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WILDetect - Part I

A new non-parametric approach, WILDetect, has been built using an ensemble of supervised Machine Learning (ML) and Reinforcement Learning (RL) techniques. We present here the first part of the paper. The concluding part will be published in next month



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Abstract

The habitats of marine life, characteristics of species, and the diverse mix of maritime industries around these habitats are of interest to many researchers, authorities, and policymakers whose aim is to conserve the earth's biological diversity in an ecologically sustainable manner while being in line with indispensable industrial developments. Automated detection, locating, and monitoring of marine life along with the industry around the habitats of this ecosystem may be helpful to (i) reveal current impacts, (ii) model future possible ecological trends, and (iii) determine required policies which would lead accordingly to a reduced ecological footprint and increased sustainability. New automatic techniques are required to observe this large environment efficiently. Within this context, this study aims to develop a novel platform to monitor marine ecosystems and perform bio census in an automated manner, particularly for birds in regional aerial surveys since birds are a good indicator of overall ecological health. In this manner, a new non-parametric approach, WILDetect, has been built using an ensemble of supervised Machine Learning (ML) and Reinforcement Learning (RL) techniques. It employs several hybrid techniques to segment, split and count maritime species – in particular, birds – in order to perform automated censuses in a highly dynamic marine ecosystem. The efficacy of the proposed approach is demonstrated by experiments performed on 26 surveys which include Northern gannets (*Morus bassanus*) by utilising retrospective data analysis techniques. With this platform, by combining multiple techniques, gannets can be detected and split automatically with very high sensitivity (Se) (≈ 0.97), specificity (Sp) (≈ 0.99), and accuracy (Acc) (≈ 0.99) —

these values are validated by precision (Pr) (≈ 0.98). Moreover, the evaluation of the system by the APEM staff, which uses a completely new evaluation dataset gathered from recent surveys, shows the viability of the proposed techniques. The experimental results suggest that similar automated data processing techniques – tailored for specific species – can be helpful both in performing time- intensive marine wildlife censuses efficiently and in establishing ecological platforms/ models to understand the underlying causes of trends in species populations along with the ecological change.

1. Introduction

The oceans cover two-thirds of the Earth's surface and the maritime economy has always been diverse and abundant. With the applications of emerging fields of science and technology in new and existing industries, prominent companies and research organisations have been recently developing and deploying evolving technologies supported by location-independent advanced maritime mechatronics systems (AMMSs) (Kuru & Yetgin, 2019; Shi et al., 2017) to explore and exploit the resources in this tough landscape. This massively evolving industry, enabling enormous continuous human control in the maritime, has the potential to impact the marine ecosystem dramatically; in particular, the seabed, birds, turtles, and fish. Birds are an inseparable part of the maritime ecosystem. Seabird population changes are good indicators of long-term and large-scale change in marine ecosystems, and important because their populations are strongly influenced by threats (e.g., entanglement in fishing gear, overfishing of food sources, climate change, pollution, disturbance, direct exploitation,

development, energy production) to marine and coastal ecosystems (Paleczny et al., 2015). Considerable differences in population trajectories of off-shore bird families have been documented, which suggests that overall offshore bird populations are decreasing (BOEM, 2022). The monitored portion of the global seabird population, representing approximately 19% of the global seabird population, has declined by nearly 70% between 1950 and 2010 (Paleczny et al., 2015), a net loss approaching 3 billion birds (u.e., %29) since 1970 (Rosenberg et al., 2019). This loss of bird abundance signals an urgent need to address threats to avert future avifaunal collapse and associated loss of ecosystem integrity, function, and services (Rosenberg et al., 2019).

One type of bird is the northern gannet (*Morus bassanus*), the largest seabird in the North Atlantic, having a wingspan of up to 180 cm and a length of up to 100 cm (RSBP, 2015). More specifically, gannets are large white birds with distinctive features including yellowish heads and black-tipped wings. They are distinctively shaped with a long neck and long pointed beak, long pointed tail, and long pointed wings (RSBP, 2015). An example is displayed in Fig. 1. The most important nesting ground for northern gannets is the UK with about half of the world's population (55.6%) (JNCC, 2015). APEM Ltd⁴ has a wide range of gannet data with geographical positions obtained from all around the world and this species is the focus of this study which aims to test the developed approaches to help perform further autonomous bird censuses paving the way for automated classification of multispecies and counting them. The censuses of gannets have been undertaken since the 1980s (JNCC, 2015; Murray et al., 2015) and all Scottish colonies were surveyed in 2013 and 2014 via manual approaches (Murray, Harris et al., 2014; Murray et al., 2015; Murray, Smith et al., 2014). In a typical marine survey programme, there might be around half a million images taken over 12 months for a specific area and it is a labour-intensive task to separate this survey into positive images with targeted objects and negative images with no objects, and then count the objects in the images deemed positive. Many surveys acquired by APEM Ltd suggest that more than 95% of the images contain no targeted objects. The detection of small objects, particularly birds, in large-scale images with more than 50 million pixels is a non-trivial task when using manual approaches. Long-term data that utilises standardised and structured methodologies

are ideal for quantifying change in species populations; Unfortunately, such data does not exist for most biogeographic regions (Clements & Robinson, 2022) due to the difficulties and high cost of manual methods. Therefore, automation of this work using an automated intelligent computer system which would help the development of effective prospective environmental models with realistic inputs is highly beneficial.

Despite recent advances in computer vision and learning techniques as well as many attempts to monitor off-shore species in an automated manner, comprehensive large off-shore wildlife censuses are still conducted manually by experienced ecologists, ethologists, ornithologists (e.g., JNCC, 2022; Thompson, 2021) due to unmet expectations in accuracy rates for the counting and classification of species via automated methods as elaborated in Sections 2, 3 and 4.1. With this motivation in mind considering the challenges mentioned in Section 3, this study proposes a new supervised Machine Learning (ML) approach supported by Reinforcement Learning (RL) enabling user-model-data interaction that can detect, split and count birds, in particular, offshore gannets, in an automated decision-making way with high accuracy rates. To clarify the novelty of this paper, particular contributions are outlined as follows.

1. This is the first attempt that explicitly aims to implement maritime bio censuses in marine surveys automatically using an ensemble of supervised ML and RL techniques with a user model-data interaction in finding the best analysis parameters for mitigating the highly dynamic characteristics of the maritime ecosystem.
2. The two phases of using ensemble techniques within the developed methodology can work successfully in performing the offshore bird censuses and most importantly, the methodology can be generalised to the automated classification and counting of broader maritime multispecies. The methodology can be expandable with more feature extraction techniques in addition to the employed three techniques to achieve higher accuracy rates.
3. The proposed approach shows a new direction for the detection of particular, small species with a diverse background and most importantly for the classification of multispecies even if there is a strong resemblance between them, as seen in bird species, where current techniques (i.e., off-the-shelf approaches (e.g., OBIA), Deep Neural Network (DNN) (e.g., CNN)) cannot converge to a desired solution with high accuracy rates based on the features of datasets.

The remainder of this paper is organised as follows. Section 2 surveys the related literature. Section 4 reveals how the methodology is built up. The implementation of the established methodology in splitting and counting the particular species in surveys is explained in Section 5. The results are presented in Section 6. Discussions are provided in Section 7. Finally, Section 8 draws conclusions and provides directions for potential future ideas.



Fig. 1. Example of a gannet in a high-resolution image.³

2. Literature review

Wang et al. (2019) reviews studies regarding wild animal surveys based on multiple platforms, including satellites, manned aircraft, and unmanned aircraft systems (UASs), and focuses on the data used, animal detection methods, and their accuracies. The resolution of (sub- metre) satellite images is not sufficient to discern small (<0.6 m) animals at the species level; Manned aerial surveys have long been employed to capture the centimetre-scale images (with a spatial resolution of 2.5 cm Hollings et al., 2018) required for animal censuses over large areas whereas UASs can cover only small areas (Wang et al., 2019). Groom et al. (2013) analysed a very limited number of images (18 frames) within two offshore areas in the Irish Sea using an off-the-shelf object-based image analysis (OBIA) algorithm, aiming at combining manual and automated image analysis, to describe marine bird distributions and abundances. Similarly, Chabot et al. (2018) used OBIA to detect and count Lesser Snow Geese in large numbers of images of breeding colonies across the Canadian Arctic, achieving better results compared to human counting. It is noteworthy to mention that the prevalent use of aerial thermal-infrared images for detecting large mammals is of limited applicability to seabirds because of the low pixel resolution of thermal cameras, the smaller size of birds (Chabot & Francis, 2016), and most importantly their low body temperature. Borowicz et al. (2019) established a semi-automated approach using deep learning networks for whale detection from satellite imagery with sub-metre resolution. Kellenberger et al. (2021) developed an approach to automatically detect and count seabirds in UAS imagery using deep convolutional neural networks (CNNs) resulting in low accuracy rates for some types of species regarding the insufficient number of training species for the CNN technique. Again, Dujon et al. (2021) developed a deep CNN using UAS imagery to detect three types of species, in particular, gannets with an overall precision of 0.74. Hong et al. (2019) employed several types of DNNs in non-marine bird detection, resulting in precision values ranging from 85.01% to 95.44%. Hayes et al. (2021) employed CNN in counting two types of birds on the shore in the sitting state using UAS at a close range, resulting in success rates of 97.66% for Black-browed Albatrosses, and 87.16% for Southern Rockhopper Penguins. Close-range use of UAS may disturb wildlife or disrupt their normal activities (Johnston, 2019), especially for flying birds. Akçay et al. (2020) conducted on-ground flying bird detection on bird population movement trends using several DNN techniques with precision values ranging from 0.86 and 0.94. Alqaysi et al. (2021) found the precision values ranging from 60% to 92% for bird detection around wind farms using DNN. There is no guarantee in achieving good accuracy rates using the most popular learning technique, the so-called DNNs. It can be concluded that these approaches require a huge amount of data samples to achieve a satisfactory training outcome (Delhez, 2022). The aforementioned techniques are discussed in Section 7 considering the proposed approach in this study. It is worth discussing the emerging promising approach, namely, Deep Reinforcement Learning (DRL) here as well.

