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A Mechanized Harvesting and Automated Grading Technology for Oil Palm Fruit

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Abstract— The purpose of this research is to design and fabricate an automated grading cum harvesting device for Oil Palm Fruits. The presence of the VIRESCENS or NIGRESCENS gene in oil palm fruits renders it possible to determine the ripeness of the fruit by mere inspection. However, this method of inspection by workers is time-consuming and error-prone. Harvesting of oil palm fruits has been aided by numerous technologies such as the pole and knife method, aluminium pole and knife (APK) method and the like. These manual methods, besides consuming the time and energy of the harvester, pose a serious threat to the safety of the harvester, as he/she runs the risk of being hit by a falling oil palm branch.

Keywords- oil palm, agriculture, UAV, drone, harvester, grading, image classification, VGGnet, ripeness, classification model

I. INTRODUCTION

The oil palm tree (Elaeis guineensis jacq)[1] has its origins in West Africa where it initially grew in the wild[10]. In the early 1870s, the British introduced the tree to Malaya, present day Malaysia as an ornamental plant. A few years later, oil palm plantation received a commercial twist in a bid to reduce the country's economic dependence on rubber and tin and also in order to eradicate the poverty that plagued the landless farmers. This laid the foundation for the vast oil palm plantation and consequently the oil palm industry in Malaysia today.

Today, Malaysia boasts of approximately 4.49 million hectares of land under oil palm cultivation, producing 17.73 million tonnes of palm oil and 2.13 tonnes of palm kernel oil. Malaysia is ranked as one of the largest producers and exporters of palm oil in the world, accounting for 11% of the world's oils & fats production and 27% of export trade of oils & fats. The industry provides employment and livelihood to around a little over a million people[10].

A. Characteristics of Oil Palm Trees

Oil palm trees grow up to sixty feet and more in height. The trunks of young and mature trees are wrapped in leaf-like structures called fronds which give them a rather rough appearance. The older trees have smoother trunks apart from the scars left by the fronds which have withered and fallen off. Oil palm trees start bearing fruits after 30 months of field planting and continue to be productive for the next 20-30 years, thus ensuring a consistent supply of oils[10]. Each tree produces compact bunches weighing between 10 and 25 kilograms with 1000 to 3000 fruitlets per bunch. Each fruitlet is almost spherical or elongated in shape. Generally, the fruitlet is dark purple, almost black and the colour turns to orange red when ripe.

Each fruitlet consists of a hard kernel (seed) enclosed in a shell (endocarp) which is surrounded by a fleshy mesocarp. Each ripe bunch is commonly known as Fresh Fruit Bunch (FFB)[10]. These FFBs are harvested and then transported to a palm oil mill, where the process of extraction of oil from each individual piece of fruit on the bunch begins. Basically 3 products are obtained:

1) Palm Oil or Crude Palm Oil, extracted from the flesh of the fruit.
2) Palm Kernel Oil extracted after crushing the kernel.
3) Palm Kernel Expeller, obtained as a by-product of the kernel-crushing process.

Palm Oil and Palm Kernel[12] Oil are widely used, both in the food and non-food industry. Its high resistance to oxidation gives it a larger shelf life, making it suitable for cooking purposes in countries with extremely hot climate. Palm Oil is also used in the manufacture of soaps and detergents and in the production of greases, lubricants and candles[13]. More recently, palm oil has also been used in the production of biodiesel and as an alternative to mineral oils for use in power stations. The fatty acid derivatives of palm oil are used in the production of bactericides, cosmetics, pharmaceuticals and water treatment products.

B. Ripeness as a Yardstick of Quality

Quality is one of the most important characteristic that one looks for in a product. This is especially true in the case of agricultural or food products. In most cases the quality of an agricultural product, or in our case a fruit is determined by its texture, shape and colour. The quality of oil palm fruits depends heavily on its ripeness, which is indicated by the colour change of the fruit. This is because the oil content of a fruit bunch is a function of its degree of ripeness. Under ripe fruit has the lowest oil content; ripe fruit has the highest oil content and the oil content deteriorates, when the fruit reaches the overripe stage. Thus, determining the optimum ripeness of the fruit is of prime importance. This necessitates oil palm harvesters to harvest the FFBs when they are at optimum ripeness for maximum oil yields.

