Analysis of Damage in Marine Piles with a Drone-Based Photogrammetric System

Dong-Moon Kim

Abstract: Marine piles form base support for all sorts of structures installed around the ocean, which means that it is highly critical to ensure their stability. Thus, this study set out to detect damaged parts of piles with a drone-based photogrammetric system. The study obtained spatial imagery information by using drone operation technologies and location and photogrammetric devices installed in drones in piles constructed at the base of marine structures or independently in zones of huge tidal differences. Obtained spatial imagery information was made into ortho-images through location information and three-dimensional rotational transformation. All kinds of altered parts of pile surfaces were detected through imagery analysis based on pre-processing and edge extraction techniques. Analysis results were presented by the damaged zone and type.The findings show that three-dimensional spatial information became available by using a drone-based photogrammetric system in marine piles whose access was very low. The mean damage of 1.9 cm was detected in 21 parts in piles with 48% and 52% of damage happening in splash and intertidal zones, respectively. Damage took place in polygonal forms close to a round rather than a line. Analysis results were used to assess damage to marine piles by the zone and form and raised a need for continuous management in splash and intertidal zones.These findings can be put to active use in work related to marine spatial information as well as the maintenance of marine structures and are expected to bring extended demands and development in related industries based on various scenarios of availability.

Index Terms:Drone, Ortho-image, Photogrammetric, Spatial information, Maintenance, Marine pile

I. INTRODUCTION

Mankind has an increasing interest in marine areas to obtain and manage resources and expand living areas and has a demand for structures in various forms to increase greater access to the ocean. It is thus a very important matter of interest to ensure stability in marine base structures, which form a major support base for all kinds of structures installed around the ocean, and establish a maintenance system for them. It is especially necessary to provide proper management for major factors to decrease the structural stability of marine structures such as large-scale meteorological and sea level changes after typhoons and tsunamis in the ocean and the deterioration of these structures[1]. One of the representative marine base structures is a marine pile. The stability of marine piles can be ensured by conducting safety checks of their exterior for damage and corrosion effectively and providing high quality damage detection information for their maintenance and management. The old technologies to check marine piles are, however, mainly based on manpower's access to a site, checking the condition with a naked eye, and measurement with measuring equipment. Since a majority of marine piles are installed in shores, it is impossible to make timely access to them according to sea level and marine environment changes and it is needed to limit a check at a short distance[2]-[4]. The present study decided to investigate drone and spatial information analysis techniques for effective checks into marine pile damage and obtained spatial imagery information by using drone operation technologies and location and photogrammetric devices installed in drones in piles constructed at the base of marine structures or independently in areas of huge tidal differences. Obtained spatial imagery information was turned into ortho-images through location information and three-dimensional rotational transformation. These images were then analyzed to detect parts for damage or corrosion in piles in a shorter amount of time.

II. TECHNOLOGIES TO DETECT DAMAGE IN PILES

Marine structures, especially marine piles, are made of reinforced concrete in most cases. Reinforced concrete is subjected to damage of various forms when exposed to sea water for a long period of time. In marine engineering, they apply various forms of coating to prevent corrosion in marine piles, but they have to take additional measures for marine piles to address the parts of excess design parameters due to various marine environments[5]. In general, appropriate reinforcement techniques are used according to pile forms and zones for the protection and reinforcement of parts of corrosion and damage in marine piles as seen in Fig. 1. As seen in Fig. 2, port or marine pile environments are comprised of the atmosphere (A), splash (B), tide (C), flooding (D) and mud (E) zones. The atmosphere zone refers to the zone where piles are exposed to air. The splash zone spans from the top of a pile to HWL, but it generally refers to the part right above HWL. The tide zone is situated between HWL and LWL. The flooding zone is under the sea level at all times. The mud zone refers to the zone where piles are buried in mud, spanning from the mud line to the end of a pile.

