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Object Detection using Machine Learning and Deep Learning

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Abstract: With the increasing automation in today's world, the need for finding and labelling objects in images and videos has grown exponentially. Be it managing traffic, self-driving cars or medical imaging, object detection is being used everywhere around us. Traditional methods for object detection, like SIFT or HOG features, are efficient but no longer compatible for today's needs as the processing of images needed are in real time that can not be done by these methods. These methods also make the procedure of training and preparing our model really complex and can only work with well-lit, front-faced, full-picture images of objects which is not always possible to achieve. So, the deep learning methods for object detection, like R-CNN, YOLO or RetinaNet, were introduced.These methods are being used worldwide to detect objects and make object detection automated and simpler. In this paper, we provide a review on both machine learning and deep learning approaches for object detection. Our review begins with an introduction to object detection, then we focus on all the methods used for object detection - machine learning approach and deep learning approach. Then we move on to all the advantages, challenges and applications of object detection. To conclude it, we mentioned the future scopes everyone can look forward to.

Keywords: *Object Detection, Convolutional Neural Network, Deep Learning, Machine Learning*

1. Introduction

Objects are substances that can be seen or touched. These objects can change over time based on velocity, structure, shape, trajectory, function, appearances, etc. These objects can be captured in images using cameras and scanners and these images can be converted to digital images using dedicated hardware and software. Humans are capable of watching a still or moving object or watching an image and labelling it as we have the tendency to learn from our environment naturally but this is not the case with machines. Machines cannot learn from the environment or label objects naturally like humans, so we need a technique called object detection. Object detection refers to a technique in computer vision which deals with the detection of instances of objects in images or videos. Due to the advancement of the needs of humans to detect objects in images, the object detection process cannot be done manually and we need to leverage machine learning and deep learning to automate the process.

The main aim of object detection is to detect objects and obtain meaningful observations from still images or moving videos. Its task is to study an image, recognize all the objects and label them. Now image detection and object detection are often coined as the same terms but there are major differences in both of them. Image detection means we can detect if we have a particular object in an image or not. For example, we can figure out if we have a cat or a dog in an image. On the other hand in object detection, the software tells us if there is an object or multiple objects and also labels those objects as where they are present in the image. For instance, it tells us if there is a cat or a dog or both in the image and labels them for us.

The objects in an image may vary, there can be one object in an image which will be easier to detect or there can be multiple objects and we will need to identify and separate each one of them, the lights in the images can be of low brightness so we won't be able to identify if there is an object or not, or the lights can be of high brightness where the objects reflect light and thus cannot be labelled properly, the quality of the image can be in high definition(HD), standard definition(SD) or with a 4K resolution and on the other hand it can also be a blur image, all these factors need to be assessed to make a model to detect objects.

Object detection is being used in various fields today which include video supervision at various restricted areas like train platforms, government organisations; health organisations can use them to detect tumours or cancer in an instance without having to wait for several days to get the

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results; video analytics can be done at several supermarkets to identify threats from intruders or to identify the most visited location; object counting can be done to manage and access crowded areas by counting number of people present. It can be used in various other fields including robotics, artificial intelligence, defence organisations to ease the process.

2. Approaches

Object detection can be done by both machine learning and deep learning. If you have a good performing GPU and well-labelled training data, then you should use a deep learning approach, otherwise use machine learning. Both these approaches work well but the main difference is in their execution.

Machine learning approach:

Machine learning can perform object detection in a supervised manner. A labelled dataset is provided to our model during training and based on that, it performs object detection. The technique also requires that the features should be defined by the programmer as it is unable to perform feature engineering on its own. We can use it for object detection but it has other applications like image segmentation and image classification where it performs better. Machine learning methods are also called traditional object detection methods.

Deep learning approach:

A deep learning model has two main parts namely encoder and decoder. An encoder takes the image as an input, runs it through hidden layers of deep learning model to extract statistical features which can in turn be used to detect and tag images. On the other hand, the decoder takes this input from the encoder and applies bounding squares and tags them. The steps involved in object detection are taking the input of our view as an image or a video, dividing the image in sections, working on each section individually, passing them through CNN to get possible labels and tags and finally combining all the individual images as one to get the final output with tags and labels.