Recent revolutionary advances in artificial intelligence (AI) using the learning principles of biological brains and human cognition has fuelled the development and use of Deep Reinforcement Learning (DRL) in numerous fields such as Atari games (Mnih et al., 2015), poker (Moravčík et al., 2017), multiplayer games (Jaderberg et al., 2019), and board games (Silver et al., 2016; Silver, Hubert et al., 2017; Silver et al., 2018; Silver, Schrittwieser et al., 2017). DRL has surpassed human-level performance in many similar applications. It, with goal-directed behaviour and representation learning with the ability to learn different levels of abstraction from data, has emerged as a very effective approach by combining the strengths of two successful approaches – RL and DNN – to overcome the representation problem of RL as function approximators, which generalises knowledge to new unseen complex situations. More explicitly, DRL can be defined as a function approximation method in DNN to generalise past experiences to new situations in complex scenarios by mapping them to near-optimal decisions using scalable and generalisable optimal policies. DRL, in particular, with the most commonly used Deep Q-Networks (DQN), has been found successful in addressing high dimensional problems with less prior knowledge. However, to the best of our knowledge, DRL has been employed for generalising past experiences to a new situation to find the best optimal decision and has yet to be employed for a problem space similar to the one mentioned in this paper. Therefore, this method seems not applicable to our objectives considering the aforementioned problem space which is defined in Section 3.

3. Problem definition

Very large areas need to be surveyed in shorter time spans to understand the ecological footprint and to take necessary measures accordingly in a timely manner. Despite recent advances in computer vision and learning techniques as well as many attempts to monitor off-shore species in an automated manner, comprehensive large off-shore wildlife censuses are still conducted manually by experienced ecologists, ethologists, ornithologists (e.g., JNCC, 2022; Thompson, 2021) due to unmet expectations in accuracy rates for the counting and classification of multispecies via automated methods. Manual approaches increase the cost of surveying large areas significantly and required regular surveys may not be conducted due to this high cost. New automated computer-based approaches are required to observe large areas efficiently and effectively to meet the desired objectives of the research community. We performed a literature survey analysis (Section 2) and conducted several preliminary experiments using the most commonly used techniques to develop the most appropriate approach that can meet the expectations of the research community. The outcomes of our preliminary tests are elaborated in Section 4.1. To summarise considering the survey analysis and preliminary tests specific to the airborne survey data, (i) template-matching approaches (e.g., SIFT) that requires no prior training are far from being able to realise any objectives desired by the research community due to the

indistinct features of very small objects within very complex background, (ii) off-the-shelf computer vision techniques (e.g., OBIA) and off-the-shelf ML techniques that require prior training don't result in high accuracy rates due to the indistinct features of very small objects in very big images, and (iii) DNN (e.g., R-CNN), requiring prior training with a large number of data instances, do not converge to a desired solution due to the limited number of instances with the indistinct features of very small objects within a diverse background; Besides, the misclassification of multispecies is high with DNN where data instances in different groups resemble each other too closely as seen in bird species.

The literature, to the best of our knowledge, has a gap that can be filled with the research of computer-automated study analyses of species datasets acquired from the photogrammetry settings which use small aeroplanes to survey very large areas in shorter time spans when compared with other approaches that use static locations, ships or UAS. Due to low accuracy rates in detecting small animals in the marine ecosystem using several off-the-shelf computer vision techniques, off-the-shelf ML techniques, template-matching approaches, and DNN, which is elaborated in Section 4.1 regarding the preliminary experiments with our findings (e.g., the changing and complicated background of the sea, number of data samples in the training set, low-quality images of small species that lack clear features due to them being captured by small aeroplanes with remotely-sensed aerial monitoring photogrammetry settings), we developed a novel approach using an ensemble of ML and RL with a motivation to increase the detection accuracy to reach our target (>0.95) and classify multispecies for the further improvement of the application with multispecies training.

4. Methodology

4.1. Technical background

Repetitive surveying of very large areas for the purpose of observing trends and population fluctuations, which also use human-dependent approaches, may result in huge financial and time costs. Therefore, sampling is commonly employed to census species within representative sample areas using varying sampling strategies and a way of statistical prediction or projection to a whole figure to avoid high costs where the larger the sample of sites, the better the approximation. However, there can be many sampling biases in such datasets like spatial, taxonomic, or temporal leading to inaccurate inferences: Spatial bias refers to uneven sampling efforts across a region; Taxonomic bias can include over or under-representation of certain species in the dataset; Temporal bias occurs when records are collected in one season only, or more often at certain times of the year (Jayadevan et al., 2022). Sampling may not be extrapolated to a reliable figure,

in particular, for rare species, considering the high percentage of negative images in whole surveys ($> 95\%$) and uneven density and variance in counts of species from one habitat to another, mostly, related to the habitat associations (e.g., food, breeding, sheltering) leading to poor sampling (i.e., oversampling, undersampling), which may produce misleading inferences. Several studies developed particular approaches to mitigate the effect of biases in surveys. For instance, Smyser et al. (2016) utilised a double-observer survey configuration to quantify and correct the bias caused by the failure of observers in aerial surveys. Monitoring all regions of interest and counting all species of interest is crucial to reach highly reliable outcomes and proper decisions with appropriate interpretations. Aerial surveys are an efficient survey platform, capable of collecting wildlife data rapidly across large spatial extents in short time frames; however, these surveys can yield unreliable data if not carefully executed (Davis et al., 2022). To this end, numerous approaches such as entropy-based information screening method (Li et al., 2021) and normalised double entropy (NDE) (Li et al., 2023) were developed to distinguish bad and redundant image data to increase the quality of sampling.

As an active research direction for decades, object recognition and detection have had increased importance within many fields such as nature, biometrics, medicine, and robotics. Current clustering algorithms, in which no prior training is performed, on visual datasets, are not successful in grouping similar objects with high rates of accuracy, particularly, for objects with very complex backgrounds (Kuru & Khan, 2018). One of the oldest methods of object recognition is the template-matching approach. It consists of sliding a particular template over the search area (usually an image in which we are trying to locate) and at each position, calculating a distortion or correlation measure that estimates the degree of dissimilarity or similarity between the template and the candidate (Reyes, 2014). Then, the minimum distortion or maximum correlation position (depending on the implementation) is taken to represent the instance of the template into the image under examination. There are various ways of calculating the degree of dissimilarity or similarity, such as the Sum of Absolute Differences (SAD) and the Sum of Squared Differences (SSD). The Normalised Cross-Correlation (NCC) is by far one of the most widely used correlation measures (Stefano et al., 2003; Yang, 2010). Recently, several well-advanced template-matching techniques have been developed to detect objects automatically. These off-the-shelf template-matching techniques are scale-invariant feature transform (SIFT), speeded-up robust features (SURF), features from accelerated segment test (FAST), binary robust independent elementary features (BRIEF), oriented FAST and rotated BRIEF (ORB), maximally stable extremal regions (MSER) and binary robust invariant scalable key points (BRISK). In these techniques, a similarity value regarding the specified number of most important key points is utilised to determine if there is a similarity between the reference object and the objects in images, videos, or real-time scenes given a threshold value. No pre-processing and

training is required. We tested these approaches on our sample datasets and the preliminary results indicated that none of these approaches is successful enough to detect and split very small birds with many different postures in large-scale images against the changing and complicated background of the sea (Ex: Figs. 6, 16). It is noteworthy to mention that variations in sea-state, marine environments, atmospheric conditions, and solar illumination angles combine to produce a wide range of sea surface image patterns that form the background to the targets of a bird mapping operation (Groom et al., 2013).

The other approach is the supervised ML approach, which requires prior datasets to both determine the common features and train the system for further similar detections based on these features. Accuracy rates of detection are mainly dependent on the quality of datasets used in training in terms of representing the real environment by avoiding overfitting. In the training process, general features are acquired and these features are then compared to the features of objects in test datasets to observe how well the features are detected and to determine if these features are suitable to be employed in real life. Trained models (i.e., detectors) are used for the detection of similar objects after the evaluation is conducted successfully by using an evaluation dataset. Our preliminary tests on the sample datasets using the supervised ML approaches showed promising results, which is elaborated in Section 4.2. The frequent low numbers of marine birds in any given area adds to the complexity of developing methods for large-scale operational surveys (Groom et al., 2013). Most of the time, there might be a single gannet in a large-scale image (Ex: Fig. 16) within our surveys.