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Fig.1 Examples of Pile Corrosion

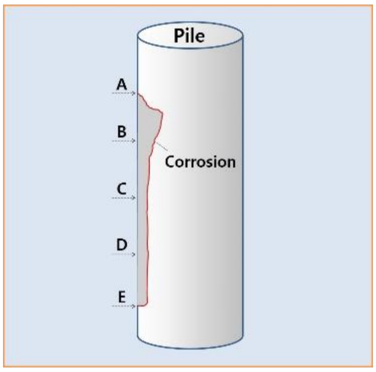

Fig.2 Forms of Pile Corrosion

There are a couple of methods to detect damaged parts and conditions including in-site survey and examinations with a naked eye, application of photogrammetric technology with professional filming equipment, and electrochemical measurement and monitoring with an embedded sensor. While an embedded sensor is applicable during pile construction, the other methods are the most common in regular in-site survey. The accuracy of in-site survey methods varies according to field conditions. There are difficulties with in-site surveys, especially in areas of huge tidal differences. In recent years, there has been active research on drone application for structures with lower access and poor availability for close measurement and check. Drones can help to detect objects and obtain observational information quickly in areas of huge tidal differences like marine piles. They can be operated with relatively small manpower at the right time and placed with various measuring instruments installed in them. Drones are thus emerging as an efficient alternative to replace old methods.

A. Drone Operation Techniques

In general, structure examinations based on in-site surveys evaluate cracks and ruptures on the surface of a structure and structural disorder in it with a naked eye.It is, however, extremely difficult to measure tiny damaged parts in structures whose access is low. Furthermore, it is even more difficult to evaluate a structural disorder in the entire structure as a whole unit. During checks into marine structures such as marine piles, the most important function of drones is the availability and accuracy of three-dimensional spatial imagery information [6]-[7].Drones in the form of a rotary wing have disadvantages in flight time and vibrations compared with drones in the form of a fixed wing, but they are able to obtain spatial imagery information in the hovering state in structures with poor accessibility.In the ocean where wind velocity is rapidly changing, it is important to resist winds to keep flight and hovering. In addition, drones are versatile and can have all kinds of equipment installed in them to obtain spatial imagery information.

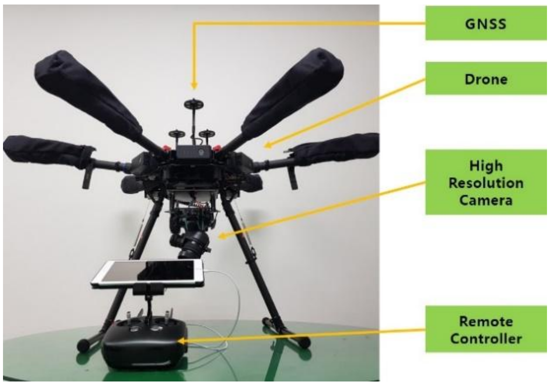

Fig.3 Composition of a Drone-Based Photogrammetric System

As seen in Fig. 3, it is required to revise and control the three-dimensional location and position information of drones with a flight controller through GPU and IMU sensors in order to ensure their precise flight and shooting. Flight controller software should be used for automatic flight and shooting in structures that are difficult to access. Such a drone-based photogrammetric system can help to obtain high definition three-dimensional spatial imagery information about marine piles and use it as basic data to detect structural damage.

B. Analysis Techniques for Imagery Information

As seen in Fig. 4, three-dimensional spatial imagery information obtained with a drone is turned into ortho-images through geometric distortion revision and conversion of location information based on relative coordinates into absolute coordinates in order to analyze the damaged parts in piles. Before image analysis, spatial imagery information goes through a pre-processing process, including noise removal and an image processing technique, to detect damaged parts and increase the efficiency of this work.