3. Methods

Machine learning methods:

The most common approaches used for performing object detection through machine learning are:

1. Scale-Invariant Feature Transformation (SIFT)
2. Histogram of Oriented Gradients (HOG) Features
3. Viola-Jones Object Detection Framework

Deep learning methods:

The most common approaches used for performing object detection through deep learning are:

1. Region-based Convolutional Neural Network (R-CNN)
2. Fast Region-based Convolutional Neural Network (Fast R-CNN)
3. Faster Region-based Convolutional Neural Network (Faster R-CNN)
4. You Only Look Once (YOLO)
5. Deformable Convolutional Network (DCN)
6. Refinement Neural Network for Object Detection (RefineDet)
7. Retina-Net

Now we will study about all these methods in detail.

1. Scale-Invariant Feature Transformation (SIFT):

Scale Invariant is a method used to describe and detect local features in images using machine learning. It involves three steps: difference of gaussian space generation (DoG), keypoints detection and feature description.

- In the first step difference of gaussian space generation, we smooth out our original image and then downsample the processed image, i.e reduce the spatial resolution while keeping the same representation.
- Then in keypoints detection, we check the neighbouring eight resolutions and nine resolutions each of top and bottom layer. If our point is largest or smallest among all 27 of these points, then it will be considered a key point.
- In the last step-feature description, we need a 128-dimensional SIFT feature as an output. For this, we take our pixels around the centre point, allocate them into blocks, divide our 360 degrees in angles, calculate gradient magnitude and express them all in one vector, i.e. 128-dimensional SIFT-feature vector.

The main advantages of using SIFT are locality of the features, detailed distinction of our features, performance in real-time, ability to extend to different types of features and its robustness.

2. Histogram of Oriented Gradients (HOG) Features:

Histogram of oriented gradient features is also a feature descriptor like SIFT. It uses the method of counting the presence of gradient orientation in the localised portion of the image. It is a commonly used practice because it uses magnitude and gradient angle to justify object features and provides the user with good results. Then it will produce a histogram as a result for the section of image it assessed using the former features.

- The main steps involved in HOG features are:
- We take the image as an input and resize it to 128*64 pixels.
- Then we use magnitude and angle to calculate the gradient of the produced images pixels.

- After obtaining gradient of each pixel, gradient matrices are divided into 8*8 pixels and a 9 point histogram is calculated.
- Then a 3D matrix of dimensions 16*8*9 will be calculated using arrays of bins.
- Then 4 different blocks of 9 point histogram will be clubbed to form a block of 2*2 dimensions.
- After that we normalise these values to minimise the effect of changes in contrast between one object's different images.
- So, the resulting length of HOG features is going to be 7*15*36=3780.

3. Viola-Jones Object Detection Framework:

Viola-Jones Object Detection framework can detect various object classes but the main goal of this framework is to detect human faces from images and videos. This does not work on only one frame but on moving frames, due to this the speed and robustness of the object detection increases. It combines the best features of algorithms like Haar-like features, the AdaBoost Algorithm, Integral Images, and the Cascade Classifier so that the result being achieved can be optimal. It can detect 384*288 pixels of an image at the rate of 15 frames per second. The biggest challenge faced here is that it can only work with images with no occlusions(full view), frontal-upright images, well-lit, full size faces with a needed resolution only. The steps involved in viola-jones object detection framework are:

- The first step involves selecting Haar-like features where the features are enclosed with rectangular boxes. Its best ability here is that it can differentiate if the pixel is an object or only the background.
- In the second step, we work with regions of our images, which can be of any size. The regions we work upon are only the regions detected as objects in the first step, which is the integral regions.
- In this step, we train our classifier through Adaboost training to detect objects of interest from our images. It works only on features detected as objects from the Haar-like features.
- In this step, we work with cascading classifiers in which we go through several stages of decision making. Each step makes a decision if the given image is the object or not.
- In the last step, we work on suppressing all the unwanted parts of the image. The required object is only one and hence all the other objects that are not required are suppressed through these series of decisions.

It has proven to be of high-speed and precision. Its precision and accuracy are lower than deep neural networks like CNN but its small size and requirement of smaller datasets for training make it useful today.