This makes detecting them highly difficult with regards to splitting the images with gannets from those without gannets, for aerial surveys with more than half a million images, into the positive folder. In other words, it would be easier to detect at least one gannet among several gannets in a large-scale image rather than detecting a single gannet in the image.

To summarise, as explained above, our preliminary test results showed that employing a template matching approach did not work for detecting and splitting birds in large-scale aerial images, because, despite their distinctive features (Ex: Fig. 1) the birds are not very clear in very complex and changing sea textures despite the high quality of the images with a very high camera resolution (i.e., > 50 Megapixels). Moreover, DNN techniques do not result in satisfactory outcomes where the number of instances in domain sets is not many as in our case in this study even though they are recently popular and successfully employed in many different types of application fields and these techniques have far exceeded the accuracy rates of current ML methods. More importantly, our preliminary test using DNN showed that the misclassification of multispecies is high if data instances in different groups resemble each other too closely as seen in bird species. Therefore, we have employed an ensemble of ML and RL techniques for automated recognition, splitting, and counting of birds in aerial surveys to both reach our goals in accuracy rates and classify multispecies in the further development of the proposed application and a user-friendly application was developed using Matlab Simulink MatWorks R2020,⁵ as displayed in Fig. 2. The algorithms were developed to work on any size of bird objects using interpolation and extrapolation techniques, providing there is a training data

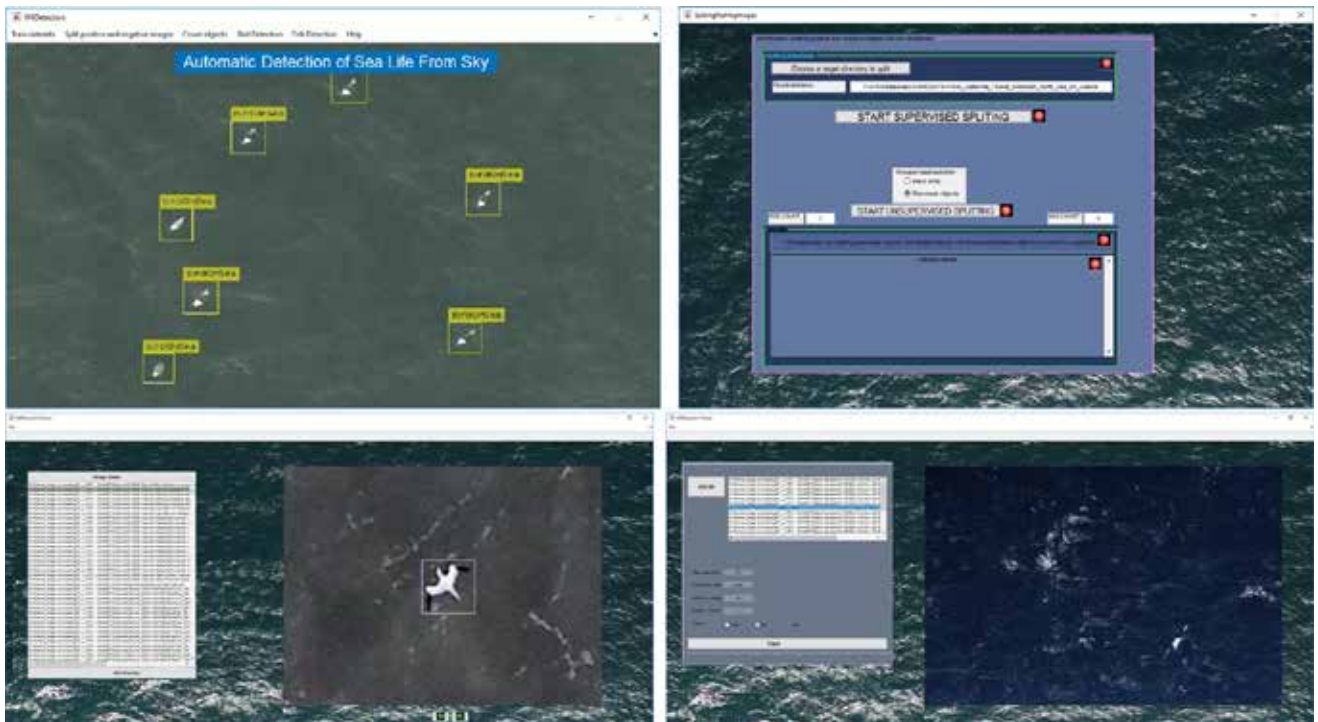


Fig. 2. Interfaces of the application from top to bottom: (i) the main, (ii) training for ROI selection, (iii) training for blank set and parameter selection and (iv) recognition/splitting.

set available. In particular, the methods of the sliding window (Forsyth & Ponce, 2012) and Gaussian pyramid (Witkin, 1984) are applied to detect any object that can appear in different regions of the image and in different scales. A detection window in the sliding window method slides over the image to extract the regions. The Gaussian pyramid (Witkin, 1984) method is primarily applied to the image during the detection stage of the sliding window to operate a scale search.

Three feature extraction techniques are employed in our methodology, namely Haar Cascades, Local Binary Patterns (LBP), and Histogram of Oriented Gradients (HOG). Each of these techniques acquires different features of objects using different mathematical modelling. We applied these techniques to establish the detectors in our implementation using Matlab ready-to-use commands along with the Viola–Jones matching technique.⁶ (i) Haar cascade technique resembling Haar wavelets was first introduced by Papageorgiou et al. (1998) and Viola and Jones (2001). First, the pixel values inside the black area are added together; then the values in the white area are added together. Following that, the total value of the white area is subtracted from the total value of the black area. This result is used to categorise image sub-regions (Cruz et al., 2015), which requires a fair amount of time to train a classifier and generate the Haar training set. The calculation method of Haar-like features is faster by introducing an integral image or summed-area table (Viola & Jones, 2001), which makes the computing of Haar-cascade classifiers more efficient. (ii) LBP was first introduced by Wang and He (1990) and analysed in detail by Ojala et al. (1994). It has been improved by several other studies regarding object identification and recognition (Ojala et al., 2002; Trefný & Matas, 2010; Zhang et al., 2007). In the LBP technique, the texture is defined as a function of spatial variations in the pixel intensity of an image with a low computational cost by focusing on a small set of critical

features, discarding most of the non-critical ones to increase the speed of the feature extraction and classification significantly without affecting accuracy; common features, such as edges, lines, points, flat areas, and corners can be represented by a value in a particular numerical scale (Cruz et al., 2015). Therefore, it is possible to recognise objects in an image using a set of values extracted a priori and several weak classifiers turn into a strong classifier regarding recognition (Cruz et al., 2015). (iii) HOG which explores gradient information and local shape information was first explored by McConnell (1986) and improved by Dalal and Triggs (2005). The technique counts occurrences of gradient orientation in localised portions of an image, which is computed on a dense grid of uniformly spaced cells and uses overlapping local contrast normalisation by the distribution of intensity gradients or edge directions. Due to the strong texture and shape description ability, HOG can be used in the detection of many different types of objects. It is highly sensitive to object orientation. It responds rapidly to changing parameters of FAR and TPR based on its feature extraction method which uses histograms. (iv) The Viola–Jones technique that is included in Matlab Computer Vision System Toolbox (i.e., vision.CascadeObjectDetector) is used to match acquired features in detectors to those of the objects in images for comparison and detection. This technique along with feature extraction techniques is highly sensitive to different orientations of objects in images/videos. The main reasons for choosing Viola–Jones are its fast detection speed and its high accuracy detection rate regarding the large-scale aerial images on which we are working. How these techniques are employed in a novel approach in our methodology is explored in the following sections, particularly, Sections 4.2 and 5.

The main components of the platform, WILDetect, built in this study are depicted in Fig. 3. The phases are (i) data preparation/pre-processing (A.1), (ii) feature extraction/training (A.2), (iii) viability testing of the detectors and specifying the best detectors (A.3), (iv) implementation of the model in splitting and counting in surveys (A.4) (i.e., determining the best detectors in splitting and counting using the recursive RL approach (A.4.1), recognition and splitting (A.4.2.Phase1), recognition and counting (A.4.2.Phase2)), and (v) database operations (A.5) that are explained in the following sections respectively.

4.2. Establishment of the methodology

The defined problem space (Section 3), considering the literature analysis (Section 2) and the obtained results from the preliminary tests (Section 4.1) using off-the-shelf approaches, necessitates the development of a new approach to achieve the objectives of the research community while performing airborne wildlife census automatically in the marine ecosystem. With this in mind, the approach built here is explained step by step in the following subsections (Sections 4.2.1, 4.2.2 and 4.2.3) and the results of the implementation using large surveys are provided in Section 5).