C. Existing Methods for Determining Ripeness

In order to facilitate the detection of ripeness, genes like VIRESCENS or NIGRESCENS are implanted in the Oil palm. Thus accordingly we obtain VIRESCENS or NIGRESCENS[14] fruits.

There are essentially 2 methods of checking for ripeness of oil palm fruits. The first method relies on the fact that fruits when mature tend to loosen and fall to the ground. Thus by observing a number of fallen fruits on the ground, one could infer and conclude that the fruit bunch of a nearby tree is ripe. Obviously this method is highly erroneous and is rarely used as an indication of ripeness as there could be several other reasons that could cause the fruit to fall to the ground. The next method and the more reliable one to detect ripeness is by observing the change in colour as the fruits matures[14]. Scientists have identified 2 genes- the NIGRESCENS and VIRESCENS gene that cause oil palm fruits to change colour when ripe. Colour changes vary depending on the gene. NIGRESCENS fruits are usually deep violet or black at the apex and yellow at the base when unripe and change to orange at the base when ripe with no significant colour change at the apex. VIGRESCENS fruits, on the other hand, the more popular variety, undergo a more profound colour change from green when unripe to bright orange when ripe. Therefore palm graders have now begun to replace their NIGRESCENS palms with VIGRESCENS plants, eventually increasing the efficiency of harvesting and oil yield.

In the existing system, the process of ripeness detection is done by workers or grading personnel who determine ripeness by mere observation. The most obvious consequence of this sort of a system is that it is subjective and prone to errors. Fatigue and the emotional state of the human grader could further influence his/her judgement. However this is not the major drawback of this system. This entire method of ripeness detection by observation rests on the assumption that the grader gets a clear view of the fruit to be tested. However, since the FFB lies on the tree, which could be up to 6 metres tall, such an observation would be impossible. This would necessitate that the FFBs be first harvested and then checked for ripeness. This could further result in inordinate amounts of wastage as the harvested unripe fruit would have to be discarded.

D. Existing System for Harvesting

In the recent past, the oil palm plantation industry has turned towards various methods to speed up the harvesting process in a bid to increase worker's productivity and efficiency. A few traditional methods of harvesting are discussed below.

1) <u>Chisel or Sickle</u>
   This traditional method involves the use of a chisel or sickle that is used to cut the FFB, which lies at a height of about 3-4 metres. This method requires manual labour and is tedious[11]. It requires skills as well as energy to ensure an effective cutting operation. Thus this method would need skilled harvesters. Besides, it is a less efficient and a slow process, which reduces productivity.

2) <u>Bamboo Pole and Knife (BPK) Method</u>
   Another method is the bamboo pole and knife (BPK) method, used to harvest fruits from trees up to a height of about 9 m. In this method a Malaysian knife, which is a curved knife with a sharp edge along its convex side, is attached to the end of a bamboo pole. The length of the pole depends on the average height of the trees on the plantation plot.

Figure 1: BPK method

3) <u>Aluminium Pole and Knife (APK) Method</u>
   In this method, a 40 mm diameter aluminium tube replaces the bamboo pole of the BPK method. It works very well and even faster than the BPK method for trees of height below 5.5 m. Above this height, bending of long harvesting poles that carry relatively heavier cutting knives on top constitutes a very serious problem as it becomes very difficult to engage the stalks of palm fronds and bunches. The harvesters' hand-pole slippage while cutting with the pole also constitutes another serious problem as the harvester inevitably sweats on his palms while on the job.

Figure 2: APK method

4) Tree Climbing Cycle
A group of researchers worked on another technology with the aim of facilitating harvesting. They called it the Oil Palm Tree Climbing Cycle. Test results showed that the cycle was not efficient for palm trees and it was not comfortable for the harvester to use, besides consuming a lot of time and energy.

5) Modified Pole and Knife (MPK) Method
An attempt was made to improve the efficiency of the traditional pole and knife method. The resulting method called the Modified Pole and Knife (MPK)[2] method sported a lighter body that would increase the ease of its transportation and a fruit catchment platform to eliminate or drastically reduce the time required for fruit collection.