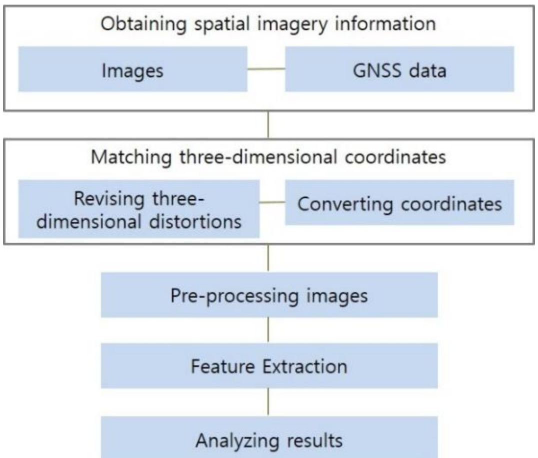

Fig.4Analysis Procedure for Imagery Information

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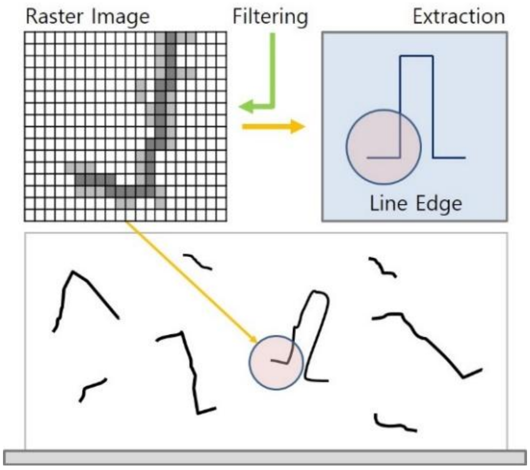

Fig.5 The Concept of Image Analysis Techniques

All kinds of filtering techniques are used in a pre-processing process applicable to imagery information analysis techniques to remove noises and increase definition. In general, a series of filtering techniques are used which calculate the average of image pixel values to remove noises. As seen in Fig. 5, such techniques can be applied effectively to revise the increase of quality of damaged images, objectify the features expressed in image pixel values, and extract desired information. In addition, a form detection-based image processing technique is used to detect damaged parts in piles. The pixel values of the damaged part in an image have different characteristics from those of the surrounding parts. That is, there is a contrast in image brightness. Such points or parts appear in a boundary with a certain distribution. When these form detection techniques are applied to extract a boundary, they can detect damaged parts in piles effectively[8]-[11].

Most techniques used to extract a boundary in damaged parts detect an edge. Good examples of edge detection methods in ramp, line, roof, and step forms include first- and second-order differential, Sobel, and Canny. A differential operator, or Canny, can extract edges not sensitive to noises and can be used to obtain the average image pixel values and extract edges in a horizontal and vertical direction. Canny, however, detects unnecessarily thick edges and has a difficult time finding a clear boundary value to detect all edges. These problems can be solved by making images soft through Gaussian filtering.

A Sobel operator should also be used to calculate the magnitude of a gradient vector and obtain edges of proper thickness by leaving only the pixel values whose gradient size is the biggest in the gradient vector direction and setting the rest as 0 in a 3x3 window. As seen in equation (1), Canny uses high threshold values to emphasize connectivity between edges, connects edges by tracking them until a low threshold value in the gradient direction, and eliminates edges whose gradient strength is not maximum.

$$C_{pixel} = Canny(I_{Array}, O_{Array}, T_{v1}, T_{v2}) \quad (1)$$

Here, C_{pixel} represents the outcome value of calculation; *Canny* represents a Canny operator; I_{Array} represents an input image; O_{Array} represents an output image; T_{v1} represents a low boundary value; and T_{v2} represents a high boundary value.

III. DATA ACQUISITION AND DAMAGE DETECTION

A. Subjects and Acquisition of Spatial Imagery Information

The subject was a representative structure in the marine support base seen in Fig. 6. Given the characteristics of marine structures, one marine pile was selected with relatively poor access and difficulty with exterior checks.

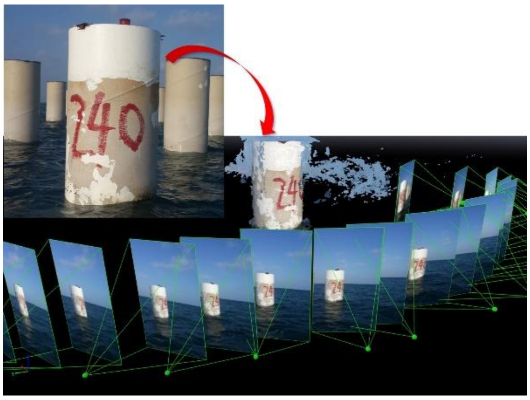

Fig.6 Subject Marine Pile

In order to obtain imagery information, the investigator reviewed the flight time and distance of drones, the camera used as equipment to obtain images, and the function of GPS and used the results to make a shooting plan and measure ground control points. Matrice 600 Pro by DJI was used in aerial photogrammetry. It can fly for approximately 30 minutes at the top speed of 65 km/h. Its maximum payload is 6 kg, and its transmission distance is 5 km. The camera installed in the drone features max-pixels of 16.0 M, Diagonal FOV of 72 degrees, focal distance of 15 mm, and support for auto focus. Scenario missions were set by taking into consideration the flight paths and shooting locations of drones, altitude, and shooting overlapping. The camera was set to shoot automatically at the positions set in the GPS coordinates in advance and was uploaded onto the automatic flight navigation software. Ortho-images were produced through three-dimensional coordinate matching based on the images shot by the camera in the drone and GPS data. Ortho-imagesdefine all the pixel values and location information in an image based on the Korean geodetic system and provide spatial imagery information containing coordinate information.