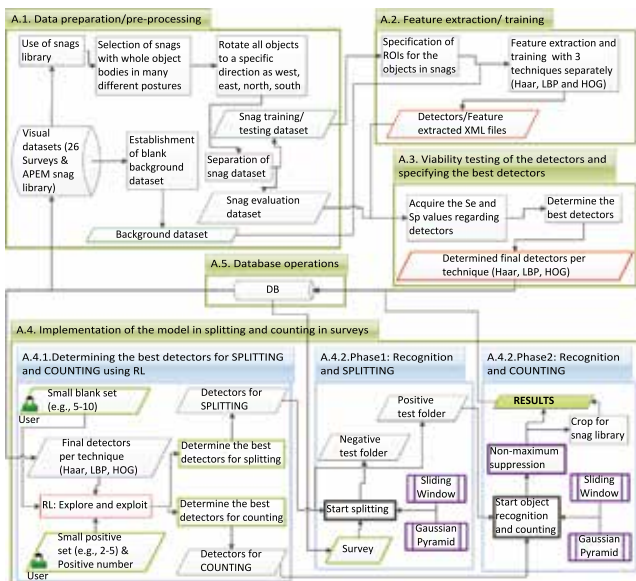


Fig. 3. Main components of the methodology.

4.2.1. Data sets, data preprocessing/preparation (A.1)

The main subcomponents of this phase along with their interaction are illustrated in the dedicated section of Fig. 3 titled “A.1”. A dataset consisting of images with the object of interest and a dataset consisting of blank/background images that represent anything except the object of interest are needed to establish a supervised ML approach for training, testing, evaluation, and validation. Data preparation and data management in those steps are demonstrated in Fig. 4. The negative set typically contains more images than the positive set in order to complete the training phase where every positive image needs more background images that represent the real-world environment. APEM has many surveys in its repository in which almost %95 of the images are blank background images with no targeted object types. APEM conducts offshore

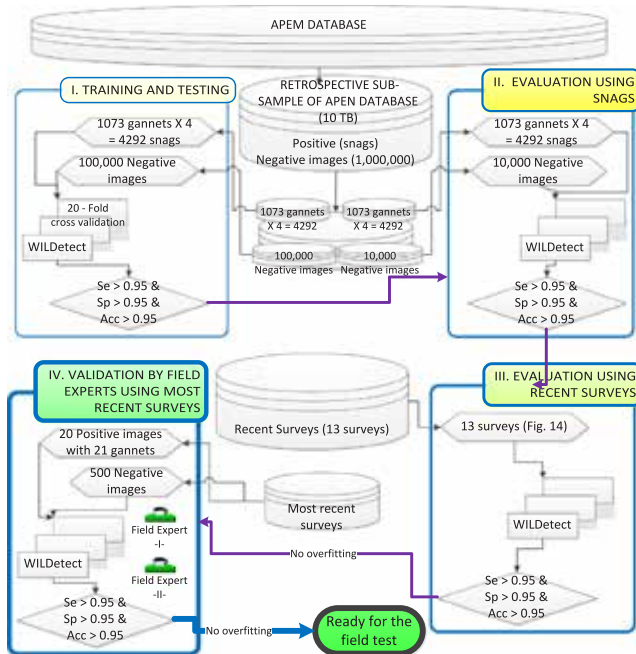


Fig. 4. Use of datasets during training, testing, evaluation, and validation of WILDetect.



Fig. 5. APEM aeroplane during a remotely-sensed aerial survey using advanced aerial high resolution photogrammetry.

digital wildlife surveys for the offshore renewables sector, reliably capturing imagery all year round in all lighting conditions and sea states up to four. The data is captured on a variety of sensor formats including both 35 mm and medium format from various manufacturers, in both single camera and multiple camera configurations, depending on the project requirements. The images are collected by these advanced cameras mounted in a small twin-engine aeroplane (Ex: Fig. 5) within a route in which all regions of interest are surveyed.

A snag library that consists of around 1 million snags (i.e., cropped images with objects of interest; ex: Fig. 6) has been established by APEM. We aimed to incorporate all possible targeted positive images into the methodology, either for training/testing or evaluation and validation to create a positive dataset that can represent the real-world object types by avoiding overfitting during the decision-making phase of the implementation in real-field tests. We pre-processed the gannets in this library by selecting the convenient gannet samples. Our preliminary tests showed that flying gannets with their partial body parts can be detected using whole body sets, but, a whole gannet body cannot be detected by a trained set that consists of various partial parts of gannets (e.g., only one wing). Furthermore, partial body parts can increase the false-positive (FP) rate. Therefore, in this phase, we aim to select as many gannets as possible that have whole bodies (i.e., two wings, head, and tail), but in all possible postures. With this in mind, we prepared two sets of gannets (50%/50%), one of which is for training/testing with 1073 snags (Fig. 4I) and the other one is for evaluation with again 1073 snags in many different postures (Fig. 4II). Our preliminary test results suggest that the detectors built using the three feature extraction techniques (i.e., Haar, LBP, HOG) based on the specific orientations (i.e., north, east, south, west) improve the accuracy rate significantly where these techniques are highly sensitive to different orientations of objects in images as explained in Section 4.1. Therefore, all the gannet objects in these sets are rotated into 4 directions automatically using the codes produced in this study for the data preprocessing phase, namely, north, east, south, and west, by which 4 sets of gannet objects totalling $1073 \times 4 = 4292$ were generated for training/testing and evaluation, rather than separating them into these directions into 4 groups, which would reduce the number of objects substantially. In this way, 4 types of detectors are needed with the orientations north, south, east, and west, as well as a large number of negative images. The greater the variety of these snags/images representing the real environment, the better the detectors avoiding overfitting and consequently the higher the accuracy of detecting targeted objects in images in real field tests. A sub-sample of the dataset in which all gannets are almost rotated to the north is presented in Fig. 6. More snag examples can be found in our technical report — MarineObjects_Gannet_Supplement_2.pdf in the supplementary materials. Moreover, the gannet objects in large-scale images (Ex: Fig. 16) are presented in our technical report — MarineObjects_Gannet_Supplement_3.pdf in the supplementary materials with many different postures and background textures.

In addition to the positive dataset, a blank/background/negative dataset was established using 26 surveys collected by APEM between 2014 and 2017. These surveys were acquired from different parts of the world in different seasons and time zones using different settings and types of image-capturing technologies. The texture of the negative images in these surveys differs from each other as displayed in Fig. 7, which makes the implementation more challenging. More examples specific to the surveys can be found in our technical report — MarineObjects_Gannet_Supplement_1.pdf in the supplementary materials. We were given around 1 million images that are the subsets of these surveys. We used this large number of surveys, a volume of around 10 TB, to find out the general characteristics of aerial surveys. The diverse features revealed from these large surveys help make our approach strong and promising for further use of the application in any circumstances while separating targeted objects from their background. This large dataset was stored in high-powered servers and processed using these servers (A storage unit (12 TB), 2 Novatech servers and 5 HP servers connected to each other via the network. The storage unit is used for placing the

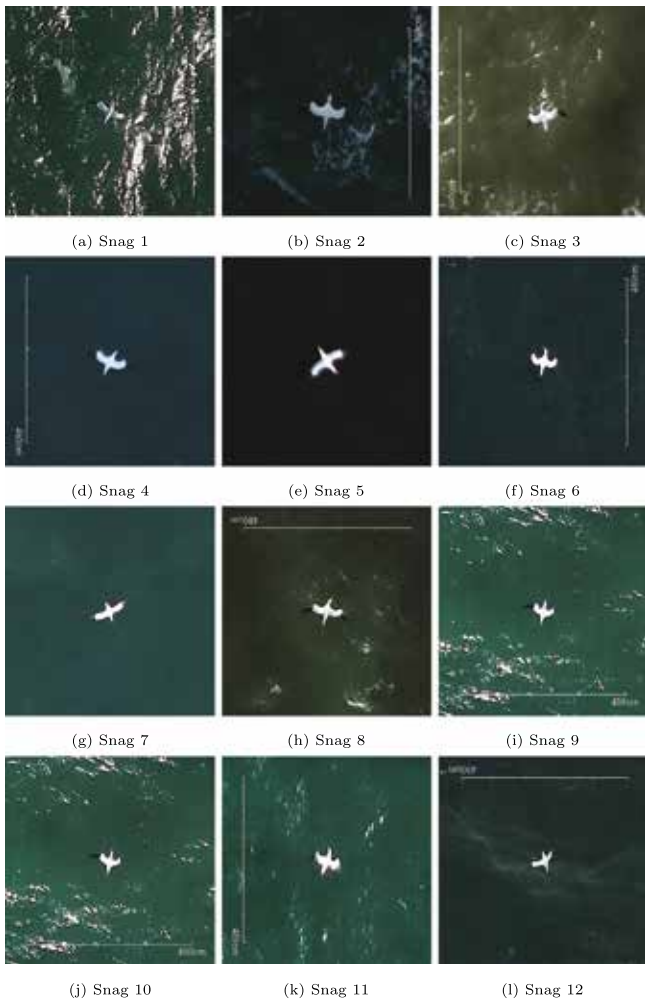


Fig. 6. Examples of the gannet snags for the north direction in several postures and background textures.

