Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Development of a Marine Mooring Lines Image Dataset for Deep Learning Applications

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ARTICLE INFO

Article history:
Received 2 March 2024
Received in revised form 3 September 2024
Accepted 12 October 2024
Available online 30 November 2024

ABSTRACT

Mooring systems, which use thin lines composed of fiber ropes, steel wires, and chains, are essential to offshore activities. These technologies play a critical role in ensuring that floating units stay in their proper positions throughout operations like offshore gas and oil drilling and production offloading into shuttle storage vessels. Early mooring line failure detection is critical to ensuring the safety and integrity of these activities since it helps avert unanticipated losses such as catastrophic catastrophes and human casualties. Recent developments in deep learning object detection have encouraged prospects for the creation of affordable mooring monitoring solutions. However, a specialized marine images dataset that includes mooring lines is required for the construction and testing of such models, and it is not publicly accessible at this time. Thus, this paper provides insights, design considerations, and general observations for the production of a high-quality marine mooring line images collection in response to the demand for one. Besides, a procedural framework has been designed for creating synthetic images consisting of mooring lines. Additionally, the real-time experimental process in the development of marine mooring lines images dataset for deep learning models that are intended to identify anomalies in mooring lines in offshore deep water has been demonstrated. The purpose of these guidelines is to improve the efficacy of deep learning solutions in determining the anomalies in mooring lines at an early stage by addressing the particular problems and peculiarities of the task.

Keywords:
Mooring lines; mooring systems; image dataset; marine images; image augmentation; deep learning; image annotation

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https://doi.org/10.37934/ard.122.1.129139

1. Introduction

The process of moving hydrocarbon products from production units to shuttle tankers for delivery to the main shore is carried out at sea using floating units that may include Floating Point Storage and Offloading (FPSOs). These production units are anchored to the ocean floor or could be spread out by installing floating structures. The smooth transfer of hydrocarbon production to storage vessels through the construction of floating units obviates the necessity for massive undersea pipeline infrastructure. However, the production facilities are secured in place by mooring systems to prevent them from moving uncontrollably in shallow or deep waters [1]. These mooring systems comprise mooring lines, which are usually made of polyester rope, steel wire rope, or chains. The vital role of station keeping and stability under harsh environmental circumstances is fulfilled by these lines, which are connected to floating structures or boats immersed in deep seas. Because they are essential to the offloading of hydrocarbon productions [2]. Therefore, the mooring systems are extremely important in the oil and gas sectors and failure in any mooring line within the mooring system can have serious repercussions, such as monetary losses, fatalities, harm to production pipelines, catastrophic failures, and are described in previous studies [1,2].

The fast development of artificial intelligence has increased the interest of several researchers to dig into deep learning and machine learning approaches to discover and monitor abnormalities in mooring lines throughout varying time periods. However, when evaluated under harsh environmental circumstances, these techniques show limitations in accuracy, dependability, and performance deterioration [3-7]. Besides, the previous research studies [8-13] have been investigated based on numerical data (time series) obtained through simulations except [1,2]. Recent advances in deep learning object detection hold promise for low-cost mooring monitoring systems. However, the development and testing of such models need the use of specialized marine images comprising mooring lines, which are currently unavailable to the public according to studies [1,2].

To fill this gap, this research paper provides insights, design considerations and general observations to aid in the creation of a high-quality marine image that consists of mooring lines, fulfilling the current demand in the field [14,15]. It emphasizes the need for careful dataset curation in assisting research and model training. Further, we present a procedural framework for designing the synthetic mooring lines images dataset. In addition to that the real-time experimental process in the development of marine mooring lines images dataset for deep learning models that are intended to identify anomalies in mooring lines in offshore deep water has been demonstrated. These recommendations and real-time experimental procedures attempt to improve the effectiveness of deep learning algorithms in detecting mooring line failures from marine images by recognizing and addressing task-specific issues and problems.

The remaining paper is organized as follows: Section 2 outlines the methodology, specifying the design considerations, general observations, and guidelines for collecting marine images featuring mooring lines in real-life scenarios. Additionally, it presents a procedural framework for the creation of a synthetic mooring lines images dataset. Section 3 details the step-by-step development process for creating and formulating the mooring lines dataset, intended for acceptance in deep learning applications for early-stage fault detection in mooring lines. Finally, Section 4 provides the conclusion of the research.