4. Region-based Convolutional Neural Network (R-CNN):

Region-based convolutional neural network is a deep learning based network used for object detection. The main aim of R-CNNs is to identify objects in an image, locate them and label them. The estimated time required for detecting an image is 40-50 seconds. The basic steps involved in R-CNNs are:

a. Selective Search
b. Warping
c. Extracting features with a CNN
d. Classification

The steps involved in region-based convolutional network are:

- The first step here is to define a few region proposals using the algorithm of selective search. Here we define regions based on features like the colour, texture, etc.
- In the second step, the features are extracted from these proposals using convolution neural networks, trained on large datasets.
- Next the features extracted are used to classify objects in the image. A support vector machine is trained to classify if the current pixels are objects or not.
- After this, another regression model is trained to refine all the bounding box coordinates. Due to this, the localisation accuracy is increased.
- In the final step, we will eliminate all the redundant detections of objects to achieve the output with the labels having highest confidence scores.

5. Fast Region-based Convolutional Neural Network (Fast R-CNN):

Fast region-based Convolutional Neural Network is an improved version of R-CNN. Instead of doing maximum pooling like R-CNN, we perform a region of interest(RoI) pooling due to which less computations are needed and hence faster. The estimated time required for fast R-CNN is 2 seconds which is 20-25 times faster than R-CNN. The steps involved in fast region-based convolutional network are:

- In the first step, we preprocess the image and resize it to a fixed pixel size and in a standard format that can be fed to the neural network. Next we subtract the mean pixel from all the pixels.
- The preprocessed image is then fed to the convolution network, trained on large datasets, to extract the feature map.
- In the next step we use region proposals which generate object proposals. It takes the feature map from the previous layer as an input and then presents an object proposal as an output.
- It uses two different heads for regression and classification. The classification head is supposed to predict the probability of an anchor box containing an

image and the regression head tells us the offset of the bounding box from the anchor box.
- In the final step, we will eliminate all the redundant detections of objects to achieve the output with the labels having highest confidence scores.

6. Faster Region-based Convolutional Neural Network (Faster R-CNN):

Faster region-based Convolutional Neural Network is an improved version of R-CNN and fast R-CNN. In this we create a region proposal method which creates regions so that further RoI pooling can be applied for faster execution of fast R-CNN. It also contains more CNNs as compared to fast R-CNN. The estimated time required for fast R-CNN is 0.2 seconds which is 10 times faster than fast R-CNN. The steps involved in faster region-based convolutional network are:

- In the first step, we preprocess the image and resize it to a fixed pixel size and in a standard format that can be fed to the neural network. Next we subtract the mean pixel from all the pixels.
- The preprocessed image is then fed to the convolution network, trained on large datasets, to extract the feature map.
- In the next step we use region proposals which generate object proposals. It takes the feature map from the previous layer as an input and then presents an object proposal as an output.
- In the next step, we pass our object proposal through a region of interest(ROI) pooling layer to obtain a fixed length feature vector. The object proposal can be of any length and size.
- It uses two different heads for regression and classification. The classification head is supposed to predict the probability of an anchor box containing an image and the regression head tells us the offset of the bounding box from the anchor box.
- In the final step, we will eliminate all the redundant detections of objects to achieve the output with the labels having highest confidence scores.

7. You Only Look Once (YOLO):

You only look once is an object detection algorithm that uses deep learning CNN to recognise objects in images. It works on real-time data. It works as a regression problem and provides class probabilities for objects present in the image. In the output, we obtain the bounding boxes of where the objects are present and the class probability for different images. It works in a single feed-forward propagation which means that all the detection and labelling is done in one iteration only. The pixels are divided into sub-pixels and then these sub-pixels are worked upon to receive the result by combining all the sub-pixels. The steps involved in you only look once algorithm are:

- In the first step, we take the image as an input and pre-process it in the size of required pixel size and in the format that can be fed to a deep neural network.
- In the next step, we train and prepare our CNN model on large labelled datasets so that it can detect objects, create bounding boxes and provide class probability with high accuracy.
- In this step, we work on our images to create bounding boxes and provide probability of each class. These bounding boxes have four coordinates, two being the centre and the other two are its height and width.
- Next, we work on suppressing the background noises by removing the redundant bounding boxes, where the boxes with highest probabilities are kept and the others are eliminated.
- In the last step we receive our output image with bounding boxes and labels that had the highest class probability. The objects detected can be one or many.

Its main advantages are its learning capabilities as it has an excellent learning capability and adaptation to changes, its speed as it works on real-time data and its high accuracy to detect objects in the images.

