

CAO-NALYZER: AN ANDROID-BASED MOLD DETECTION IN CACAO BEANS USING FASTER R-CNN ALGORITHM

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ABSTRACT

Mold-infested cacao beans present a substantial hurdle for the cacao industry, affecting not only the quality of the beans but also the cocoa products derived from them. With this issue, the proponents of the study developed an application aimed to detect moldy cacao beans using Faster Region-based Convolutional Neural Network algorithm for online mode and You Only Look Once version 8 for offline mode. After training the model, it resulted in a Mean Average Precision (mAP) of 83.96% in the Faster R-CNN algorithm and 98.16% in the YOLO algorithm. During the testing phase, the researchers conducted several tests such as Android Testing, Camera Resolution Testing, Ram Testing, Capture Distance Testing, Light Testing, Function Analysis Test, and Module Testing. The application then underwent refinements and enhancements based on their feedback.

Keywords: *BS Computer Science, moldy cacao beans, image processing, Philippines.*

INTRODUCTION

Cacao beans are the main raw materials in processing chocolates, cocoa powder, cocoa butter, etc. It is used in industries such as chocolate, pharmaceutical, and cosmetics. Numerous technological advancements are revolutionizing the cacao industry, enhancing production processes from bean to chocolate bar. Among the important stages in cocoa manufacturing, fermentation emerges as a critical process, exerting a profound influence on the final product's quality. Fermentation not only facilitates the removal of the mucilaginous pulp but also curbs germination while catalyzing the development of the cacao bean's intriguing aroma, exquisite flavor, and captivating color palette

[1] The reasons why mold detection is crucial, include minimizing health risks (1), as moldy cacao beans may contain mycotoxin that can lead to serious health problems. Product quality (2) ensures the safety and reliable commodities that improve customer satisfaction; and lastly, to prevent financial loss (3), cacao producers can take preventive measures against mold contamination that leads to wasting resources and revenue loss

[2] In the Juaboso District of Western-North, Ghana, small-scale farmers do postharvest procedures manually and efficiently which leads to an increased quality specification. Afterward, the following procedures are drying, fermentation, and classifying process which takes several days to complete. Poor fermentation of cacao beans can lead to poor quality. Determining the different specifications such as moldy, slaty, and insect-infested cacao beans is difficult for the reason that it is manually performed and exerts effort and time

[3] The cacao industry in the Philippines has recently gained recognition in domestic and international markets. Since the supply and demand gap has been increasing, the demand for cacao has

tripled since 1970 at a rate of 3% annually, with India and China growing at 7.9%. The expanding middle class, rising disposable income in developing nations, uses of cocoa in culinary, cosmetics, and pharmaceutical industries, and cacao's position as a health food are some of the main factors driving the increase in its demand

[4] In the research locale, a cacao bean manufacturing company Kennemer at Tagum City stated that moldy-cacao beans became frequent during rainy seasons. This unanticipated circumstance may lead to the bitterness of chocolate when the moldy beans are processed thereby causing a potential market loss due to not meeting the standards of the industry. They also emphasized that only a percentage of the bean population must meet and exhibit desirable characteristics for the cacao products to have consistency in their flavor and quality.

After analyzing the problem, the researchers conducted the study entitled: "Cao-nalyzer: An android-based mold detection in cacao beans using Faster R-CNN Algorithm". It is a program that identifies the quality of cacao beans while maintaining the accuracy of quality checking. The program helps the farmers to reduce their effort of manual quality checking.