6) Ckat TM
Researchers and harvesters turned to mechanization to improve the harvesting procedure. Ckat[11] TM is a mechanical chisel, comprising of a cutting head, a pole and a two-stroke petrol engine. It was designed for harvesting oil palm fruit trees having height less than 2m. Unlike the methods discussed above, Ckat TM has been proven very fast and effective and it also increases harvesting productivity, enabling workers to earn more.

Figure 3: Ckat TM

7) Cantas TM
Cantas TM[11] was introduced in 2006, designed for palms lower than 5 m in height, it employs a specially designed sickle, (patented C-sickle) driven by a vibrating mechanism to perform the cutting operation mechanically. The C-sickle has been proven to provide a higher cutting efficiency. Powered by a two- stroke petrol engine, it is equipped with a telescopic pole and a cutting head.

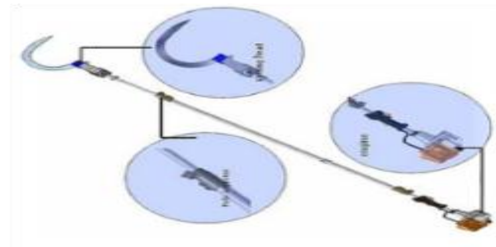

Figure 4: Cantas TM

Though some of the aforementioned methods enjoy a little success, they seem to suffer from the following major drawbacks:-

1) All the methods are by far typically manual in nature- that is the mechanism or apparatus must be hand-held by the operator.
2) Tremendous effort is needed on the part of the operator, as in most of the methods the force needed to cut comes from the operator himself.
3) There lies the risk of the branch of the tree falling on the operator, which could obviously have disastrous consequences.
4) These methods are not designed for ease of operation. As a result the operators suffer from back and waist pain due to prolonged usage.
5) There lies the tendency of handles used in above methods to slip from the hands of the operator as he/she invariably sweats during the process of harvesting.

II. METHODOLOGIES

UAV, an acronym for Unmanned Aerial Vehicle[5] commonly known as drone. It is an aircraft with no pilot on board. They can be controlled by a pilot at a ground control station or fly autonomously based on pre-programmed flight plans or complex dynamic automation systems. The UAV, a ground-based controller and a system of communication between the two, together form an Unmanned Aerial System (UAS). UAV's originated mostly from military applications such as surveying areas too dangerous or soiled for humans. Apart from military applications use of UAV in areas of agriculture, product deliveries, aerial photography etc. is rapidly increasing[4].

Multi-rotor[5] or multi-copter is similar to a helicopter that can take off and land vertically. The term multi-rotor means that the craft uses more than two rotors, providing the advantage of simpler flight control mechanics. The Breguet brothers Louis and Jacque with the aid from Professor Charles Richet designed the world's first Multi-rotor in 1907[4], it was called the Gyroplane No.1 and could carry one pilot. Presently many variants of the multi-rotor UAV are being used in many applications, most popular variant being the Quadcopter having four motors. Other popular variants are Tricopter, Hexacopter and Octacopter having three, six and eight motors respectively. Increase in the number of motors provides more stability, but requires more power to fly the craft.

Components of Multirotor

Pre-built Multi-rotor drones and components to build one are commercially available. This section lists the components required to build a Multi-rotor. Figure 2 shows a block diagram of a Multi-rotor drone.

Total weight of the craft is of utmost importance. An estimate of the weight will help in determining the thrust required to lift the craft. Thrust[7] generated should be at least twice that of the total weight i.e. a thrust to weight ratio of 2:1[16].

Propulsion system of the drone consists of motors, ESC, propellers and a power supply. Necessity of each component is given below.