8. Deformable Convolutional Network (DCN):

Deformable convolutional network is a technique of CNN used for object detection as well as segmentation in deep learning. It allows merging of two sets of information to increase speed and accuracy of our model. The main task involved here is to deform the convolutional network to adjust to the shape of our object. They are trained by the method of backpropagation, which means that the model learns and improves from the past errors. The steps involved in deformable convolutional network are:

- In the first step, we preprocess our image to a particular size and defined resolution and then subtract the mean pixel value for each pixel.
- This preprocessed image is then fed to our CNN network. This CNN network is trained using large datasets.
- In DCN, the regular convolution layer is replaced by deformed one.This layer has some learnable offsets. The sampling grid is deformed based on the shape of the object and then as a result we obtain feature maps that can further be used.
- In the next step, these feature maps are fed to the Region Proposal Network; these RPN provide us with proposals if the given pixels contain the object or not. These are accompanied by their objectness scores with anchors to where the image might be present.
- In the next step, we pass our object proposal through a region of interest(ROI) pooling layer to obtain a fixed length feature vector. The object proposal can be of any length and size.

- The fixed length feature vector is then passed through a convolution network of two fully connected layers. The first layer is responsible for object classification and the second layer is responsible for bounding box regression.
- Then we eliminate all the redundant detections of objects to achieve the output with highest confidence score labels.

The main advantages associated are spatial deformation, small objects can also be detected, occlusion is not a major setback here and has a better localisation of bounding boxes as per the object's location.

9. Refinement Neural Network for Object Detection (RefineDet):

Refinement neural network model is a very popular forward propagating neural network and is often used as an alternative to YOLO and CNN. First this model defines all the different boxes in the image which signify that objects are present in the image. The two major components of RefineDet are:

Anchor refinement module (ARM)

Object Detection Module (ODM)

The steps involved in refinement neural network are:

- In the first step, we preprocess the image and resize it to a fixed pixel size and in a standard format that can be fed to the neural network. Next we subtract the mean pixel from all the pixels.
- The preprocessed image is then fed to the convolution network, trained on large datasets, to extract the feature map.
- In retina-net, there are several anchor boxes which have predefined scales and ratios. These anchor boxes are used as the starting point of the object proposals.
- Next we form default boxes. These default boxes are made to better fit the shape of our object. These are the next points for our object proposals.
- Next the refine-det will combine feature maps of different CNNs together, due to which objects of different aspects and sizes can also be detected.
- In the next step, all the objectness scores are brought together to refinement network, along with additional information from CNN. This data is used to define offsets of bounding boxes and objectness score.
- In the final step, we will eliminate all the redundant detections of objects to achieve the output with the labels having highest confidence scores.

10. Retina-Net:

RetinaNet is a one stage object detection model which means that it performs object detection in one stage only and can work well with dense and small objects. There were already few single stage object detectors but this was made with two major improvements:

Feature Pyramid

Focal loss

It can very well detect rotating or moving objects and is hence used in aerial and satellite imagery. The steps involved in retina-net are:

- In the first step, we preprocess the image and resize it to a fixed pixel size and in a standard format that can be fed to the neural network. Next we subtract the mean pixel from all the pixels.
- It uses a feature pyramid network to extract all the features of our image. It uses a predefined set of features from pre-trained CNN to create the feature pyramid.
- In retina-net, there are several anchor boxes which have predefined scales and ratios. These anchor boxes are used as the starting point of the object proposals.
- It uses two different heads for regression and classification. The classification head is supposed to predict the probability of an anchor box containing an image and the regression head tells us the offset of the bounding box from the anchor box.
- It uses a function called focal loss to improve our object detection process. Here, higher weights are assigned true positives and lower weights are assigned true negatives.
- In the final step, we will eliminate all the redundant detections of objects to achieve the output with the labels having highest confidence scores.

4. Advantages:

Object detection has several advantages in every field and sector around us today, some of them include:

1. Unlike other methods to classify objects in an image, it gives out accurate predictions as well as labelled data and can hence be used in various fields requiring accurate data like medical diagnosis.
2. They can process any amount of large data within a short time period and can hence be used for large datasets.
3. They also help in automating the tasks in the real world like analysis of goods in manufacturing, instead of checking all the goods manually, we can use automated models of object detection to do so.
4. They also provide us with the flexibility to scan and detect various objects like humans, animals, manufactured goods, vehicles and hence can be used in various sectors today.
5. It has helped us today to improve safety around us in various fields like traffic analysis can be done to be safer on roads, alerts can be applied on detecting inappropriate actions or objects.
6. Object detection, in the commercial world, can help you in bringing competitive advantage over other

competitors in sectors like retails, manufacturing, transportation.