Table 1. Comparison of Related Studies

| Features | Studies | | | | | |
|--------------------------|--------------------|------------------|------------------|----------------|-------------------|-------------|
| | Obediencia, et al. | Nasution, et al. | Sisneros, et al. | Adhitya et al. | Hortinela, et al. | Cao-nalyzer |
| Real-time mold detection | × | × | × | × | × | ✓ |
| Image mold detection | ✓ | ✓ | × | ✓ | ✓ | ✓ |
| Mobile Application | × | × | ✓ | ✓ | ✓ | ✓ |

| | | | | | | |
|---|---|---|---|---|---|---|
| Gallery Module | × | × | × | × | × | ✓ |
| Mold Count | × | × | × | × | × | ✓ |
| Faster R-CNN Algorithm (Online Mode) | × | × | × | × | × | ✓ |
| You Only Look Once Algorithm (Offline Mode) | × | × | × | × | × | ✓ |

Table 1 shows the differentiation of the related studies conducted by various researchers. This helps the proponents identify the gaps in the existing studies to enhance methods of dealing with problems related to classifying the quality of cacao beans using the naked eye. In addition, the typical studies used captured images for detecting the qualities of cacao beans.

However, studies in detecting the quality of cacao beans do not focus on developing a mobile application. The researchers aim to develop an application with real-time object detection to produce instant and consistently high-accuracy results with portability.

The key features of this study provide users with good utility for identifying and verifying moldy cacao beans in real-time. Real-time image detection enables users to instantaneously recognize and tally the objects; it also utilizes the Faster R-CNN algorithm, which relies on cloud-based processing to achieve high levels of accuracy, and the YOLO algorithm, for the situations when the internet is not available. The aforementioned features are unique compared to other related works of literature making it more robust, efficient, and reliable utility for mold identification of cacao beans.

1.1 Objectives of the Study

The objective of this study was to develop an Android application capable of detecting moldy cacao beans to minimize the amount of work the user has to accomplish in cacao production.

Specifically, the study aimed to:

1. Implement image processing in mold detection.
2. Develop and train AI Model using a Faster Region-based Convolutional Neural Network (Faster R-CNN) algorithm to detect moldy cacao beans, for Online Mode.
3. Develop and train AI Model that uses a You Only Look Once algorithm to detect moldy cacao beans, for Offline Mode.
4. Develop and count the number of moldy cacao beans, based on the captured image.

1.2 Purpose and Description

The main objective of this project was to significantly enhance the accuracy of moldy cacao bean detection, achieved through the development of an advanced software called Cao-nalyzer. Once fully realized, Cao-nalyzer employed cutting-edge image processing techniques to identify moldy cacao beans, revolutionizing the quality assessment process and elevating the overall efficiency of cacao production precisely and efficiently.

Cao-nalyzer, a mobile application has the following capabilities:

1. Implement a Faster R-CNN algorithm to detect moldy cacao beans by employing a mobile camera while the user is in Online Mode;
2. Implement a You Only Look Once algorithm to detect moldy cacao beans by employing a mobile camera while the user is in Offline Mode;

3. Real-time detection of moldy cacao beans;
4. Develop a gallery module to view the captured images and a tallied result.

To achieve the features stated above, the researchers must guarantee that the code and algorithm that will use in the application will give an accurate result. The technology that will be utilized in this application are TensorFlow Lite; for embedding AI models in an Android mobile device, Visual Studio Code; a text editor for writing dart code, Flutter Framework; for writing, compiling, and building Android Package (APK), for labeling the cacao beans images, Labelbox; for converting the labeled images to a dataset with augmentation, Roboflow. The Faster R-CNN algorithm which will be implemented in TensorFlow and the You Only Look Once which will be implemented by Ultralytics HUB will both use Google Collab for its GPU resources for training the model.

As for the model deployment of Faster R-CNN, the researchers will utilize Docker with a custom TensorFlow Serving docker image, as a Restful Application Programming Interface (Rest API) web server, for the mobile devices to connect when the user is in online mode. This algorithm is a type of object detection algorithm that evaluates the details of the cacao beans meticulously, which is effective at detecting small objects. On the other hand, the You Only Look Once (YOLO) algorithm will be embedded in mobile devices and will be used when the user is in Offline Mode. Technologies such as Ultralytics will be crucial for model training as it offers YoloV8 which is the latest version released making it the highest-performing object detection model to date.