2. Methodology

2.1 General Observations

In this section, the general observations that include but are not limited to the mooring line variability, environmental conditions, mooring configuration, and camera perspective in preparation for capturing and collecting real-time marine images that consist of mooring (thin) lines objects have been described one by one as below.

2.1.1 Mooring line variability

A marine images dataset comprises various kinds of mooring lines which give an assurance that the machine learning and deep learning models can be generalized to an extensive range of marine environments. Mooring lines are made up of various materials that are found in the chain, steel wire rope, or polyester fiber rope, and each of these is found with distinct characteristics that measure the line's behavior under high load in different environmental conditions. In addition to that, it has been demonstrated by Stanisic *et al*., [16] that the complexity level of the mooring system can be mended on the basis of changes in the structure and the thickness of the mooring lines. Besides, these indefinite numbers of various kinds of mooring lines are added to the dataset to construct a comprehensive library that assists in creating machine learning models for an extensive range of real-life situations. Thus, variability is critical to train the models that can be adjusted to various kinds of vessels, strong sea environments, and the arrangement of the mooring systems.

2.1.2 Environmental conditions

It is important to consider that the marine dataset symbolizes the range of the ocean conditions and weather situations before capturing the possessions of environmental factors accurately. The mild waves, humid situations, and the squally days furnish the peculiar complications of mooring systems [17]. However, the model can determine and regulate the altering features of the marine environment by admitting the mooring lines images from various kinds of weather. Besides, the inclusion of night and day conditions can enhance more complications by altering the illumination, which can result in an immense impact on the visual observations. The inclusion of such environmental circumstances in creating the marine images dataset not only makes the solid ground for training the model but, it can also ensure dependability throughout various scenarios that are often seen during the mooring operations [16].

2.1.3 Mooring configurations

To create a marine images dataset, it is crucial to capture images that include single mooring lines and images with the combination of various interlinked groups of mooring lines. Mooring systems can be found in a variety of designs comprising single-point moorings and may contain small vessels to complex multiline installations for large vessels or offshore structures. Moreover, this is assured that artificial intelligence-based models are trained on a broad range of configurations by admitting several sorts of scenarios [18]. Besides, for the comprehension of the machine learning models in the determination of several mooring configurations, a crucial rule is played by the variability to improve the flexibility of the model in the real marine environment. In addition to that, several types of vessels such as floating vessels can be added to enhance the degree of complexity which primes the machine learning models for the diversity of marine applications.

2.1.4 Camera perspectives

A diversity of Camera angles can be utilized to depict the subtleties of mooring lines. The images with zoom furnish in-depth perspectives of the particular mooring lines which allow for a more systematic examination of the load and condition of mooring lines [19]. Various views from a broad viewpoint portray full mooring systems, and their connections to the vessels and the anchor points, which yields context. However, the aerial views furnish more distinct viewpoints specifically in the condition where a broad view of the offshore facilities is required. However, the addition of such viewpoints in the dataset can ensure the difficulties encountered in the real-life observations of mooring lines from a diversity of angles and distances, enhancing the model's generalizability throughout the variety of visual conditions.

2.2 Design Considerations

In this section, the design considerations in preparation for capturing and collecting real-time marine images that consist of mooring (thin) lines have been discussed. These considerations include annotation, resolution and quality, dataset size, and diversity. Each of these has been enlightened one by one as below.

2.2.1 Annotations

The accurate annotation process is crucial specifically when dealing with marine images which consist of mooring lines for efficient training of the machine and deep learning models [20]. Further, the spatial range of the mooring lines in each image can be outlined and highlighted accurately by using segmentation masks and bounding box annotation techniques [21]. The machine learning and deep learning models use such annotation techniques to automate the annotation process in determining the location and shape of mooring lines in addition to their existence in an image. However, the detailed inspection and subtle determination of the mooring line enable such a process to be considered more accurate.