B. Pre-processing of Spatial Imagery Information and Detection of Damaged Parts

A pre-processing technique was applied to ortho-images as preliminary work to detect damaged parts on the surface of a marine pile. That is, a filtering technique was used that obtained means of image pixel values as seen in Fig. 7. The next stage used the Canny edge extraction technique in Fig. 8 to detect the outlines of damaged parts. Python OpenCV was used to make a program and perform Canny edge detection. This work went through four stages including Stage 1 of noise reduction, Stage 2 of edge gradient detection, Stage 3 of non-maximum suppression, and Stage 4 of

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hysteresis thresholding to find a boundary with the Canny algorithm to extract edges.

Fig.7 Pre-processed Images

Stage 1 applied a 5x5 Gaussian filter to remove as many noises as possible from the images. Stage 2 checked gradient direction and strength in the images to find a boundary since gradient values would vary along a pixel boundary. Stage 3 compared boundary pixels with other pixels, assessed whether it was a boundary, and made the pixel value not on the boundary 0 of the identified boundary candidates. Stage 4 set maximum and minimum values and defined the ones above maximum values as strong edges and the ones between maximum and minimum values as weak ones.The outline of damaged parts detected with the Canny edge extraction technique were extracted as features for detailed classification and quantification. As seen in Table 1, the detection of damaged parts centered around the central coordinates and width and length components of damaged parts. Of the detection results, the ones under 0.5

Table 1: Detection Results of Damaged Parts

No.	X(m)	Y(m)	Z(m)	Length(m)	Width(m)	No.	X(m)	Y(m)	Z(m)	Length(m)	Width(m)
1	417.010	-99.510	64.190	0.032	0.022	12	417.250	-100.230	64.130	0.032	0.014
2	417.000	-99.530	63.770	0.022	0.010	13	417.440	-99.280	63.720	0.020	0.010
3	417.470	-99.280	64.700	0.022	0.017	14	417.400	-99.300	63.730	0.030	0.024
4	417.480	-99.290	64.610	0.010	0.010	15	417.400	-99.290	63.690	0.022	0.017
5	417.120	-99.390	64.380	0.017	0.014	16	417.190	-99.360	63.800	0.044	0.014
6	417.110	-99.400	64.380	0.022	0.014	17	417.160	-99.360	63.720	0.030	0.022
7	416.960	-99.890	64.460	0.014	0.010	18	417.040	-99.470	63.710	0.017	0.014
8	417.470	-99.290	64.230	0.014	0.010	19	417.020	-99.490	63.710	0.014	0.014
9	417.450	-99.290	64.040	0.017	0.014	20	416.990	-99.560	63.730	0.030	0.022
10	417.350	-99.290	64.070	0.033	0.022	21	417.160	-100.210	63.810	0.033	0.010
11	417.100	-99.420	64.020	0.014	0.014						

Fig. 8 Extraction Edges

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cm were excluded. The damaged parts were 1.9 cm on average. Its average width was 1.5 cm between 2.4 cm maximum and 1 cm minimum. Its average length was 2.3 cm between 4.4 cm maximum and 1 cm minimum.As seen in Fig. 9, the marine pile examined in the study was categorized into the atmosphere, splash, and tide zones to analyze the damaged parts in environment and forms. The damaged parts in zones and forms were detected at 52% and 48%, respectively, in the splash and intertidal zones as seen in Fig. 10. The detected damaged parts were in the form of polygons (approximately 90%) except for the features that had no impact on paint rusts or structural damage to the structure.

