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Edge Technology Based Artificial Intelligence System for Ocean Patrol and Surveillance

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ABSTRACT

The oceans are a principal source of biodiversity, and with a global seafood market worth over $120B, they're a crucial resource to almost half of the world's population [1]. Costing society $23.5B annually, overfishing caused by illegal, unreported, and unregulated fishing (IUU fishing) contributes significantly to this depletion of fisheries. According to the World Wide Fund for Nature, IUU fishing "threatens marine ecosystems, puts food security and regional stability at risk, and is linked to major human rights violations and even organized crime." In some locations, government-employed observers accompany boats to prevent IUU fishing [2]. However, even in wealthy countries, observers only monitor a minuscule percentage of fishing vessels. For example, in the expansive region of the Pacific Ocean from Indonesia to Hawaii, just 2% of fishing operations are monitored by observers. To combat the problem of IUU the experimenter developed an Edge Technology Based Artificial Intelligence System for marine protected areas (MPAs) using low-cost edge computing devices to track illegal fishing activity through AI-based image recognition services. The product is a solar-powered, inexpensive, edge computing and monitoring device mounted on buoys with a video camera and processor to analyze images using machine learning models. The model detects vessels, monitors their illegal activity in the oceans, thus reducing the overexploitation of fishing. The edge device does processing locally and sends relevant data to the database, reducing the need for processing vast amounts of images & videos centrally. A stealth Autonomous Aerial Vehicle (drone) with a pre-programmed flight path collects the data from buoys and reports predictions to ground stations providing 24x7 surveillance capabilities.The product has a broad range of potential applications to detect overfishing, piracy, smuggling, and instances of ocean pollution, including oil spills. It can also be deployed for marine surveillance, primarily supporting the national defense. The immediate application for this product is the continuous surveillance and protection of targeted MPAs by alerting illegal fishing activities to governments and NGOs in real-time.

Keywords : Edge Technology, Artificial Intelligence System, Ocean Patrol and Surveillance, Illegal, unreported, and unregulated (IUU) fishing, Marine ecosystem, Marine protected areas

I. INTRODUCTION

According to the US National Intelligence Council, "4.3 billion people depend on fish stocks as a source of dietary protein." 90% of workers onboard the 4.6 million fishing vessels worldwide are small-scale fishers from coastal communities in developing nations. Their income, and as an extension many of their communities, are being threatened by an alarming decline in fish stocks due to their overexploitation [3]. According to the UN Food and Agriculture Organization, over 90% of the world's fish stocks are at or exceeding sustainable capacity, 30% are no longer biologically sustainable, and in less than ten years, production will grow by 17%. Due to their enormous reliance on fish, the collapse of fisheries would result in widespread food insecurity and poverty in many developing nations [4]. Illegal, unreported, and unregulated (IUU) fishing contributes significantly to the depletion of fisheries, costing society over $23.5B annually. According to the UN Food and Agricultural Organization (FAO), about 1 in 5 consumed fish is procured through IUU fishing. According to the World Wide Fund for Nature, "IUU fishing threatens marine ecosystems, puts food security and regional stability at risk, and is linked to major human rights violations and even organized crime.

Current products used to combat IUU fishing use four main approaches, which have not addressed the IUU fishing issue effectively. Products such as MAZU rely on photos taken by human observers, which are then sent to a centralized database for manual identification of the IUU fishing vessels. However, even in wealthy countries, observers only monitor a minuscule percentage of fishing vessels [5]. Another way to identify illegal fishing activity is by satellite tracking of the vessel's Automatic Identification System (AIS) signals. Tracked AIS data is inputted into machine learning models to make inferences on vessel activities. However, only 15% of the fishing vessels have AIS installed [6]. Most vessels engaging in illegal activities hide their location and mask their GPS/AIS signals, making it harder to detect vessels operating "under the radar." More recent approaches such as tracking high-radiance lure lights used by commercial fishing vessels and tracking illegal fishing activity from autonomous drones are costly to implement and have yet to be proven effective [7].