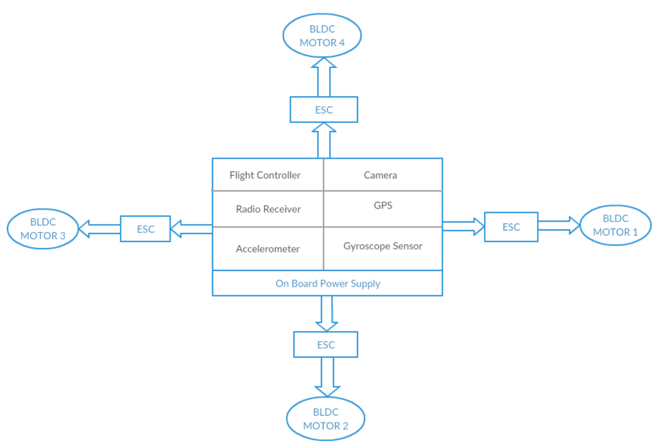

Figure 5: Block diagram of Multirotor UAV

- **Motor**: They spin the propellers hence generating the required thrust for take-off and flight. All motors should deliver the same amount of thrust to achieve stability. Electric motors are made up of permanent magnets and windings which cause the motor to spin. Size of the motor is represented by a 4 digit number. Taller the stator more will be the power at higher RPM and wider the stator more torque at lower RPM. Motors also have a KV rating which indicates the theoretical increase of RPM when voltage increases. KV = thousand RPM per volt[15].
- **ESC (Electronic Speed Controller)**: Responsible for controlling the speed of the motors depending on the throttle signal. ESC's have a current rating in Amps which states the maximum value of current it can handle.
- **Propellers**: Size of a propeller is determined in terms of length and pitch. Length is the diameter of the disk the propeller makes while spinning. Pitch is defined as the travel distance of a single rotation if it were moving through a soft solid.
  Propellers used to build a drone are designed to spin either in clockwise (CW) or counter clockwise (CCW)[6].
- **Power Supply**: Lithium polymer batteries also known as LiPo batteries provide high energy density, high discharge rate and are light weight making them suitable to power a drone. LiPo battery specifications are given by a cell count, capacity (in mAh) and discharge rate (C-rating). The number of cells determine the voltage which is provided by the battery. Eg. A battery with specifications given as 4S 1500mAh 100C, is a 4 cell battery with capacity 1500mAh and discharge rate of 100C[15].

Amperage of the system is given by,
Number of ESC * Max Amp rating of ESC = amount of Amperage required
Amperage of battery
mAh * C = Amperage provided by battery
Amperage provided by the battery should be greater than or equal to the amperage required by the system. It is advisable to select a battery with amperage greater than that required by the system.

Behaviour of all the components is governed by a circuit board known as the Flight Controller, which is the brain of the drone. It performs various calculations on the input received from in-built sensors that detect orientation changes, speed, height etc. and determines how much power is to be applied to each motor for a stable flight. It also receives user commands. Following are some of the sensors included on a flight controller:

- **Accelerometer**: It senses static or dynamic forces of acceleration. Static forces include gravity and dynamic forces include vibrations. It plays a major role in stabilizing the drone in air.
- **Gyroscope**: It measures orientation and angular velocity.
- **Compass**: Determines the drone's direction.
- **Barometer**: It measures the atmospheric pressure and determines how high the drone is.
- **GPS**: Determines the geographic co-ordinates of the drone.

A pilot on the ground can control the drone with the help of a radio transmitter and receiver. The receiver is placed on the drone and the transmitter present on the ground station, from which commands are sent. The basic commands that can be sent are throttle, yaw (rotate left/right), pitch (lean forward/backward) and roll (roll left/right).

III. REQUIREMENTS AND DESIGN

Height of an oil palm tree can range from 4 meters (13 foot) to 20 meters (65 foot). Due to the introduction of genetic modifications it is common to see shorter trees in oil palm plantations. The drone is to be designed by considering the worst case i.e. to harvest a fruit bunch 20 meters high. Therefore the drone should carry the harvesting tool up to a height of 20 meters and remain stable to efficiently harvest the fruit bunch.