Furthermore, the addition of metadata [22,23] such as tension and size of the mooring line with the annotated marine images dataset can enhance the dataset prosperity and such data furnish the highlights on actual environmental conditions adjacent to the mooring operation. Annotations aid by creating a bridge between the unprocessed data and the meaningful interpretation throughout the training of the model [20]. Also, a major role is played by annotations in enhancing the practicality of the dataset by assuring that the model is exposed to adequate data for consistent learning. Thus, annotation has a diverse role in improving the cognitive comprehension of the model, increasing the dataset, and lastly assisting in the creation of cutting-edge machine and deep learning models for the identification of mooring lines accurately and analysis in marine environments [21].

2.2.2 Resolution and quality

While training the machine and deep learning models on marine images dataset that comprises mooring lines. The importance of the high-resolution images must be underlined. The efficacy of the process of model training purely depends on the quality of the marine images [21]. Thus, the details of the accurate analysis are maintained while capturing the high-resolution images that are tactically crucial. Because only the images with high resolution can furnish the high degree of information as stated by Zhang *et al*., [20] that is needed to completely raise the subtleties of mooring lines, their arrangements, and their multifaceted interaction with the adjacent marine environment.

The uniformity of the image quality while maintaining the entire dataset is considered vital by Khatri *et al*., [2]. Sustaining similarity indicates a more stable and reliable learning process by avoiding accidental biases in the perception of the model. This constancy is specifically important in conditions where mooring lines can be visible to a diversity of conditions, such as altering ocean conditions and brightness settings. High-resolution images and reliable quality are prioritized, making the dataset a steadfast training set [20,24]. This critical phase ultimately reinforces the resilience of the models and guarantees their application in real-life marine circumstances by considerably contributing to the capacity of the overall model to simplify over a range of mooring conditions and various lighting conditions [25].

2.2.3 Dataset size and diversity

The efficiency and adaptability of the machine and deep learning methods are determined by the size of the dataset [22,23], particularly the dataset that contains mooring lines in marine images [2]. The direct relationship between the size of the marine images' dataset and the performance of the model is considered the crucial factor throughout building a stable training environment. A larger dataset pretends as a reservoir by which patterns can be extracted using a model since the dataset possesses a broad set of images. However, there are lower chances of overfitting because of plenty of data which allows the model to become well simplified to a broader range of conditions instead of being focused on a small number scenario.

The variety of marine image datasets becomes critical in marine circumstances [6]. For instance, a dataset can be heightened by the inclusion of various types of mooring lines, environmental conditions, and vessel attributes which imitate the composite problems that rise in real-life mooring operations. This experiences the model in obtaining the strength to adjust and react competently to a diversity of marine conditions. Thus, the size of the dataset is a crucial consideration in creating machine and deep learning models that perform well under diverse scenarios and are flexible [8]. To make it further simple, a large and balanced dataset aids in training models, ensuring their practicality and efficiency during mooring operations in marine scenarios that are found in real-life environments [1,26].

2.3 Procedural Framework for Synthesizing Mooring Lines Dataset

OrcaFlex is standardized software for the analysis of dynamic offshore systems [2,27], and has been utilized in this study to simulate and examine the behaviors of mooring lines for FPSO vessels. A step-by-step guideline for synthesizing the mooring lines image dataset has been portrayed in Figure 1. The initial step to creating the simulation is to launch the OrcaFlex application and create a new simulation. This simulation proceeds to configure the FPSO vessel and familiarize with the 12 mooring lines to design a spread mooring system for enhanced stability. The mooring lines are arranged into four groups and each group is comprised of 3 mooring lines. Each of these groups is strategically attached to the vessel at 30 and 60-degree angles at the Bow and the Stern of the vessel to recreate the spread mooring conditions.

One of the crucial aspects of this method is the flexibility of the simulation which allows the mooring lines to either move freely or fixed with the vessel. Furthermore, the simulation is performed in either "shaded graphic mode" or "wireframe mode" based on the created marine circumstances. Then the simulation outcomes are stored in the dot "sim" format after being taken out. Later on, the video streams are acquired by transforming the dot "sim" file format into dot "avi". The dynamic behaviors of the mooring lines during the simulation are then depicted in depth by isolating and annotating each individual frame of the video. These annotated frames, which provide important information about the operation of the mooring system, are methodically kept in a specific directory. The dataset is further processed to support machine learning and deep learning applications.