With Edge Technology Based Artificial Intelligence System, the experimenter aims to provide continuous and reliable monitoring of MPAs using cost-effective and easy-to-use technology suitable for large-scale deployment. The aim is to significantly improve the surveillance of MPAs by utilizing a low power edge computing device with an automated and highly accurate machine learning model to classify illegal fishing activities with computer vision. The edge computing device [8] can locally process collected data, avoiding the need to stream and process significant amounts of data, which can become very costly. The edge system also addresses the issues of low connectivity and latency, allowing the deployment in harder-to-reach areas. When illegal fishing activity is detected, the device promptly alerts centralized servers using Iridium Short Bursts Data (ISBD) signals. Once an alert is sent, a drone can be sent to the location of the edge device to collect image data of the illegal fishing activity using LiFi. The edge AI device can be mounted on any ocean-going vessel, buoy, or drone. For example, the low-cost and portable device could be installed on legal fishing vessels, recreational or patrol boats, cruise ships, cargo ships, yachts, etc. In addition to vessels, one can utilize deployed buoys and autonomous drones for mounting our devices. By embracing flexible mounting, the experimenter is creating a constantly expanding network of surveillance devices, making the process of covering the vast distances of the ocean much more manageable. The product can be used by governmental agencies, NGOs, and private fishing operators with a stake in the continuous monitoring of illegal fishing activities. The constantly expanding network of devices also allows distinguishing legally caught fish from illegal fishing activity. The proposed edge AI system solution has broad applicability with different use cases for surveillance of ocean health in MPAs. For example, a model can be trained to detect tuna in fishing vessels caught in protected areas where tuna fishing is illegal.

II. SCIENTIFIC PREMISE

Edge Technology Based Artificial Intelligence System will use multiple components to detect illegal fishing vehicles. Firstly the experimenter plans to use a lightweight Arduino computer that takes pictures using an onboard camera. The NVIDIA Jetson Nano 2GB Edge AI device then calls on the classification model to sort through the images and identify an illegal fishing vehicle. The Jetson Nano will run the model at sea. The NVIDIA Jetson Nano is a small form factor computer specifically built by NVIDIA for machine learning at the edge. It harnesses an NVIDIA Maxwell GPU with 128 CUDA cores to create a powerful platform for machine learning processing. The experimenter plans to utilize the Jetson Nano model with two gigabytes of RAM instead of the more expensive four-gigabyte version.

The ISBD sensor on a buoy will send a signal to a satellite and from the satellite to an Ipad that the Coastal Guard owns. Iridium Short Burst Data (ISBD) is simple, efficient packet-based service for frequent short data transmissions between equipment and centralized host computer systems This quick alert can help the Coastal Guard act quickly and precisely because they know when and where to catch the illegal fishing vessel. There is also a light on a drone that shines a direct light towards a Lifi sensor on top of the buoy. The Lifi sensor is capable of sending gigabytes worth of images. The experimenter will use LiFi in order to transmit data between the buoys and the drones used to collect data.

Due to power limitations, the experimenter plans to use the Adafruit Feather M0 Basic Proto as our microcontroller for this project. The small PCB is lightweight, weighing in at only 4.6 grams. The microcontroller is not powerful; however, it is simply necessary to control the rest of the onboard systems, such as the Jetson and the Camera. The Arduino Feather uses very little power, allowing it to run constantly on a solar panel inside the buoy. On the other hand, the Jetson is extremely power-hungry, meaning that it can only run for around 5 minutes every hour. Therefore, the Feather microcontroller is used to boot the Jetson, allow it to do processing, and shut it down. It also takes a picture using the onboard camera and stores it every 60 seconds.

The experimenter plans to use MakerBouy to hold all the components including the NVIDIA Jetson Nano Board, LiFI sensor, IBSD sensor. All the components will be placed in a case to protect all the technology from water and any sea creatures that are curious about our product. The buoy will also be fitted with a solar panel to keep the components charged and ready. Due to the constraints of a buoy floating in the open ocean for long periods of time, The experimenter has chosen solar cells as source of energy.