big size of the datasets and applications on servers are run using the datasets placed in the storage unit for development, evaluation and validation. The specifications of the Novatech servers: Intel (R) Xeon (R) CPU E5 26300 2.30 GHz 2.30 GHz (2 processors), 64 bit, 64 GB RAM, GPU (NVIDIA GeForce GTX 680). The specifications of the HP servers: Intel (R) Xeon (R) CPU 5160 3.00 GHz, 64 bit, 8 GB RAM. We established a sub-sample set from the diverse surveys that consisted of 100,000 images (Fig. 4I) to use in the training process, with the aim of incorporating all the characteristics of the current and future surveys into implementation. It is worth emphasising that an equal number of negative images from all sub-surveys (107 sub-surveys), within the above-mentioned 26 surveys, were included considering the seasons and time zones to create a negative dataset that can represent the real-world circumstances. Rather than using 1 million images, this sub-sampled set would

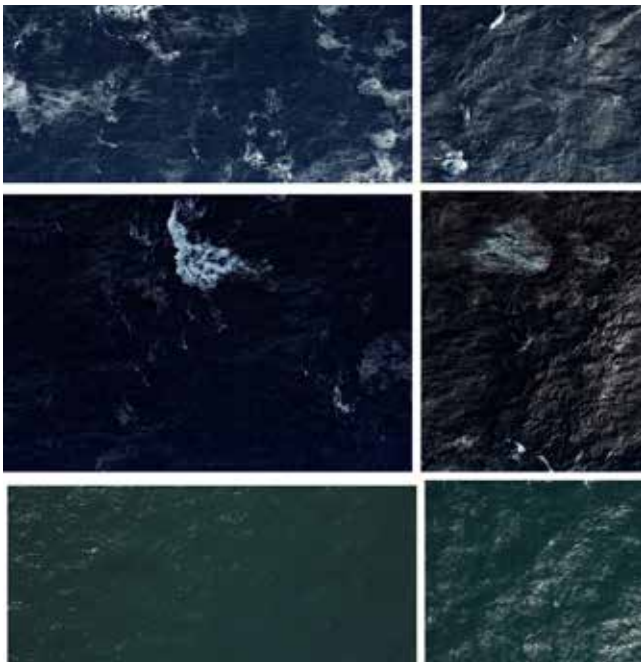


Fig. 7. Examples of blank images from 6 different surveys with various textures.

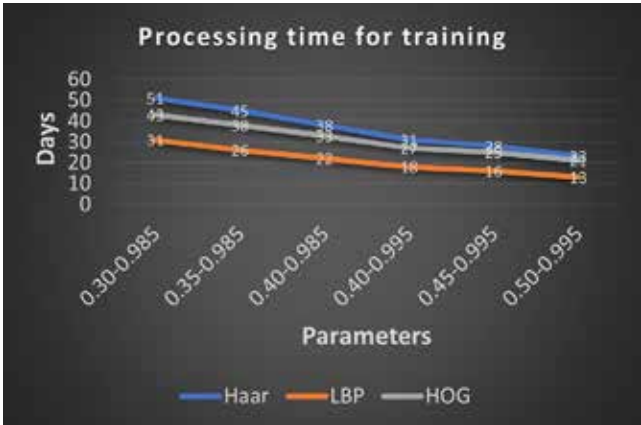


Fig. 8. Processing time of detectors in Table 1.

Table 1 Processing time of the detectors in days.

Techniques	0.30–0.985	0.35–0.985	0.40–0.985	0.40–0.995	0.45–0.995	0.50–0.995
Haar	51	45	38	31	28	23
LBP	31	26	22	18	16	13
HOG	43	38	33	27	25	21

Table 2 Accuracy rates of the training phase with the snag dataset based on the detectors with 6 different parameters: all snags are recognised successfully by the parameters, FAR = 0.50 and TPR = 0.995 with the combination of 3 techniques.

Techniques	0.30–0.985	0.35–0.985	0.40–0.985	0.40–0.995	0.45–0.995	0.50–0.995
Haar	0.825	0.975	0.98	0.985	0.989	0.993
LBP	0.675	0.925	0.935	0.966	0.984	0.992
HOG	0.735	0.85	0.9	0.993	0.994	0.994
Combined	0.84	0.99	0.992	0.995	0.996	1

reduce the processing time of training significantly, in particular, while singling out the consecutive new sets for each following training iteration, which is elaborated in Section 4.2.2. Readers are referred to Fig. 4 in the related sections below in which the evaluation and validation are explained after revealing the establishment of the methodology in the following sections.

4.2.2. Feature extraction and training (A.2)

The main subcomponents of this phase along with their interaction are illustrated in the dedicated section of Fig. 3 titled “A.2”. Automatic detection systems usually require large and representative training datasets to achieve good detection rates with fewer FP rates (Vállez et al., 2015). The training phase is very important for the successful recognition of objects in the further use of the application. One badly trained file/classifier can cause the splitting process (A.4.2. Phase1 in Fig. 3) to function poorly and many positive images may be placed in the negative folder and vice versa, which we aim to avoid. The user interface developed for the training phase is displayed in Fig. 2ii and iii. With this interface, the detectors can be generated using several parameters such as true positive rate (TPR), false alarm rate (FAR), number of training stages, number of background images, and negative sample factor (NSF), with respect to the number of positive images in each training stage and the feature extraction techniques, i.e., Haar, LBP, and HOG. A mathematical model of the objects is extracted using these techniques as explained in Section 4.1. These techniques were selected, because, in addition to providing detectors with encouraging accuracy, they produce detectors that can function efficiently. For instance, objects can be detected in a few seconds in an image with 50 million pixels. The training interface lets the user feed the system with positive images for ROI selection and negative images for background analysis, as well as specify the parameter values. ROIs are specified in positive images by the user (at least one ROI in each image), and the feature descriptors are extracted based on ROIs using the aforementioned techniques in the training process. Several training sets were acquired using different FAR and TPR parameters for each feature extraction technique. In each training, the number of training stages was 20 (i.e., 20-fold cross-validation) along with the number of the negative samples 3,

which means that the number of the different negative images to be used in each training stage of the 20 iterations would be as many as 3 times the number of positive images. Our preliminary tests show that (1) decreasing the number of iterations (e.g., 10-fold) increases the training time significantly, (2) the recognition accuracy rate is almost the same with negative sample factors of 3 and 10; however, the processing time increases significantly with the value of 10. Therefore, the training parameters 20 for iterations rather than most commonly used 10-fold and 3 for negative sample factor were selected to decrease the training time. In each iteration, the techniques choose a set of different negative images in the negative dataset whose texture features

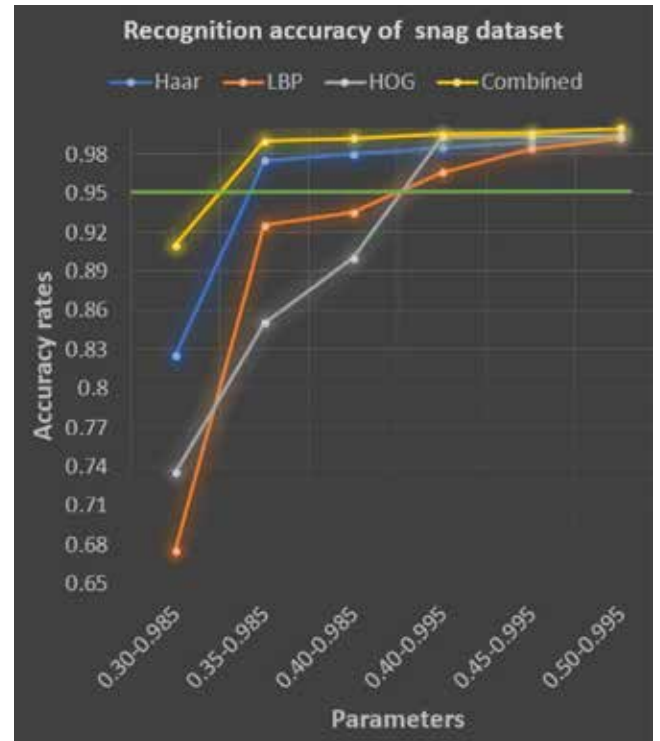


Fig. 9. Results for Table 2: The accuracy rate of recognition is increased by combining 3 techniques, which is depicted by the yellow line. Combination of 3 techniques is more important where the FAR and TPR parameters are smaller to acquire a satisfactory recognition rate. The horizontal green line drawn on 0.95 Se is the objective threshold level; the Se values over this line are acceptable in terms of the yellow line.

are supposed to be different from the previously selected sets. The system stops if not sufficient negative images with different features are provided.

Therefore, the images in the negative dataset must be different from each other with respect to their textures. A large number of images in the negative dataset increase the chance of finding a new set for each following training iteration. As explained earlier, 100,000 images selected for the negative datasets from different surveys provide enough distinctive iteration sets for our training iteration steps.