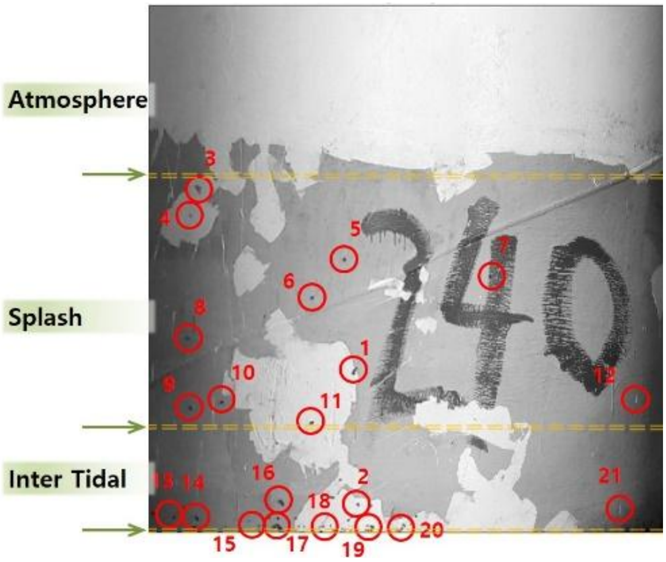

Fig. 9 Zones of a Marine Pile

Table 2: Zones and Forms of Damaged Parts

Zone	Number	Percentage (%)	Max(m)	Min(m)
Splash	11	52	0.033	0.01
Inter tidal	10	48	0.044	0.014
Class	**Number**	**Percentage (%)**	**Max(m)**	**Min(m)**
Line	2	10	0.033	0.032
Polygon	19	90	0.044	0.01

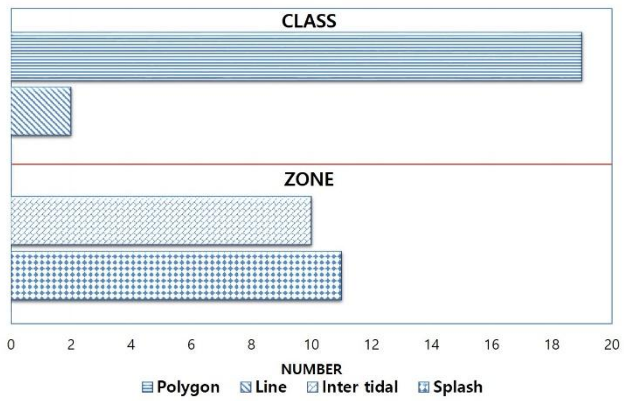

Fig. 10 Zones and Forms of Damaged Parts

The other remaining 10% were in the form of lines and under 1 cm in width that could be disregarded. As seen in Table 2, no damaged parts were found in the atmosphere zone with damaged parts of 1~3.3 cm and 1.4~4.4 cm in the splash and intertidal zones, respectively. Detection was impossible in flooding and mud zones.

IV. CONCLUSION

The present study established a methodology of detecting and analyzing damaged parts in marine piles with a drone-based photogrammetric system and demonstrated its level and availability to replace old checking methods with a naked eye or measuring device through field access. The study collected spatial imagery information with a high completion level at the right time and place by applying drone technologies, positioning and coordination technologies of drones, camera shooting and collecting skills, and techniques of establishing spatial imagery information and increased the detection rate of damaged parts by making use of image pre-processing, filtering, and edge extraction techniques. The study detected damaged parts in a marine pile and distinguished the damaged zones and forms. Damage happened at a similar percentage between intertidal and splash zones, but it was based on the analysis of detection outcomes except for the ones under 0.5 cm and thus contrasting to the general tendency of major damage in the splash zone. The detected parts were 4.4 cm or less. That is, the subject structure was not that old. The systematic monitoring of its damaged parts will be possible if there is ongoing detection and analysis planned as a long-term process. This methodology produced overall satisfying results in the attempt and availability of detecting damaged parts, but it had limitations with detecting all the damaged parts in their types and precision. Thus, there is a definite need to obtain imagery information of higher precision, make it fuse with three-dimensional spatial information, and generate three-dimensional spatial imagery information. It is also needed to perform pre-processing, extraction, and classification for images through more advanced learning based techniques to increase the detection rate of damaged parts. These findings can be put to active use in various types of work for the maintenance of marine structures as well as the management of marine piles and propose proper countermeasures to meet the recent diverse needs of establishing and utilizing marine spatial information.

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