The experimenter plans to use the Maritime vessels classification dataset (MARVEL) for training the model [9].The dataset consists of two million maritime vessel images and information on each vessel, such as its identity and the year it was built. These images were sorted into 26 different superclasses, including yachts, trawlers, crude oil tankers, and more. The experimenter plans to use computer vision and a classification model to predict whether a given ship shown in an image is an illegal fishing vessel or not. The model was trained on a cloud machine through AWS Dreamweaver due to the large amount of computational resources required for the process. The experimenter plans to utilize the classic AI development lifecycle for building the product. Data was collected and then engineered to fit the needs for model training. The experimenter proceeded to the algorithm selection stage and chose transfer learning as the most accurate training process for the project. The experimenter then continually tested and tuned the model as a continuous feedback loop for improvement.

Edge Technology Based Artificial Intelligence System utilizes a transfer learning approach for machine learning model development. Transfer learning is a style of model development where an existing machine learning model trained to do a specific purpose is repurposed to be used on a different but fairly similar problem. Transfer learning is commonly used in computer vision problems because most efficient and accurate computer vision models require massive datasets and extended amounts of computation time, even on cutting edge hardware, to train. The experimenter selected a computer vision model already available on the internet, reused that model for our purposes, and tuned the model to increase the accuracy and precision of the classification.

III. EXISTING TECHNOLOGY

Multiple government agencies and private firms are building products and services to combat IUU fishing.

The four methods typically employed in tackling IUU fishing are as follows :

1. Human observers
2. Utilizing AIS signals from Vessel Monitoring Systems
3. Satellite-based tools that detect the high-radiance lure lights used by commercial fishing vessels
4. Artificial Intelligence guided autonomous drones

Mazu, a mobile application for information exchange on illegal fishing vessels relies on photos taken by human observers, which are then sent to a centralized database for manual identification [10]. This process is expensive and error-prone as it depends on compiled data from human monitors. Moreover, even in wealthy countries, observers only monitor a small percentage of fishing vessels. Conversely, Edge Technology Based Artificial Intelligence System uses a compact, high-speed NVIDIA Jetson Nano Board to perform data collection and object detection without manual intervention and provides continuous monitoring.

Capella Space, an American space company tracks illegal fishing vessels using Automated Identification System (AIS) signals from the Vessel Monitoring System [11]. While Capella Space identifies some illegal fishing activity, a significant portion remains undetected, as only 15% of fishing vessels have AIS systems installed. Additionally, fishing vessels engaging in illicit activities tend to hide their location and mask their GPS/AIS signals. As a result, it is difficult to find these illegal fishing vessels in MPAs because of their behavior "under the radar".

Edge Technology Based Artificial Intelligence System captures optical images (in contrast to global positioning data and radar images captured by satellites) through the camera and the machine learning models on the edge device to analyze the images locally to detect the fishing activity.

ATLAN Space, builds Artificial Intelligence to mimic human navigators aboard drones, allowing operators to perform safe, cost-efficient, and Beyond Visual Line Of Sight (BVLOS) missions [12]. Their products are drones that are armed with information about unlawful fishing hotspots. For example, once a drone detects a boat, AI will enable it to verify whether it is a cruising boat, tanker, or fishing vessel. The drone will then establish whether the ship operates inside an MPA and an authorized fishing vessel. Their patent, WO2019112405A1, relates to detachable landing gear for land or water, for drones (unmanned fixed-wing heavier-than-air flying craft), particularly small drones, which require careful handling during takeoff. Edge Technology Based Artificial Intelligence System differs from ATLAN Space in that the product offers an edge device that can be mounted on a drone, buoy, or shipping vessel. Additionally, ATLAN identification is only overhead imagery. Contrarily, Edge Technology Based Artificial Intelligence System allows for both surface imagery and overhead imagery.

Shediac Fresh Seafood Inc, implements seafood traceability by using Radio Frequency Identification (RFID) and computer software to trace Shellfish from Harvest to the consumer [13]. They use this information to trace seafood from the fishing boat and fishing area to the destination or end customer. Their patent, CA2675841A1, relates to using RFID and GPS technology. Edge Technology Based Artificial Intelligence System proposes seafood traceability by using AI for identifying legal fishing vehicles.