The training process is repeated to obtain several detectors using different parameters, in particular, reducing the values of TPR and FAR to flag fewer FPs. This is mainly beneficial to the analysis of different types of surveys with regard to their varying textures, as explained in the following sections. As soon as the detectors are generated, they are tested on the sample test dataset and the threshold parameters are reduced until almost all negative images are transmitted into the negative directory. This may cause several positive images to be missed with respect to each technique with reduced threshold parameters. However, these techniques use different features and if one detector with a technique misses one positive image, there is a high probability that one of the other two detectors using the other two techniques may specify this image as a positive image. Therefore, we are employing these three techniques at the same time for the splitting phase to overcome the reduced sensitivity (Se) because of the FNs with respect to each

technique in order not to miss any positive image, which is explained in Section 4.2.3 in detail with examples.

Detectors for the specific types of objects are created only once and can be used whenever needed to recognise, split and count specific objects in images for further analysis. Six trained sets — detectors consisting of 72 trained files (i.e., 6 threshold values \times 3 techniques \times 4 directions = 72) were created using 6 threshold values, as displayed in Table 1. In other words, 12 trained files were obtained for each trained set, 4 for each technique (i.e., Haar, LBP, HOG) and each of which represents the gannet sets in one of the four directions (i.e., north, east, south, west) (i.e., 12 trained files for each detector \times 6 detectors = 72). The processing time of the training in terms of threshold values is shown in Table 1 and Fig. 8. The smaller the threshold values, the longer the training time.

4.2.3. Viability testing of the detectors and specifying min/max threshold parameters (A.3)

The acquired trained files were evaluated on the evaluation dataset (i.e., 1073 snags in four directions) spared for evaluation (Fig. 4II) as mentioned in Section 4.2.1. The evaluation results are presented in Table 2 and Fig. 9. As it is noticed in Fig. 9, the detection success of the feature extraction techniques varies depending upon the approaches followed in these techniques as elaborated in Section 4.1 as the parameters concerning the features of

the datasets changed. For instance, the effect of the HOG technique is relatively poor when the parameters are small, and it increases rapidly after the values of parameters are increased. In this way, the drawbacks of one technique considering the features of data can be compensated by the other two techniques while the parameters need to be changed for achieving the desired goals, either for increasing Se or for increasing Sp . The trained files with the parameters FAR = 0.30 and TPR = 0.985 resulting in a Se value of 0.840 are excluded from the trained folder in order not to be used for further recognition and splitting process. Because the main objective of this research is to obtain a Se value greater than 0.95 which is one of the targeted success criteria, i.e., threshold level, as shown in Fig. 9 with the green line. In other words, we do not want to miss positive images at any cost even with small Sp values by achieving this success criterion. As explained in Sections 5.1 and 5.2, the system with established detectors was run on various evaluation and validation surveys (Fig. 4III and IV) with varying characteristics to find out the detectors' viability on further surveys based on the observed Se and Sp values, strictly speaking, Sp after achieving a satisfactory Se value with 5 threshold intervals, all of which are above the targeted sensitivity value, 0.95.

The use of three feature extraction techniques at a time is more important where the detectors with smaller threshold parameters are selected by the system with the RL approach as explained in the following Section 5. Some of the gannet objects detected by only one of the feature extraction techniques are presented in Fig. 10 where FAR = 0.35 and TPR = 0.85. These three gannet objects are detected by the three techniques at the same time with bigger threshold values where FAR = 0.50 and TPR = 0.95. We would like to note that these high threshold values may cause many FPs depending on the complexity of the background and it may not be a good option to use them for particular types of surveys, which is explained in the following sections in detail.



(a) The snag detected by only Haar technique using the trained file Haar right. (b) The snag detected by only LBP technique using the trained file LBP down. (c) The snag detected by only HOG technique using the trained file HOG up.

Fig. 10. Snag examples detected by only one of the techniques with the parameters of FAR = 0.35 and TPR = 0.85.

Endnotes

¹ <https://apem-inc.com>.


² <https://www.apemltd.co.uk>.

³ Courtesy of the photographer and artist Rahul Alvares.

⁴ APEM Ltd is a leading independent environmental consultancy specialising in freshwater and marine ecology. The company is the world's leading provider of digital aerial wildlife surveys for the offshore wind industry, having carried out over 2000 surveys in the North Sea, Irish Sea, Baltic Sea, Pacific, Atlantic, and Gulf of Mexico.

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To be continued in next issue. 