1.3 Scope and Limitation

The Cao-nalyzer is designed for farmers that own cacao farms. The application can detect moldy cacao beans. Additionally, the application will use a real-time feature to have better accuracy,

make the work significantly faster by scanning the cacao beans, and use a captured image from the application to store the gathered data for the record. The captured images can be viewed in the gallery module. Furthermore, this project utilizes the camera of a mobile phone to precisely detect moldy cacao beans within a specially designed holder, benefitting from controlled lighting conditions that ensure consistent results.

However, the application is compatible with Android version 8 and higher. In addition, the specification of the application is limited to detecting moldy cacao beans and it cannot detect non-moldy cacao beans. The maximum quantity of detected moldy cacao beans amounts to 15. Nevertheless, the system cannot identify instances where the count exceeds this limit. Real-time object detection might produce inaccurate results if the image captured is blurry and cannot be clearly detected by the camera due to poor lighting.

1.4 Significance of the Study

The following individuals and organizations are the beneficiaries of this study:

1. Cacao Farmers / Cacao Farmer Organization. This study proves immensely valuable to cacao farmers as it effectively reduces their laborious workload. Through the implementation of the Cacao Analyzer, farmers can swiftly access precise and real-time results during the cacao bean quality assessment process. The utilization of this technology allows them to identify moldy cacao beans accurately, not only in real-time scenarios but also by analyzing captured images, further simplifying their operations, and enhancing productivity.

2. Department of Agriculture. This study will be beneficial in promoting a technological approach in the field of agriculture as it

focuses on accuracy and speed by identifying the quality or grade of cacao beans to classify them accordingly.

3. Future Researchers. This allows researchers who will continue this study to improve the accuracy of detecting moldy cacao beans, enhance the algorithm, and solve the known limitations in this study.

METHOD

2.1 Agile Software Development Method

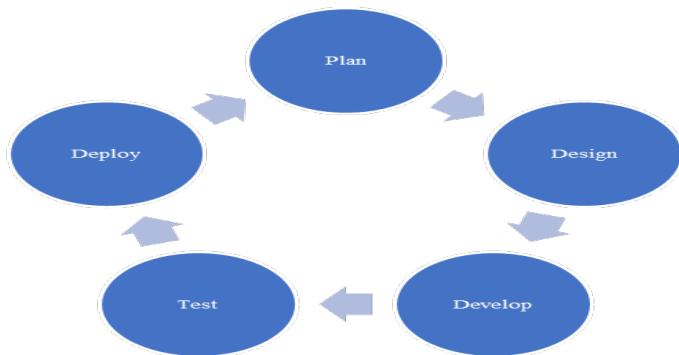


Figure 1. Agile Method.

This study utilized the Agile Methodology, which is also recognized as the iterative approach. The project was segmented into iterations and encompassed six (5) phases: Plan, Design, Develop, Test, and Deploy [11].

This method aligns with the research as it promotes swift and flexible adaptation to changes, emphasizing customer collaboration and minimizing overall risk [12]. Moreover, it enhances the product's quality by ensuring that the requirements are closely aligned with the desired outcome.

Step 1: Plan

Table 2. FAQ: Bean Classification

| <i>Parameters</i> | | <i>Selected</i> |
|---------------------------------|----------------------|------------------|
| <i>Cut Test (In 100 beans)</i> | <i>Slate</i> | <i>2.00% max</i> |
| | <i>Mold</i> | <i>0.00% max</i> |
| | <i>Insect Damage</i> | <i>0.00% max</i> |

Plan, the researchers conducted an interview with their beneficiary regarding the struggles they faced in examining the cacao beans' quality after fermentation. Table 2 shows Kennemer's standard of quality checking. However, researchers focus only on moldy cacao beans.

Step 2: Design

Design, the researchers designed a system architecture that outlines the features, components, and technologies utilized in this study. Also, they designed a prototype that serves as the blueprint for developing the app.

