsic parameters from two cameras in off line step. Next, we get center points from both cameras to solve the correspondence problem. Finally, triangulation is used to extract the 3D information of the buoy. Figure 7 shows experimental environments.

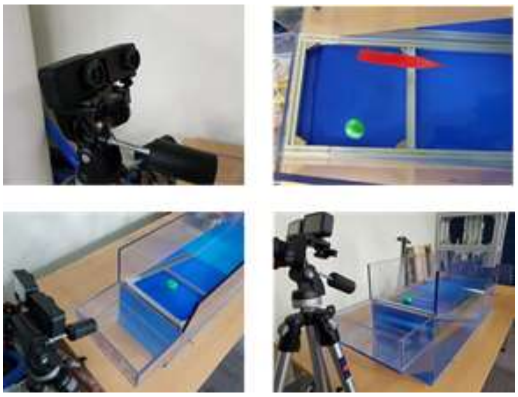

Figure 7: Experimental Environments

In order to verify the performance of the proposed simulator, we measure the height of the buoy in 500mm steps. The height of the buoy is measured after the virtual wave is generated according to the motion of the wave generator. The wave generator can generate waves according to the up and down movement, and in the experiment, waves are generated in 50mm increments. Table 2 shows experimental results. Experimental results show that the simulator has error between -6mm and + 5mm.

Table 2: Experimental Results (unit: mm)

Measuring Distance / Height of wave	0.5m	1m	1.5m
50mm	51	48	52
100mm	98	105	95
150mm	153	145	144

In this paper, we propose a marine breakwater simulator by applying 3D printing and stereo vision technology. As a future work, we will apply the depth camera as ToF to the proposed simulator to reduce the error range, and we will further analyze the location change of the breakwaters according to the wave height.

Acknowledgment

This Research was supported by the Tongmyong University Research Grants 2018(2018F018). It was also supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. NRF-2017R1C1B5017751).

References

[1] Ching-Piao Tsai, Ying-Chi Chen, Chun-Jen Chen, and Chang Lin(2016).SIMULATION OF THE EFFECT OF BREAKWATER ON THE PROPAGATION OF SOLITARY WAVES, *Journal of Marine Science and Technology*, 24(4), pp. 780-789

[2] Arikawa, T., M. Sato, K. Shimosako, I. Hasegawa, G.-S. Yeom and T. Tomita(2012). Failure mechanism of Kamaishi breakwater due to the great east Japan Earthquake Tsunami,*Proceedings of 33rd Conference on Coastal Engineering*, Paper No. 33.

[3] Dentale, F., G. Donnarumma and E. Pugliese Carratelli(2014). Simulation of flow within armour blocks in a breakwater, *Journal of Coastal Research*, 30(3), pp. 528-536.

[4] Dean, Robert G., and Robert A. Dalrymple(1991). *Water wave mechanics for engineers and scientists.* Vol. 2. World Scientific Publishing Company.

[5] Rafael C. Gonzalez, Richard E. Woods, Steven L. Eddins(2003), *Digital image processing using matlab*, Prentice Hall.

[6] KalmanRE(1960).new approach to linear filtering and prediction problems. *Trans ASME J Basic Eng.*, 82, pp. 34-45.

[7] Bishop G., Welch G. (2001). An introduction to the Kalman filter. *In SIGGRAPH 2001, Course 8.* Los Angeles, CA, USA

[8] R.I. Hartley, A. Zisserman(2004), *Multiple View Geometry in Computer Vision*, 2nd ed., Cambridge University Press.

[9] Hartley, R.(1995).In Defence of the 8-points Algorithm, *In Proceedings Fifth International Conference on Computer Vision*, Cambridge, Mass.

[10] Sangheon Park, SunjinYu, Joongrock Kim, Sungjin Kim, SangyounLee(2012). 3D hand tracking using Kalman filter in depth space, *EURASIP J. Adv. Signal Process*. 36.

[11] Sunjin Yu, Il HyukAhn and Kyung Sung Kim(2018). Visual and Depth Information based Marine Breakwater, *In Proceedings of International Conference on Next-generation Convergence Technology*, pp. 246-247.