Wind speed can greatly affect the stability and can cause the drone to collide with the tree. This problem can be solved to some extent by locking the drone in its geographical position with the GPS. Once the position is fed to the flight controller, the motor speeds will be adjusted to remain stable at the desired spot. Another major issue is jamming of the propellers due to the leaves. Propeller cage will prevent the sucking in of leaves at the cost of increase in weight and slightly reduced thrust. Lastly the drone must remain stable while using the harvesting tool. The requirements are summarised as follows:

- Lifting of heavy payload up to a height of 20 meters.
- Maintaining a fixed position in air to prevent collision due to wind.
- Prevent jamming of propellers due to leaves getting sucked in.
- Maintaining stability during the harvesting process.

To be able to lift heavy loads the installed motors must have a wide stator and a low KV rating. A low KV rating means that the motors will produce higher torque and thrust at low RPM. The KV rating of the motors should be less than 800KV and a wider stator. The ESC are to be chosen depending on the current requirement of the motors. Quad configuration is not recommended as failure of one motor in mid-air will result in a crash. Also a quadcopter is less stable as compared to a hexacopter or octacopter. Even better option in terms of stability would be to use a hybrid configuration, two of which are Tri-hexa and Quad-octa. The frame shape of both the configurations is same as that of tricopter and quadcopter respectively, but instead of one motor on each arm they have two motors one below the other spinning in opposite directions.

Implementation

Tri-hexa configuration on a T-frame was selected due to the fact that a harvesting tool could be mounted on the T intersection. The prototype was designed as follows:

- Frame- T frame, fabricated using 1 inch x 1½ inch hollow square section of aluminium 1.5mm thick. Dimensions of the frame are shown in Figure 3. The solid circle in Figure 3 represents the cutting mechanism. Legs for landing gear were cut from ½ inch diameter hollow aluminium rod 0mm thick. Additional pieces such as base to mount flight controller and motor mounts were cut out from 1mm thick aluminium sheet.
- Motors- six 700KV motors with maximum current rating of 27Amps at full throttle with 11inch propellers, this data was provided in the specification sheet of the motors.
- ESC- maximum current rating of 30Amps and burst rating of 40Amp for 10sec. Burst rating of esc states that the esc can handle 40Amp for few seconds.
- Propellers- 11-inch length 4.5-inch pitch, Carbon Fiber propellers. Carbon fiber propellers are strong and light weight. Use of plastic propellers in applications requiring high thrust is not recommended since the propellers are susceptible to breakage at high speeds.
- Power Supply- 5000mAh 60C 4S LiPo battery
  Amperage of system-
  6 * 30 = 180Amps
  Amperage of battery-
  5000mAh * 60C = 300Amp
- Flight Controller- Pixhawk[16] it is an independent, open-hardware project aiming at providing high-end autopilot hardware to the academic, hobby and industrial communities at low costs and high availability. Pixhawk offers features such as-
  168 MHz Cortex M4F CPU (256 KB RAM, 2 MB Flash), sensors: 3D accelerometer, gyroscope, magnetometer, and barometer. Integrated backup, override and failsafe processor, micro SD slot, 5 UARTs, CAN, I2C, SPI, ADC, etc.

There are many other flight controllers to choose from, but presently Pixhawk provides more GPS accuracy. The flight controllers offer a variety of operating modes. Different operating modes are suitable for different applications. Some useful operating modes for harvesting application are:

- **Altitude Hold**- keeps the drone at a fixed height using the barometer. Drone may move around due to wind, but will retain its height.
- **Loiter**- keeps the drone fixed at particular point using the Barometer and GPS. Flight controller fetches its geographical location from the GPS and keeps the drone fixed at the obtained coordinates; hence, the drone does not move around and remains at a fixed height.

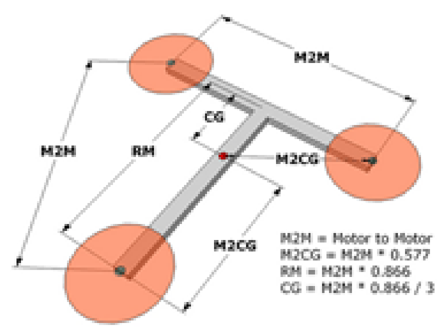

Figure 6: Standard measurements of T frame

Since Pixhawk does not have a built-in GPS, an external GPS with compass module was mounted on the drone. A small camera was also mounted which will enable the operator to get a first person view to determine if the fruit is ready to be harvested or not. T-frame was extended at the intersection to mount the cutting mechanism. For a cutting wheel, an additional motor was mounted to which power was provided by the same battery. GPS module provides the geographical position of the drone to the flight controller. It enables a feature called return to launch, which is useful in cases such as signal loss or low battery. In addition, with the help of GPS the drone can be programed to travel a pre-defined route autonomously[8].