The dataset is separated into training and testing sets when the data is read from the directory. To improve dataset variety and guarantee strong model training, image augmentation techniques are carefully implemented. To facilitate supervised learning, ground truth data is methodically produced for every frame. Frames are also rescaled to meet the neural network's input specifications. This all-inclusive technique makes sure that mooring line data (synthetic marine images) is processed, analyzed, and simulated methodically and thoroughly, ready for further machine learning and deep learning uses.

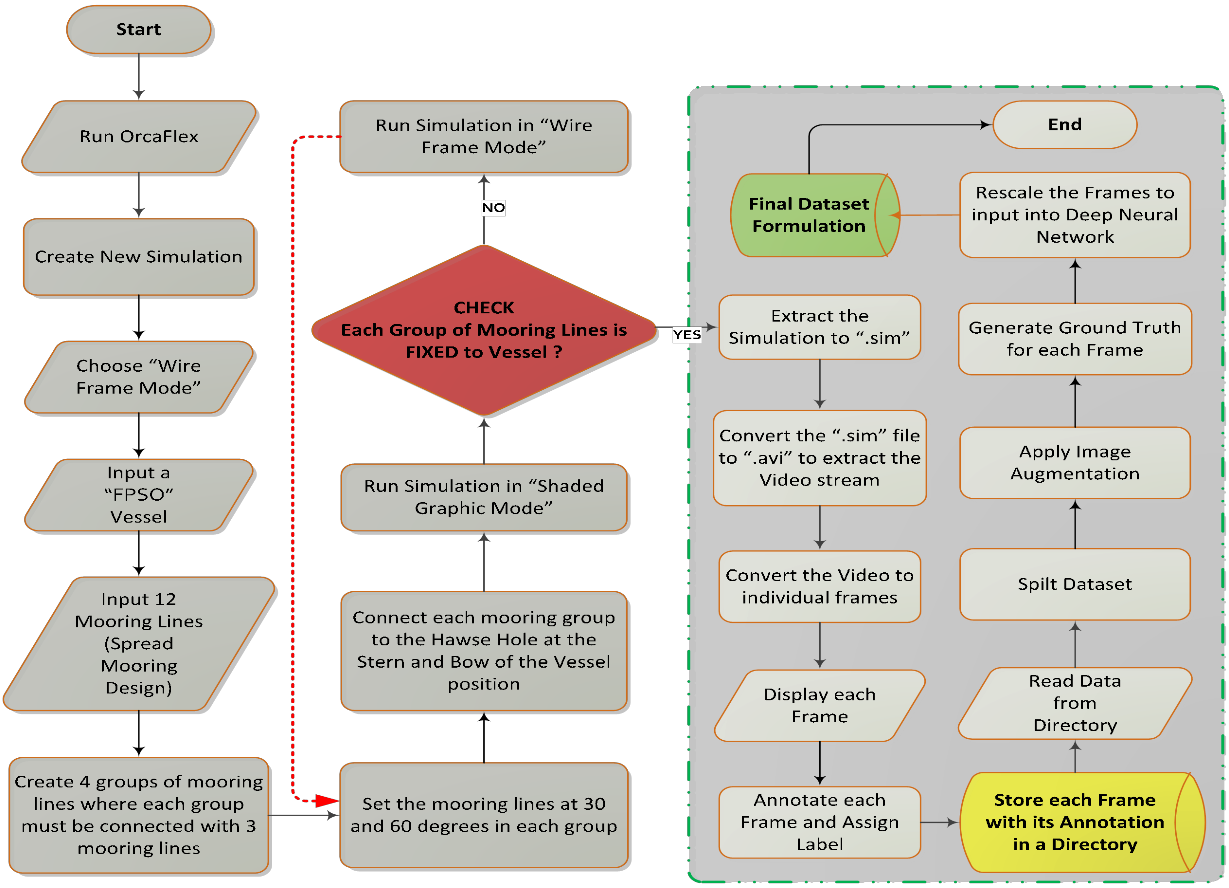

Fig. 1. Step-by-step guidelines to create a synthetic marine images dataset

3. Development of Marine Images

3.1 Image Acquisition

As seen in Figure 2, image acquisition is an important procedure that is carefully planned to record the mooring lines of a moored marine vessel. In order to provide thorough coverage, this operation calls for the strategic deployment of four cameras: two in the front (Vessel Bow) and two in the back (Vessel Stern). At regular intervals, the cameras produce video feeds that capture the mooring lines' dynamic motions and fine details. These video streams are then split into individual frames and converted using an appropriate transformation tool into the commonly used Portable Network Graphics (PNG) picture format.