Another way to track fishing vehicles is by using a satellite-based tool that detects the high-radiance lure lights used by commercial fishing vessels. VIIRS (visible infrared imaging radiometer suite) is one such technology [14]. However, most small-scale fishers use under-equipped boats with lights that aren't powerful enough to be detected by VIIRS. Conversely, our edge AI devices can be mounted on buoys, drones and other vessels traversing through the marine protected areas. A network of such devices enables continuous monitoring of the vast regions of MPAs.

IV. MATERIALS AND METHODS

All of the Edge Technology Based Artificial Intelligence System's hardware is enclosed in a small form factor buoy which is moored. All of the hardware is controlled through a lightweight Arduino computer. During a Edge Technology Based Artificial Intelligence System's buoy deployment, the Arduino is started. Every minute, the Arduino takes a picture using the onboard camera and stores it with date-time data. Every sixty minutes, the Arduino then powers on the NVIDIA Jetson Nano [15]. The Nano then inferences using a pre-trained in-house classification model on the image. If the model decides the image is likely an illegal fishing vessel, the image is stored on the SD card of the Jetson. The Jetson then uses onboard ISBD communications to alert the Edge Technology Based Artificial Intelligence System's server that an illegal fishing vessel has been spotted, along with coordinates and date-time information. On the other hand, if the model predicts the image is not an illegal fishing vessel, it simply discards the image to save storage space.

Each week, a drone arrives at the location of each Edge Technology Based Artificial Intelligence System's buoy. Using LIFI, the images, along with date-time and coordinate information for them, are transmitted from the Jetson's SD card to the storage onboard the drone. This data is then taken back to the Edge Technology Based Artificial Intelligence System on land to the customers.