Figure 7: Final prototype

IV. CUTTING MECHANISM

The cutting mechanisms[3] are classified into contact and non-contact.

1) Contact cutting mechanism

The mechanism will have to come in physical contact with the tree.

- **Metal cutting wheel**– this cutting wheel is used to cut metal such as aluminum, it has no sharpness nor does it have teeth but its surface is rough and green in color. It produces a thick cut and a moderate amount of force is required to cut. This extra force can be provided by adding an extra motor on the rear, which will start when the cutting mechanism starts giving it that extra force to push.
- **Wood cutting wheel**- this cutting wheel is made of steel and it has teeth producing a deep cut. This type of blade comes in various sizes. This blade requires extra force to overcome the jerking caused by the teeth of the blade while cutting this extra force can be provided by adding an extra motor on the rear, which will start when the cutting mechanism[3] starts giving it that extra force to push.

Figure 8: Metal cutting blade (left), wood cutting blade (right)

- **Hydraulic cutter-** it is hydraulic tool that is designed to cut through metal, consisting of a pair of hydraulic shears. This technology is becoming popular with fire fighters to cut open damaged vehicles in rescue operations. For the purpose of using this mechanism with a multirotor, customized smaller version must be designed which will snap the leaf or the fruit bunch without any opposing force being created. This will be the most suitable contact cutting mechanism.

2) Non-contact cutting mechanism

The mechanism does not come in contact with the tree. The drone and the cutting mechanism will be at a safe distance from the tree to avoid the cut leaf or fruit bunch from falling on the drone.

- **Laser cutter-** sufficiently high power laser can be used to cut the palm fruit and leaves. Due to the moisture in the tree it will not catch fire while cutting. The cutting laser will be mounted on a gimbal allowing the user to cut the leaves and fruit accurately. Gimbal is a device having one or two or three axis motors allowing it to rotate in x, y and z axis allowing the user to cut from any position.
- **Hydraulic water jet-** water jet, is an industrial tool capable of cutting a wide variety of materials using a very high-pressure jet of water, or a mixture of water and an abrasive substance. For our purpose a more powerful drone will be required to carry a pipe from the ground this will also require a specially designed gimbal which can move in x, y and z axis with the pressure of water being sprayed.

V. SOFTWARE

The image processing software is used to check the ripeness of the fruit. A perfectly ripe fruit yields better quality as well as greater quantity of oil. Following sections describe an image classification based solution for the problem of ripeness detection.

Convolution Neural Network

This is a type of neural network used to identify whether the oil Palm fruits are ripe, over ripe or unripe by means of image classification.

- **CNN Architecture**- Oil palm fruit is classified into 4 categories- ripe, unripe, overripe and background. The CNN architecture we have utilizing is a compact variant of the VGG network[9]**.**
- **Training the VGGnet**- The flow diagram in the figure 6 shows the structure of VGG net used for implementing the classifier.
  Conv 3-64 means that 64 filters with 3 channels are used for convolution at that point in time. Similarly Conv 3-128, Conv 3-256 and Conv 3-512 represent 128, 256 and 512 filters of 3 channels respectively. Activation function used is ReLU (Rectified Linear Unit).
  Max pooling is done with a 2*2 filter size and having stride value equal to 2.
  Before any image is given for classification, the CNN has to be trained with images in the dataset. The size of an input image will be reduced before the CNN starts extracting features from it. The reduction in size is done for the purpose of increasing the processing speeds.
  Using bigger image sizes can help the CNN extract more clear features and hence result in a more accurate model, but it requires a lot of processing power. Training time required for larger images is significantly high. The training and processing time can be reduced either by using smaller images or by using a high end GPU. Training with a GPU is much faster than using only a CPU.
  The fully connected layers are the final layers of the network and determine the class of the images with the help of a softmax classifier. Output of the softmax function is a probability distribution over the number of possible outcomes.
- **Classifying an Image**- After the training is completed, two files are generated, one containing the model itself and the other having the labels of classes. The model file will be used to test the input image and the label file will contain the labels i.e. the names of all classes. The model can be applied either to a single image file or to a video feed. Classifying an image takes negligible time, this is due to the fact that the network now has certain weight measures to distinguish between the input images. During classification, the image has to be resized to the size used for training the network.