Following that, the captured video frames are handled as input images, serving as the basis for the suggested deep-learning models. A number of preprocessing steps are taken on the input images before moving on to the modeling phase. These processes are meant to improve the image quality and appropriateness for further examination. Deep learning techniques are applied to analyze and comprehend the dynamics of mooring lines on marine vessels, and this is made possible by the image acquisition procedure, which carefully integrates video recording, frame transformation, and preprocessing stages.

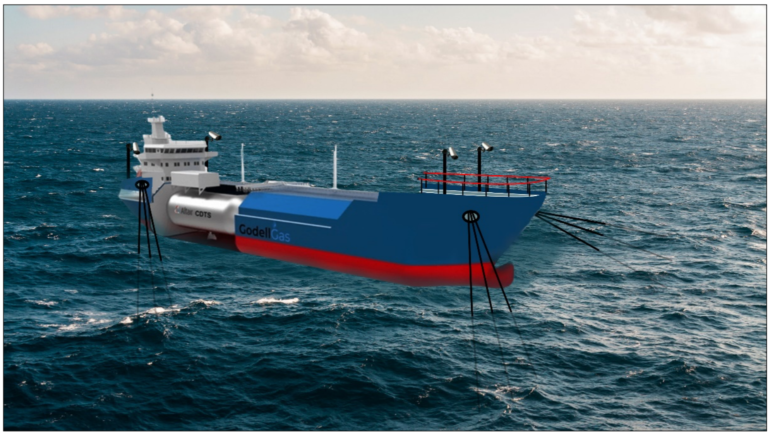

Fig. 2. Image acquisition scenario

3.2 Description of Marine Images Dataset

The development of a synthetic marine image dataset became essential as there is not any publicly available dataset that comprise of mooring lines [2]. To remedy this, marine images with mooring lines were created using the well-known software "OrcaFlex" [13,27]. Prominent worldwide as a preeminent software for the dynamic study of offshore marine systems, OrcaFlex is distinguished by its intuitive interface and extensive technical capabilities [27].

Eight 3D simulations were created using OrcaFlex that adhered to the spread mooring system's guiding principles. Besides, the various featured positions of FPSO vessel consisting of mooring lines have been shown in Figure 3. Every simulation, which lasted 12 seconds, showed several locations for the FPSO vessel. A common video-to-image conversion application was used to extract individual frames from each simulation, which were captured at a frame rate of 20 frames per second. After that, these frames were saved in "PNG" format, keeping their original size. With a recording ratio of 10, the picture width and height for every output frame were adjusted to -1 to preserve the proportions that come with the simulation. After a laborious procedure, 180 marine images with mooring lines were acquired. As Figure 3 illustrates, these images all show the subtleties of spread mooring lines, which are shown in the images as thin black and yellow lines.