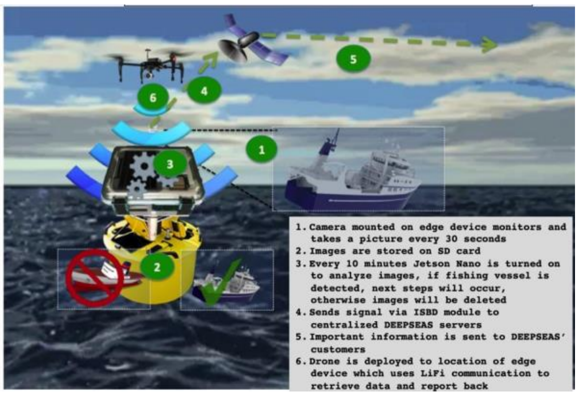

Figure 1.1: System Architecture and Process

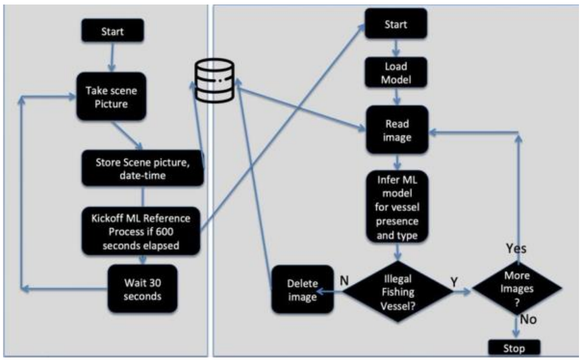

Figure 1.2: IUU Fishing Vehicle Identification Process

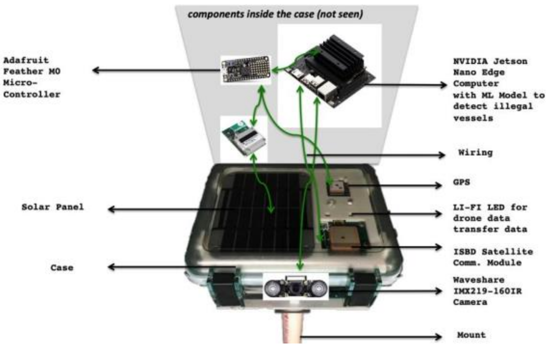

Figure 1.3: Edge Device Schematic Architecture

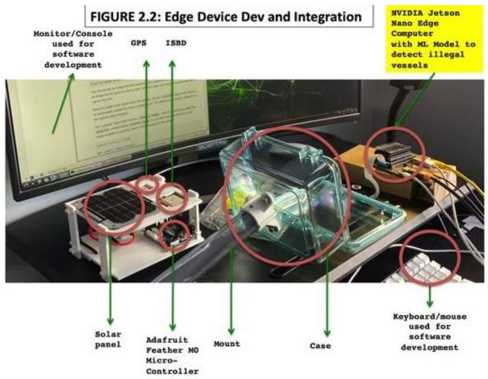

Figure 2: Edge Device Development and Integration

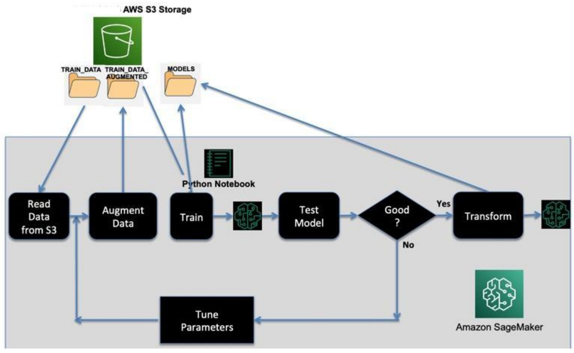

Figure 3: IUU Fishing Vessel Identification Machine Learning Process In Cloud

- Adafruit Feather M0

Due to power limitations, the experimenter plans to use the Adafruit Feather M0 Basic Proto as our microcontroller for this project [16]. The small PCB is lightweight, weighing in at only 4.6 grams. The microcontroller is not powerful; however, it is simply necessary to control the rest of the onboard systems, such as the Jetson and the Camera. The Arduino Feather uses very little power, allowing it to run constantly on a solar panel inside the buoy. On the other hand, the Jetson is extremely power-hungry, meaning that it can only run for around 5 minutes every hour. Therefore, the Feather microcontroller is used to boot the Jetson, allow it to do processing, and shut it down. It also takes a picture using the onboard camera and stores it every 60 seconds.

- NVIDIA Jetson Board

AI on the edge powers Edge Technology Based Artificial Intelligence System. Cloud computing is used for most deep learning applications in the current status quo. Due to the vast amount of data and processing power required to train effective deep learning models for the likes of computer vision and language processing is usually done on the cloud. However, the inference process, running new data points on the model to achieve a result, can effectively be done both on the edge or in the cloud. Running inferencing on the edge, smaller distributed devices has trade- offs compared to inferencing in the cloud. Inferencing in the clouds means more latency as data must be transferred between data collection devices and the cloud. However, runtimes can be faster due to more powerful hardware. Inferencing on the edge reduces latency and means more security and privacy in many cases, as critical data does not have to be placed in the cloud. In the case of Edge Technology Based Artificial Intelligence System, the model is trained in the cloud; Also, Edge Technology Based Artificial Intelligence System utilizes the Jetson Nano 2GB Edge AI device to run the model at sea. Because storage and the ability to connect to the cloud is limited at sea, and so is storage, this edge model is an integral component of the product. Images taken by the camera can be run through the model, and only the ones flagged as possibly containing illegal fishing vessels are stored.

The NVIDIA Jetson Nano is a small form factor computer specifically built by NVIDIA for machine learning at the edge [17]. It harnesses an NVIDIA Maxwell GPU with 128 CUDA cores to create a powerful platform for machine learning processing. Edge Technology Based Artificial Intelligence System utilizes the Jetson Nano model with two gigabytes of RAM instead of the more expensive four-gigabyte version. NVIDIA's model is priced at 60 dollars, allowing our product to be a reasonably cheap solution to IUU fishing.

The NVIDIA Jetson Nano runs a Linux operating system. On top of the operating system, a Docker container runs. A Docker Container is a lightweight platform that packages all of the software required to run an application together. All of the Edge Technology Based Artificial Intelligence System's machine learning inference will run inside a docker container.

- Maker Buoy

The MakerBouy is a buoy that will hold all the components, for example, NVIDIA Jetson Nano Board, LiFI sensor, IBSD sensor [18]. All the components will be placed in a case to protect all the technology from water and any sea creatures that are curious about our product. The buoy is also fitted with a solar panel to keep the components charged and ready.