References

- Akçay, H. G., Kabasakal, B., Aksu, D., Demir, N., Öz, M., & Erdoğan, A. (2020). Automated bird counting with deep learning for regional bird distribution mapping. *Animals*, 10(7), <http://dx.doi.org/10.3390/ani10071207>, URL: <https://www.mdpi.com/2076-2615/10/7/1207>.
- Alqaysi, H., Fedorov, I., Qureshi, F. Z., & O’Nils, M. (2021). A temporal boosted YOLO- based model for birds detection around wind farms. *Journal of Imaging*, 7(11), <http://dx.doi.org/10.3390/jimaging7110227>, URL: <https://www.mdpi.com/2313-433X/7/11/227>.
- Bibby, C., Jones, M., & Marsden, S. (1998). *Expedition field techniques: Bird surveys*. London: Royal Geographical Society.
- BOEM (2022). Ocean wind 1 offshore wind farm draft environmental impact statement. URL: <https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/OceanWind1-DEIS.pdf>.
- Borowicz, A., Le, H., Humphries, G., Nehls, G., Höschle, C., Kosarev, V., & Lynch, H. J. (2019). Aerial-trained deep learning networks for surveying cetaceans from satellite imagery. *PLOS ONE*, 14(10), Article e0212532. <http://dx.doi.org/10.1371/journal.pone.0212532>.
- Burger, J., & Gochfeld, M. (2004). Marine birds as sentinels of environmental pollution. *EcoHealth*, 1(3), <http://dx.doi.org/10.1007/s10393-004-0096-4>.
- Caswell, N., Kuru, K., Ansell, D., Jones, M., Jon Watkinson, B., Leather, P., Lancaster, A., Sugden, P., Briggs, E. et al (2020) Patient Engagement in Medical Device Design: Refining the Essential Attributes of a Wearable, Pre-Void, Ultrasound Alarm for Nocturnal Enuresis. *Pharmaceutical Medicine*, 34 (2), pp. 1-19. <https://doi.org/10.1007/s40290-019-00324-w>.
- Chabot, D., Dillon, C., & Francis, C. M. (2018). An approach for using off-the-shelf object-based image analysis software to detect and count birds in large volumes of aerial imagery. *Avian Conservation and Ecology*, 13(1), <http://dx.doi.org/10.5751/ace-01205-130115>.
- Chabot, D., & Francis, C. M. (2016). Computer-automated bird detection and counts in high-resolution aerial images: a review. *Journal of Field Ornithology*, 87(4), 343–359. <http://dx.doi.org/10.1111/jof.12171>, URL: <https://onlinelibrary.wiley.com/doi/abs/10.1111/jof.12171>.
- Clements, N., & Robinson, W. (2022). A re-survey of winter bird communities in the Oregon Coast Range, USA, initially surveyed in 1968–1970. *Biodiversity Data Journal*, <http://dx.doi.org/10.3897/arphapreprints.e91575>.
- Cruz, J. E. C., Shiguemori, E. H., & Guimaraes, L. N. F. (2015). A comparison of Haar-like, LBP and HOG approaches to concrete and asphalt runway detection in high resolution imagery. *The Journal of Computational Interdisciplinary Sciences*, 6(3), 121–136.
- Dalal, N., & Triggs, B. (2005). Histograms of oriented gradients for human detection. In *Proceedings of the 2005 IEEE computer society conference on computer vision and pattern recognition (CVPR’05) - Volume 1 - Volume 01* CVPR ’05, (pp. 886–893). Washington, DC, USA: IEEE Computer Society, <http://dx.doi.org/10.1109/CVPR.2005.177>.
- Davis, K. L., Silverman, E. D., Sussman, A. L., Wilson, R. R., & Zipkin, E. F. (2022). Errors in aerial survey count data: Identifying pitfalls and solutions. *Ecology and Evolution*, 12(3), <http://dx.doi.org/10.1002/ece3.8733>.
- Delhez, A. (2022). *Multiple flying bird and bird keypoint detection toolbox for processing bird videos* (Master’s thesis), Belgium: University of Louvain.
- Dujon, A. M., Ierodiakonou, D., Geeson, J. J., Arnould, J. P. Y., Allan, B. M., Katsefidis, K. A., & Schofield, G. (2021). Machine learning to detect marine animals in UAV imagery: effect of morphology, spacing, behaviour and habitat. *Remote Sensing in Ecology and Conservation*, 7(3), 341–354. <http://dx.doi.org/10.1002/rse2.205>, URL: <https://zslpublications.onlinelibrary.wiley.com/doi/abs/10.1002/rse2.205>.
- Forsyth, D., & Ponce, J. (2012). *Computer vision* (2nd ed.). London: Pearson.
- Gibert, K., Horsburgh, J. S., Athanasiadis, I. N., & Holmes, G. (2018). Environmental data science. *Environmental Modelling & Software*, 106, 4–12. <http://dx.doi.org/10.1016/j.envsoft.2018.04.005>, URL: <http://www.sciencedirect.com/science/article/pii/S1364815218301269>. Special Issue on Environmental Data Science. Applications to Air quality and Water cycle.
- Groom, G., Stjernholm, M., Nielsen, R. D., Fleetwood, A., & Petersen, I. K. (2013). Remote sensing image data and automated analysis to describe marine bird distributions and abundances. *Ecological Informatics*, 14, 2–8. <http://dx.doi.org/10.1016/j.ecoinf.2012.12.001>, URL: <https://www.sciencedirect.com/science/article/pii/S1574954112001185>. The analysis and application of spatial ecological data to support the conservation of biodiversity.
- Hayes, M. C., Gray, P. C., Harris, G., Sedgwick, W. C., Crawford, V. D., Chazal, N., Crofts, S., & Johnston, D. W. (2021). Drones and deep learning produce accurate and efficient monitoring of large-scale seabird colonies. *Ornithological Applications*, 123(3), <http://dx.doi.org/10.1093/ornithapp/duab022>.
- Hollings, T., Burgman, M., van Andel, M., Gilbert, M., Robinson, T., & Robinson, A. (2018). How do you find the green sheep? A critical review of the use of remotely sensed imagery to detect and count animals. *Methods in Ecology and Evolution*, 9(4), 881–892. <http://dx.doi.org/10.1111/2041-210X.12973>, URL: <https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.12973>.
- Hong, S.-J., Han, Y., Kim, S.-Y., Lee, A.-Y., & Kim, G. (2019). Application of deep-learning methods to bird detection using unmanned aerial vehicle imagery. *Sensors*, 19(7), <http://dx.doi.org/10.3390/s19071651>, URL: <https://www.mdpi.com/1424-8220/19/7/1651>.
- Jaderberg, M., Czarnecki, W. M., Dunning, I., Marris, L., Lever, G., Castañeda, A. G., Beattie, C., Rabinowitz, N. C., Morcos, A. S., Ruderman, A., Sonnerat, N., Green, T., Deason, L., Leibo, J. Z., Silver, D., Hassabis, D., Kavukcuoglu, K., & Graepel, T. (2019). Human-level performance in 3D multiplayer games with population-based reinforcement learning. *Science*, 364(6443), 859–865. <http://dx.doi.org/10.1126/science.aau6249>.
- Jayadevan, P., Nameer, P. P. O., Jha, A., Aravind, A., Dilip, K. G., Karuthedathu, D., Tom, G., Mavelikara, H., Mannar, H., Palot, M., Johnson, J., Raveendran, J., Rodrigues, M., Mujeeb, M., Namassivayan, L., Payyeri, N., Nesrudheen, P., Narayanan, S. P., Prasanth, S., & Yathumon, M. A. (2022). Kerala Bird Atlas 2015–20: features, outcomes and implications of a citizen-science project. *Current Science*, 122, 298–309. <http://dx.doi.org/10.18520/cs/v122/i3/298-309>.
- JNCC (2015). Northern Gannet *Morus bassanus*. URL: <http://jncc.defra.gov.uk/page-2875>.
- JNCC (2022). Seabirds count – the fourth breeding seabird census. URL: <https://jncc.gov.uk/our-work/seabirds-count/>.
- Johnston, D. W. (2019). Unoccupied aircraft systems in marine science and conservation. *Annual Review of Marine Science*, 11(1), 439–463. <http://dx.doi.org/10.1146/annurev-marine-010318-095323>, PMID: 30020850.
- Kellenberger, B., Veen, T., Folmer, E., & Tuia, D. (2021). 21 000 Birds in 4.5 h: efficient large-scale seabird detection with machine learning. *Remote Sensing in Ecology and Conservation*, 7(3), 445–460. <http://dx.doi.org/10.1002/rse2.200>, URL: <https://zslpublications.onlinelibrary.wiley.com/doi/abs/10.1002/rse2.200>.
- Kuru, K., Ansell, D., Hughes, D., Watkinson, B. J., Gaudenzi, F., Jones, M., Lunardi, D., Caswell, N., Montiel, A. R., Leather, P., Irving, D., Bennett, K., McKenzie, C., Sugden, P., Davies, C., & DeGoede, C. (2024). Treatment of Nocturnal Enuresis Using Miniaturised Smart Mechatronics With Artificial Intelligence. In *IEEE Journal of Translational Engineering in Health and Medicine* (Vol. 12, pp. 204–214). <https://doi.org/10.1109/jtehm.2023.3336889>.
- Kuru, K., Clough, S., Ansell, D., McCarthy, J., & McGovern, S. (2023). Intelligent airborne monitoring of irregularly shaped man-made marine objects using statistical Machine Learning techniques. In *Ecological Informatics* (Vol. 78, p. 102285). Elsevier BV.