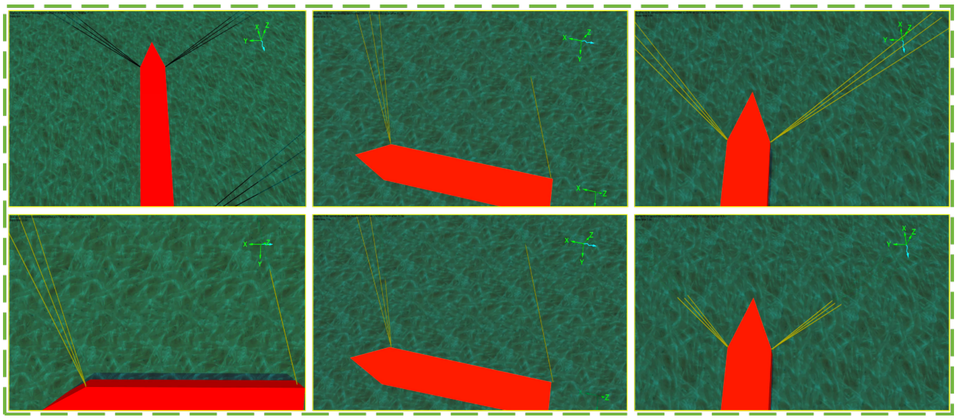

Fig. 3. Various featured positions of FPSO vessel consisting of mooring lines

3.3 Image Annotation and Labeling

During the data-gathering phase, as previously noted, 180 marine images were collected. These images were then arranged into a directory, and each image's mooring line objects were manually labeled using the "SuperAnnotate", tool using the “Polyline” annotation as depicted in Figure 4 and the said tool is previously used in research study [24]. To help deep learning models recognize and track mooring line objects in marine images with accuracy, a thorough annotation procedure was implemented. Preeminently, "SuperAnnotate" ensures the best training data by facilitating the rapid development, optimization, iteration, and management of AI models [28].

After being labeled for each image, they were all stored in JavaScript Object Notation (JSON) format. The end product of this work was the final marine images collection, which included input images together with their annotations and class label files. This dataset was further segmented, with 80% going towards training, 10% going towards validation, and an additional 10% going towards testing, with the intention of using it in deep learning models. As a result, there were 144 samples in the training dataset and 18 in the validation dataset. Eighteen picture samples comprised the testing dataset, which focused on mooring lines in sea imagery. Moreover, understanding that a large dataset is essential for deep learning applications, image augmentation was applied to the final training dataset to increase its robustness and variety.

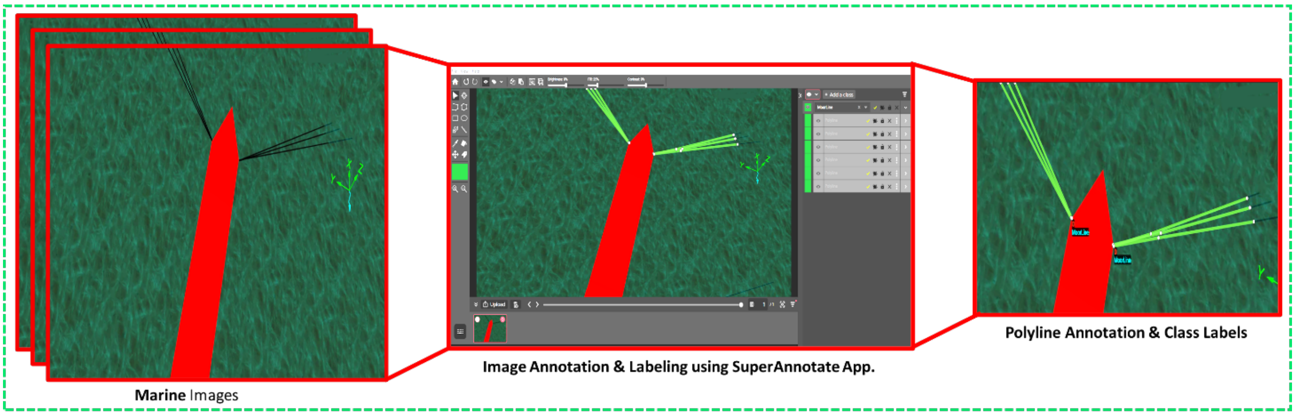

Fig. 4. Annotation and labelling of mooring lines using SuperAnnotate tool

3.4 Image Augmentation

One method that is frequently used in computer vision is image augmentation, which helps deep learning models perform better and generalize their performance [26]. Through this procedure, the training dataset's size is artificially increased by adding new images and was proposed by Umair *et al*., [29]. Position augmentation and color augmentation are two frequently used image enhancement techniques [2,29]. However, position augmentation from research studies [30,31] which involves randomly augmenting the training dataset 12 times was the main focus of the current investigation.