- Power Source

Due to the constraints of a buoy floating in the open ocean for long periods of time, the experimenter chose solar cells as our source of energy. Light is abundant on the high seas, and allows a Edge Technology Based Artificial Intelligence System buoy to sustain itself for much longer than if a conventional battery was used which would have to repeatedly be replaced. Solar cells, also known as photovoltaic cells, convert energy from the sun into electricity, usually using doped layers of silicon which create a circuit as photons knock electrons out of their orbitals. Due to the fact that a solar cell is only able to pick about 15% of the sun's energy, a single solar cell which is about the size of a CD can generate about 4 watts. The experimenter plans to use a small solar panel about the size of the top of the buoy, which should be able to generate 12 watts of power.

- Iridium Short Burst Data (ISBD)

Once the NVIDIA Jetson Nano detects an illegal fishing vessel, the ISBD will take place to send an alert signal. ISBD sensor also known as Iridium SBD terminal is an efficient network transport capable of sending short burst data messages between two materials [19]. Iridium's global low latency SBD service is great for monitoring objects such as vessels. The ISBD sensor can only send hundreds of bytes, this means that the sensor can only send signals/alerts. Edge Technology Based Artificial Intelligence System will have an ISBD sensor that will send a signal to a satellite. Once retrieved, the satellite will send the signal to an Ipad owned by the Coastal Guard. The Coastal Guard will see this and send an autonomous drone to retrieve the images, using a LiFi sensor, of the illegal fishing vessel.

- LiFi Data Retrieval

The experimenter plans to use LiFi in order to transmit data between the buoys and the drones used to collect data [20]. LiFi was first introduced by Harald Haas in a 2011 Ted Global talk. While WiFi uses radio waves to transmit data, LiFi utilizes the visible light spectrum. A LiFi network has a transmitter and a receiver. A transmitter is simply an LED light. LEDs are useful in that they can turn on and off extremely quickly, as well as change intensity extremely finely. The receiver is simply a solar cell that can pick up light signals. The LED light transmitter makes billions of changes in the intensity of light per second, so quickly it is imperceptible to the human eye. These changes are then picked up by the receiver and converted into a digital signal. LiFi has numerous benefits over conventional WiFi. LiFi allows for much higher rates of data transmission-scientists have reached rates such as 10 gigabits per second using LiFi, much higher than standard WiFi rates. LiFi is quite secure as a visible line of sight is required to piggyback on the network. LiFi is also estimated to be 100 times more energy efficient when compared to WiFi; this point is quite pertinent to Edge Technology Based Artificial Intelligence System as power is limited on board a small buoy in the ocean. Each Edge Technology Based Artificial Intelligence System drone will be fitted with LiFi communications, as well as each buoy. When a Edge Technology Based Artificial Intelligence System's buoy sends an ISBD signal stating an illegal vessel has been spotted, a drone will fly out to its location, and once a connection is established, receive all of the images of the illegal vessel stored on the buoy.

- Application Architecture

Edge Technology Based Artificial Intelligence System utilizes computer vision and a classification model to predict whether a given ship shown in an image is an illegal fishing vessel or not. The model was trained on a cloud machine through AWS Dreamweaver due to the large amount of computational resources required for the process [21]. The experimenter utilized the classic AI development lifecycle for Edge Technology Based Artificial Intelligence System. Data was collected and then engineered to fit the needs for model training. The experimenter proceeded to the algorithm selection stage and chose transfer learning as the most accurate training process for the project. The experimenter utilized then continually tested and tuned the model as a continuous feedback loop for improvement.

After the model is developed, it is then converted into the format usable on a Jetson Nano, and transferred into the Jetson. The Jetson is then asked by the Arduino microcontroller to run inferencing on new data using the model once the buoy is deployed.

- Marvel Dataset

The MARVEL dataset was created specifically to benefit computer vision-based classification approaches by giving access to a large-scale image dataset of maritime vessels. MARVEL is a dataset of two million maritime vessel images and information on each vessel, such as its identity and the year it was built. These images were sorted into 26 different superclasses, including yachts, trawlers, crude oil tankers, and more.