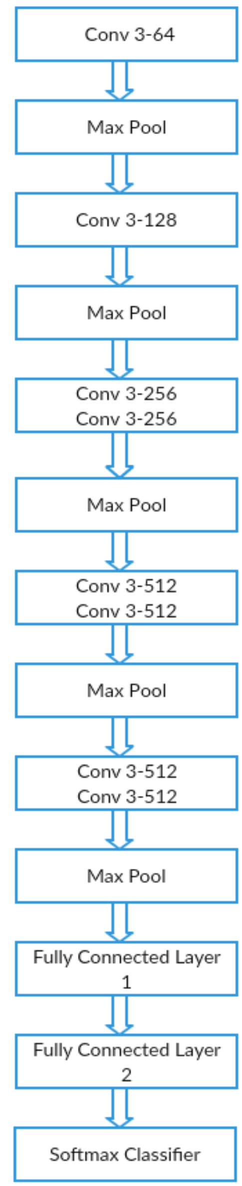

Figure 9: VGGnet architecture

VI. CONCLUSION

The delivered prototype is a multirotor drone designed for the purpose of harvesting oil palm fruits from tall trees along with speeding up the process of harvesting and making it risk free. The current system is of manual labor with hand held tools, some being mechanized while some being primitive. The grading of the palm fruit is also manual and tends to be biased. Use of a multirotor reduces the labor and the risk involved along with speeding up of the work. The drone is equipped with a camera that captures live feed and sends it to the controller making it easy for maneuvering the drone. The video feed is also used to check ripeness of oil palm fruits for harvesting.

Altitude hold and Loiter are two flight modes that were tested and proved to aid in image capture and cutting processes. The altitude hold mode allows the multirotor to maintain a constant height above the ground and hence capturing a steady image of the fruit. On the other hand loiter allows the drone to remain fixed at a particular point in air which is made possible because of the GPS module. While in Loiter the multirotor can move slowly towards the fruit bunch, to get a clear view of the fruits without crashing into the tree.

The software recognizes the palm fruits and grades it as unripe, ripe and overripe successfully using a VGGnet model, a type of Convolution Neural Network. The model proved to be much faster than the traditional image processessing approach(IP) which consisted of processing an image pixel by pixel. The IP approach took a significant ammount of time to process a single image hence proving it unsuitable to use on a video feed. The classification model helped in overcoming these hurdles as it classifies an image in negligible amount of time, suitable for a video feed.

VII. FUTURE SCOPE

The designed multirotor lacks the power required to cut the fruit bunch effectively. The multirotor being less powerful bounces back on contact with the bunch, also the torque of the rotating blade makes the multirotor lose its balance; these factors can lead to a crash. The battery is not able to provide long flight time or support a more powerful cutting mechanism. Absence of propeller guards endangers propeller safety. These problems can be solved by building a better version of the multirotor having configuration of Octa-Quad meaning 8 motors arranged one below the other making a ‘X’ shape. Using more powerful motors with lower KV rating and higher torque will enable the multirotor to carry more weight. Bigger battery will allow for longer flight time. In case of a contact type cutting mechanism, a better mechanism with more power can be used. For noncontact type cutting mechanism high power laser is a very good option, as it is accurate, lightweight in comparison with contact type and favorable for using with a multirotor. Lightweight propeller guards can be built to safeguard the propellers against crashes and can prevent sucking in of leaves while in close proximity to vegetation.

In terms of software, Instead of a single fruit detection, a whole bunch can be detected. The classification can be extended to use image localization in which the model will be able to recognize where exactly the fruit bunch is inside a captured image which is not possible in the case of classification alone.

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