The position augmentation methods that were utilized included rotation, skew (both horizontal and vertical) within a 20-degree range, 20% scaling of the pictures' height and width, and flips (both horizontal and vertical) as shown in Figure 5. In order to reduce overfitting and improve model performance in deep learning applications, these augmentations were purposefully used to increase the size of the training dataset. Figure 5 shows a visual representation of a subset of randomly selected data that demonstrates image enhancement. Additionally, the "image rescaling" approach needs to be utilized to resize the images according to the model input acceptance requirement before feeding images into the deep convolutional neural networks (DCNN) for the purpose of mooring line recognition.

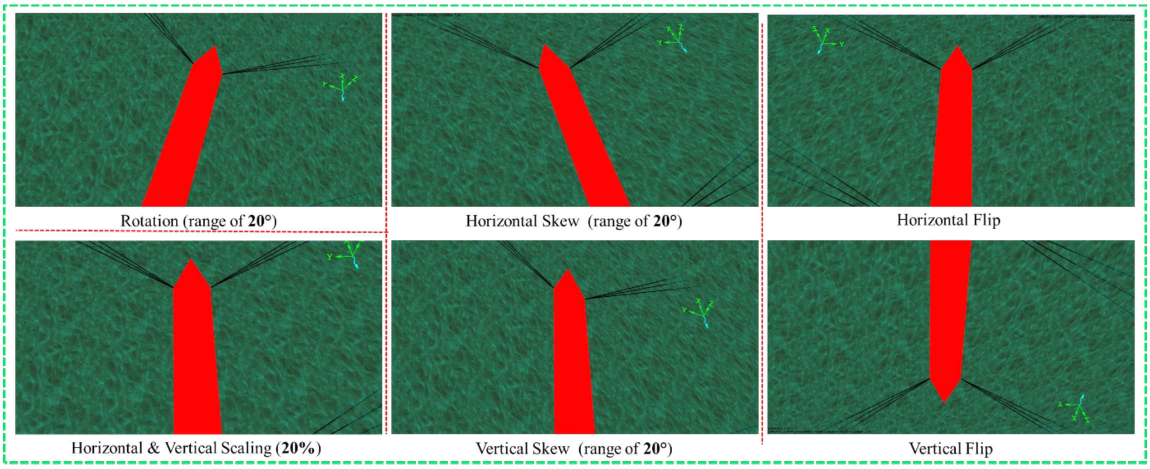

Fig. 5. Random samples of augmented images based on position augmentation

4. Conclusions

This study digs into the vital topic of offshore oil and gas mooring system safety, emphasizing its critical role in the steady and secure transfer of hydrocarbon products. It highlights the changing landscape of deep learning applications for identifying anomalies in mooring lines. The machine learning and deep learning approaches have been used to discover and monitor abnormalities in mooring lines throughout varying periods. However, when evaluated under harsh environmental circumstances, these techniques show limitations in accuracy, dependability, and performance deterioration. Besides, these studies have been investigated based on numerical data (time series) obtained through simulations. Recent advances in deep learning object detection hold promise for low-cost mooring monitoring systems. However, the development and testing of such models need the use of specialized marine images comprising mooring lines, which are currently unavailable to the public.

Recognizing the inherent limits of current methodologies, especially in difficult environmental circumstances, this paper has made important contributions by giving vital insights, design considerations, and general observations for establishing a specialized marine mooring line image dataset. In addition to that, a procedural framework for designing the synthetic mooring lines images dataset has been demonstrated. Furthermore, the real-time experimental process in the development of marine mooring lines images dataset for deep learning models that are intended to identify anomalies in mooring lines in offshore deep water has been demonstrated. The emphasis on thorough dataset curation, supported by a precise procedural architecture and real-time experimental setup, increases the ability of deep learning algorithms to efficiently identify mooring line failures from images. This study not only exposes the present status of mooring line anomaly detection but also gives practical answers and directions for expanding safety measures in the offshore oil and gas sector, defining the trajectory of future endeavours in this crucial field.

Acknowledgement
This research study was supported by Centre for Cyber-Physical Systems (C^2PS), Universiti Teknologi PETRONAS and Yayasan UTP (YUTP) – Grant number 015LC0-332 for provision of materials and resources to carry out this research work.

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