Data Preprocessing

The data was scraped from shipspotting.com using a python script downloadable from the MARVEL GitHub. The images were downloaded and placed into a dataset folder using beautiful soup, a python package for parsing HTML. Each image was named in a random number format along with the filename extension .jpg. The images, when downloaded, were not placed into subfolders based on classification, nor did the image names give any information on the type of maritime vessel found in the image. Instead, a second file, provided on the MARVEL GitHub, named VesselClassificationUpdated.dat, provided this information. Each row was information about a different image in the dataset. The file consisted of comma-separated values in 4 different columns. The first column provided the name of an image in the dataset without the .jpg file extension, and the fourth and final column provided the classification of that vessel. For example, the first column of the first entry was 993293. The final column in that row contained the string 'Container Ship.' Hence, the file 993293.jpg from the downloaded dataset was an example of a container ship. A python script was written in order to take this information and load it into a set of parallel arrays. The first array, named X, would store the images as a pixel array. The second array stored the classification type for the respective image. Each line of the Vessel Classification Updated. dat was read and parsed. The image name was then taken and, if the file were found in the dataset folder, the OpenCV library would be used to read the image into X. Then, the class of the vessel in that image would be placed in Y as found in the VesselClassificationUpdated.dat.

- Transfer Learning Using VGG16

Edge Technology Based Artificial Intelligence System utilizes a transfer learning approach for machine learning model development [22]. Transfer learning is a style of model development where an existing machine learning model trained to do a specific purpose is repurposed to be used on a different but fairly similar problem Transfer learning is commonly used in computer vision problems because most efficient and accurate computer vision models require massive datasets and extended amounts of computation time, even on cutting edge hardware, to train. The experimenter selected a computer vision model already available on the internet, reused that model for our purposes, and tuned the model to increase the accuracy and precision of the classification.

VGG16 is a convolutional neural network-based model developed by Oxford University. It was trained for the ImageNet database, a database of over 14 million images in more than 1000 different classes. VGG16 was one of the most famous models developed for the ImageNet recognition challenge and Google Inception and Microsoft ResNet. VGG16 recorded a 92.7% test accuracy. Transfer learning is significantly faster when compared to creating a model from scratch, meaning cheaper development as less time is required to pay developers and fewer computer resources are needed. In addition, these models are usually more accurate than a model developed from scratch due to the robustness and quality of models such as VGG16.

To use transfer learning, Edge Technology Based Artificial Intelligence System utilizes the VGG16 model with the same weights used when it was trained on the ImageNet dataset. A flatten layer is added for dimensionality reduction in order to save space. Two dense layers with ReLu activations are placed after, leaving the model with one final output at the end. This top layer becomes the output layer that classifies between the 20 output classes. The model is compiled and then fit over ten epochs.

- Testing

The model is tested using two metrics. The experimenter measured the accuracy of the model the number of times the predicted class is the same as the ground truth class. The experimenter also measured the loss of the model using categorical cross-entropy, a common loss function used in ML problems where each data point only belongs to a single class. Using these metrics, the experimenter plans to continue to tune the model in the iterative ML development process, in order to increase accuracy and decrease loss. The experimenter plans to do this by changing the training layers added to the model, as well as using a different transfer learning model, such as ResNet. Once the experimenter found the model with the highest accuracy, the experimenter will deploy that model to our Jetson Nanos.

- Model Deployment

Once the model is developed, the finished model is saved as a file and loaded onto the Jetson, as well as the necessary libraries for running the model such as TensorFlow [23]. From there, the Jetson Nano inferences at the command of the Arduino microcontroller every hour.

V. CONCLUSION

The experimenter aims to provide a local, real-time, and accurate detection system to identify illegal fishing vessels. Edge Technology Based Artificial Intelligence System is a low-powered, low-cost edge computing device, which can be mounted anywhere. The device can be mounted on any type of vessel, including legal fishing vessels, recreational boats, cruise ships, cargo ships, and more. The device can monitor from boats and stationary buoys, and autonomous drones. Ultimately, the experimenter is creating a constantly expanding network of surveillance devices, covering partitioned sections of the oceans utilizing vessels, buoys, and drones depending on the use cases [24].

The edge device combined with a video camera and an NVIDIA Jetson Nano processor will use machine learning object detection models to capture and analyze images locally. The model can detect fishing vessels directly from these captured images.

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