- <https://doi.org/10.1016/j.ecoinf.2023.102285>
- Kuru, K., Clough, S., Ansell, D., McCarthy, J., & McGovern, S. (2023). WILDetect: An intelligent platform to perform airborne wildlife census automatically in the marine ecosystem using an ensemble of learning techniques and computer vision. In *Expert Systems with Applications* (Vol. 231, p. 120574). <https://doi.org/10.1016/j.eswa.2023.120574>
- Kuru, K., Girgin, S., Arda, K., & Bozlar, U. (2013). A novel report generation approach for medical applications: The SISDS methodology and its applications. *International Journal of Medical Informatics*, 82(5), 435–447. <http://dx.doi.org/10.1016/j.ijmedinf.2012.05.019>, URL: <https://www.sciencedirect.com/science/article/pii/S138650561200113X>.
- Kuru, K., & Khan, W. (2018). Novel hybrid object-based non-parametric clustering approach for grouping similar objects in specific visual domains. *Applied Soft Computing*, 62, 667–701. <http://dx.doi.org/10.1016/j.asoc.2017.11.007>.
- Kuru, K., Pinder, J. M., Watkinson, B. J., Ansell, D., Vinning, K., Moore, L., Gilbert, C., Sujit, A., & Jones, D. (2023). Toward Mid-Air Collision-Free Trajectory for Autonomous and Pilot-Controlled Unmanned Aerial Vehicles. In *IEEE Access* (Vol. 11, pp. 100323–100342). <https://doi.org/10.1109/access.2023.3314504>.
- Kuru, K., & Yetgin, H. (2019). Transformation to advanced mechatronics systems within new industrial revolution: A novel framework in automation of everything (AoE). *IEEE Access*, 7, 41395–41415. <http://dx.doi.org/10.1109/ACCESS.2019.2907809>.
- Li, Y., Yang, J., & Wen, J. (2021). Entropy-based redundancy analysis and information screening. *Digital Communications and Networks*, <http://dx.doi.org/10.1016/j.dcan.2021.12.001>.
- Li, Y., Yang, J., Zhang, Y., Wen, J., & Kumar, P. (2023). Healthcare data quality assessment for cybersecurity intelligence. *IEEE Transactions on Industrial Informatics*, 19(1), 841–848. <http://dx.doi.org/10.1109/TII.2022.3190405>.
- McConnell, R. (1986). Method of and apparatus for pattern recognition. URL: <http://www.google.co.uk/patents/US4567610>. US Patent 4, 567, 610.
- Mnih, V., Kavukcuoglu, K., Silver, D., Rusu, A. A., Veness, J., Bellemare, M. G., Graves, A., Riedmiller, M., Fiedjeland, A. K., Ostrovski, G., Petersen, S., Beattie, C., Sadik, A., Antonoglou, I., King, H., Kumaran, D., Wierstra, D., Legg, S., & Hassabis, D. (2015). Human-level control through deep reinforcement learning. *Nature*, 518(7540), 529–533. <http://dx.doi.org/10.1038/nature14236>.
- Moravčík, M., Schmid, M., Burch, N., Lisý, V., Morrill, D., Bard, N., Davis, T., Waugh, K., Johanson, M., & Bowling, M. (2017). DeepStack: Expert-level artificial intelligence in heads-up no-limit poker. *Science*, 356(6337), 508–513. <http://dx.doi.org/10.1126/science.aam6960>.
- Morelli, F. (2015). Indicator species for avian biodiversity hotspots: Combination of specialists and generalists is necessary in less natural environments. *Journal for Nature Conservation*, 27, 54–62. <http://dx.doi.org/10.1016/j.jnc.2015.06.006>, URL: <https://www.sciencedirect.com/science/article/pii/S1617138115300078>.
- Murray, S., Harris, M. P., & Wanless, S. (2014). An aerial survey of Northern Gannets *Morus bassanus* on Scar Rocks, southwest Scotland, in 2014. *Seabird*, 27(1), 104–109.
- Murray, S., Harris, M. P., & Wanless, S. (2015). The status of the gannet in Scotland in 2013–14. *Scottish Birds*, 35(1), 3–18.
- Murray, S., Smith, I., & Smith, A. (2014). Gannet and Guillemot breeding on Rockall, North Atlantic. *Scottish Birds*, 34(1), 13–15.
- Ojala, T., Pietikainen, M., & Harwood, D. (1994). Performance evaluation of texture measures with classification based on Kullback discrimination of distributions. In *Proceedings of 12th international conference on pattern recognition, Vol. 1* (pp. 582–585). <http://dx.doi.org/10.1109/ICPR.1994.576366>.
- Ojala, T., Pietikainen, M., & Maenpää, T. (2002). Multiresolution gray-scale and rotation invariant texture classification with local binary patterns. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 24(7), 971–987. <http://dx.doi.org/10.1109/TPAMI.2002.1017623>.
- Palczyński, M., Hammill, E., Karpouzi, V., & Pauly, D. (2015). Population trend of the world's monitored seabirds, 1950–2010. *PLOS ONE*, 10(6), Article e0129342. <http://dx.doi.org/10.1371/journal.pone.0129342>.
- Papageorgiou, C. P., Oren, M., & Poggio, T. (1998). A general framework for object detection. In *Sixth international conference on computer vision (IEEE Cat. No.98CH36271)* (pp. 555–562). <http://dx.doi.org/10.1109/ICCV.1998.710772>.
- Reyes, E. (2014). *A comparison of image processing techniques for bird detection* (Master's thesis), the Faculty of California Polytechnic State University.
- Rosenberg, K. V., Dokter, A. M., Blancher, P. J., Sauer, J. R., Smith, A. C., Smith, P. A., Stanton, J. C., Panjabi, A., Helft, L., Parr, M., & Marra, P. P. (2019). Decline of the North American avifauna. *Science*, 366(6461), 120–124. <http://dx.doi.org/10.1126/science.aaw1313>, URL: <https://www.science.org/doi/abs/10.1126/science.aaw1313>. arXiv:https://www.science.org/doi/pdf/10.1126/science.aaw1313.
- RSBP (2015). Gannet. URL: <https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/bird-a-z/gannet/>.
- SeabirdCentre (2017). Gannet. URL: <https://seabird.org/wildlife/seabirds/gannet/12/26/47>.
- Shi, Y., Shen, C., Fang, H., & Li, H. (2017). Advanced control in marine mechatronics systems: A survey. *IEEE/ASME Transactions on Mechatronics*, 22(3), 1121–1131. <http://dx.doi.org/10.1109/TMECH.2017.2660528>.
- Silver, D., Huang, A., Maddison, C. J., Guez, A., Sifre, L., van den Driessche, G., Schrittwieser, J., Antonoglou, I., Panneershelvam, V., Lanctot, M., Dieleman, S., Grewe, D., Nham, J., Kalchbrenner, N., Sutskever, I., Lillicrap, T., Leach, M., Kavukcuoglu, K., Graepel, T., & Hassabis, D. (2016). Mastering the game of Go with deep neural networks and tree search. *Nature*, 529(7587), 484–489. <http://dx.doi.org/10.1038/nature16961>.
- Silver, D., Hubert, T., Schrittwieser, J., Antonoglou, I., Lai, M., Guez, A., Lanctot, M., Sifre, L., Kumaran, D., Graepel, T., Lillicrap, T. P., Simonyan, K., & Hassabis, D. (2017). Mastering chess and shogi by self-play with a general reinforcement learning algorithm. ArXiv, [abs/1712.01815](https://arxiv.org/abs/1712.01815).
- Silver, D., Hubert, T., Schrittwieser, J., Antonoglou, I., Lai, M., Guez, A., Lanctot, M., Sifre, L., Kumaran, D., Graepel, T., Lillicrap, T., Simonyan, K., & Hassabis, D. (2018). A general reinforcement learning algorithm that masters chess, shogi, and Go through self-play. *Science*, 362(6419), 1140–1144. <http://dx.doi.org/10.1126/science.aar6404>, arXiv:https://www.science.org/doi/pdf/10.1126/science.aar6404.
- Silver, D., Schrittwieser, J., Simonyan, K., Antonoglou, I., Huang, A., Guez, A., Hubert, T., Baker, L., Lai, M., Bolton, A., Chen, Y., Lillicrap, T., Hui, F., Sifre, L., van den Driessche, G., Graepel, T., & Hassabis, D. (2017). Mastering the game of Go without human knowledge. *Nature*, 550(7676), 354–359. <http://dx.doi.org/10.1038/nature24270>.
- Smyser, T. J., Guenzel, R. J., Jacques, C. N., & Garton, E. O. (2016). Double-observer evaluation of pronghorn aerial line-transect surveys. *Wildlife Research*, 43(6), 474. <http://dx.doi.org/10.1071/wr16006>.
- Stefano, L. D., Mattoccia, S., & Mola, M. (2003). An efficient algorithm for exhaustive template matching based on normalized cross correlation. In *12th international conference on image analysis and processing, 2003. Proceedings* (pp. 322–327). Mantova, Italy: IEEE.
- Thompson, D. (2021). Seabird survey methods for offshore installations: Black-legged kittiwakes. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/974338/Kittiwake_survey_advice_v2.1.pdf.
- Trefný, J., & Matas, J. (2010). Extended set of local binary patterns for rapid object detection. In *Computer vision winter workshop 2010. Czech Society for Cybernetics and Informatics*.
- Vállez, N., Deniz, O., & Bueno, G. (2015). Sample selection for training cascade detectors. *PLOS ONE*, 10(7), 1–16. <http://dx.doi.org/10.1371/journal.pone.0133059>.
- Viola, P., & Jones, M. (2001). Rapid object detection using a boosted cascade of simple features. In *Proceedings of the 2001 IEEE computer society conference on computer vision and pattern recognition. CVPR 2001, Vol. 1* (pp. 511–518). <http://dx.doi.org/10.1109/CVPR.2001.990517>.
- Wang, L., & He, D.-C. (1990). Texture classification using texture spectrum. *Pattern Recognition*, 23(8), 905–910.
- Wang, D., Shao, Q., & Yue, H. (2019). Surveying wild animals from satellites, manned aircraft and unmanned aerial systems (UASs): A review. *Remote Sensing*, 11(11), <http://dx.doi.org/10.3390/rs11111308>, URL: <https://www.mdpi.com/2072-4292/11/11/1308>.
- Witkin, A. (1984). Scale-space filtering: A new approach to multi-scale description. In *ICASSP '84. IEEE international conference on acoustics, speech, and signal processing, Vol. 9* (pp. 150–153). <http://dx.doi.org/10.1109/ICASSP.1984.1172729>.
- Yang, Z. (2010). Fast template matching based on normalized cross correlation with centroid bounding. In *2010 international conference on measuring technology and mechatronics automation, Vol. 3 ICMTMA*, (pp. 224–227). Changsha, China: IEEE.
- Zhang, L., Chu, R., Xiang, S., & Liao, S. (2007). *Lecture notes in computer science, Facts and fallacies: A book of definitive mistakes and misguided predictions in advances in biometrics*. Berlin Heidelberg: Springer.

- Kuru, K. (2014). A Novel Hybrid Clustering Approach for Unsupervised Grouping of Similar Objects. In *Lecture Notes in Computer Science* (pp. 642–653). https://doi.org/10.1007/978-3-319-07617-1_56
- Kuru, K. (2014). Optimization and enhancement of H&E stained microscopical images by applying bilinear interpolation method on lab color mode. In *Theoretical Biology and Medical Modelling* (Vol. 11, Issue 1). <https://doi.org/10.1186/1742-4682-11-9>
- Kuru, K. (2021). Planning the Future of Smart Cities With Swarms of Fully Autonomous Unmanned Aerial Vehicles Using a Novel Framework. In *IEEE Access* (Vol. 9, pp. 6571–6595). <https://doi.org/10.1109/access.2020.3049094>.
- Kuru, K. (2022). TrustFSDV: Framework for Building and Maintaining Trust in Self-Driving Vehicles. In *IEEE Access* (Vol. 10, pp. 82814–82833). <https://doi.org/10.1109/access.2022.3196941>
- Kuru, K. (2021). Management of geo-distributed intelligence: Deep Insight as a Service (DINSaaS) on Forged Cloud Platforms (FCP). In *Journal of Parallel and Distributed Computing* (Vol. 149, pp. 103–118). <https://doi.org/10.1016/j.jpdc.2020.11.009>
- Kuru, K. (2023) Definition of Multi-Objective Deep Reinforcement Learning Reward Functions for Self-Driving Vehicles in the Urban Environment. *IEEE Transactions on Intelligent Transportation Systems*. (Submitted)
- Kuru, K. (2023). MetaOmniCity: Toward Immersive Urban Metaverse Cyberspaces Using Smart City Digital Twins. In *IEEE Access* (Vol. 11, pp. 43844–43868). <https://doi.org/10.1109/access.2023.3272890>
- Kuru, K. (2021). Conceptualisation of Human-on-the-Loop Haptic Teleoperation With Fully Autonomous Self-Driving Vehicles in the Urban Environment. In *IEEE Open Journal of Intelligent Transportation Systems* (Vol. 2, pp. 448–469). <https://doi.org/10.1109/ojits.2021.3132725>