7. It can help to solve complex business tasks at hand without spending a lot of time in identifying and labelling images as that is an automated process.
8. It can help physically challenged people with their day-to-day lives, improving user's daily experience like helping visually impaired people to walk.

5. Challenges:

Despite having several advantages of object detection, we cannot ignore the challenges faced during object detection:

1. One of the biggest challenges faced are different sizes of objects, and how much part of the object is captured in the image. Large sized objects can be difficult to capture but easy to label whereas small sized objects are easy to capture but difficult to label.
2. An object in the image may be covered by another object, this property is known as occlusion and is a major challenge as we may miss out an important object due to this.
3. Objects can be deformed which makes it difficult to label them because due to deformation, their shapes change, making it difficult to tag them appropriately.
4. Objects may have been captured from different angles, due to this same object can look like different objects depending on the angles and hence be labelled inappropriately.
5. The lighting can also affect the object detection model. If the lights are too dim, then the objects may not be detected and hence can cause undetected objects in the model. On the other hand if the lighting is too bright, the objects may reflect them and it can be difficult for the model to label them.
6. The training of object detection also requires a huge amount of data which may not always be available, hence it is a major setback to object detection.
7. It is also a very complex field, the complexity can be in the matter of computation due to which we have to buy specialised hardware, it can be in the matter of learning due to which there is a lack of experts, it can be in the matter of produced results which cannot be understood by someone who does not know about the model completely.
8. It may also give false positive results which can cause panic in the real world especially in the field of medical diagnosis.

6. Applications:

Object detection is an emerging technology and has various applications in several sectors. Some of its applications include:

1. The first application is optical character recognition(OCR), in which our machine figures out the characters written from an image, which is very profitable especially in the field of traffic analysis. We do not have to manually figure out the number plate of the cars, instead that work can be done by object detection.
2. Another major application being used today is self driving cars. Self driving cars are driven automatically without any human involvement. Object detection helps here by scanning and assessing the environment on a continuous basis so that the car can decide the way to go on the roads.
3. Object detection is being used today to track objects including human beings and animals, it can be used in restricted areas to track the illegitimate users entering, it can be used in traffic analysis.
4. Face detection is also an example of object detection. The system separates all our facial features, matches them in its database and provides the match. It is being used today by Facebook to automatically identify faces so that you can stay connected easily.
5. Biometric scanning is another widely used application of object detection being used today. Biometrics being used today are eyes, thumbprint, face, etc. it can be used to mark attendance, to provide access to legitimate users in a device or an organisation.
6. Medical imaging is a very prosperous use of object detection. Nowadays, we can scan a patient's body and detect cancer, tumours or any other underlying diseases without having to wait for several days to get the results from different labs.
7. It has also been seen that object detection is being used in sports today. In cricket when the decision goes to the third umpire, they detect the movement of the ball towards the stump using object detection and give the correct outcome.
8. It is also being used in the manufacturing industry to track faulty products and separate them from good ones, to identify which machinery needs attention or to track movements of workers working in large workplaces.

7. Conclusion:

Object detection is an evolving and innovative technology that has several advantages and is being widely used in various sectors including robotics, computer vision and automation. It can produce data accurately and without mistakes but it has to deal with several challenges like occlusion and illumination too. By using methods like R-CNN, Fast R-CNN or faster R-CNN, we can automate the task of object detection. With the emerging techniques of deep learning and machine learning, object detection can come out as a very essential and helpful tool to ease our day-to-day lives. With the growth in the IT sector, object detection will become an even more effective technique in the upcoming years.

8. Future Scope:

Object detection has a bright future in the evolving world and a huge scope of improving. The major ones are:

1. Autonomous vehicles are the biggest future scope of object detection. During driving these vehicles need to detect the environment, pedestrians and traffic signals with new data every moment. These technologies have started emerging recently and can be worked up on to great lengths.
2. Augmented and virtual reality are other future scopes of object detection. They can be improved by tracking the environment in real time and having the users play games in the real environment instead of a prerecorded or predetermined one.
3. Another vast scope of object detection is in the world of artificial intelligence including robotics. The robots can identify human expressions so that they can have a sentimental analysis and hence be able to answer the humans with the current mood.

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