Step 3: Develop

Develop, this stage is the most important part of the application's development. The researchers write a code using flutter and used flutter vision for YOLO. Also, they used the http library for web requests to the server that serves Faster R-CNN.

Step 4: Test

Test, after the development of the application is done, the researcher conducts a compatibility test to ensure that the application is working as expected on the listed devices. Also, test the functionality to make sure that the application is error-free.

Step 5: Deploy

Deploy, when the testing stage is finished, the researcher launched the application. The researchers build the APK to distribute their beneficiaries. In Addition, they demonstrate the application to the users on how to use it.

This methodology is suited for the study because it emphasizes customer collaboration and lowers overall risk, which fosters a quick and adaptive response to changes. Additionally, because the requirements and expected results are in line, the product's quality is also improved.

2.2 Conceptual Framework

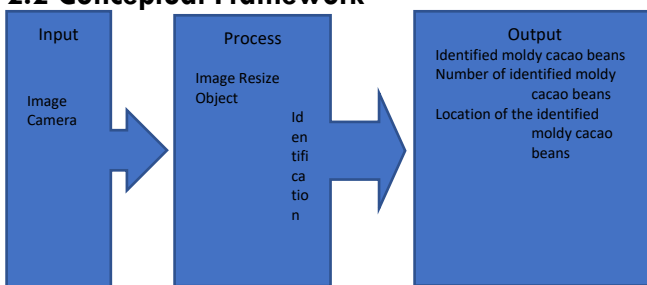


Figure 2. Input-Process-Output Model

Figure 1 shows the input, process, and output needed to accomplish in developing Cao-analyzer. The input section contains the image captured that consists of cacao beans as the subject. The process section describes the methods and technologies used to process the previously specified input which is the image. The Faster

R-CNN algorithm will be utilized to perform object detection with TensorFlow, for the online mode. As for the offline mode, YOLOv8 will be used which is a widely used algorithm for object detection in edge devices. Additionally, Flutter is employed as the UI/UX framework alongside with Visual Studio Code for developing the mobile application. The proponents can develop the Cao-analyzer by completing all of the relevant processing activities. The output section shows the result of the identified cacao beans, the location and the number of the identified cacao beans.

2.3 Faster R-CNN Algorithm in Molds Detection

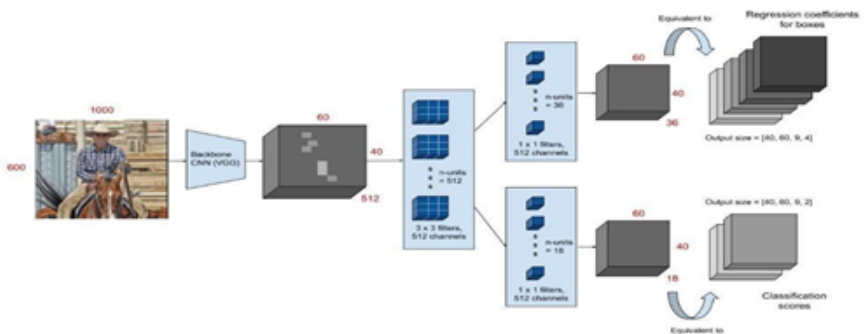


Figure 3. Faster R-CNN Algorithm.

Faster R-CNN is an end-to-end trained model that employs a unique region proposal network (RPN) to generate region proposals, resulting in time savings compared to conventional algorithms like Selective Search [13].

The Faster R-CNN algorithm is a deep convolutional network devised for object detection. It is capable of detecting small objects effectively, making it suitable for the researcher's use case. For the training phase, the dataset image format is 640 width and 640 height. The researchers used a pre-trained Faster R-CNN TensorFlow model which then used the researcher's custom dataset to train. Then, the model is deployed via a web server that uses Docker.

Furthermore, the web server is used to communicate with Android mobile devices and the faster R-CNN model.

2.4 You Only Look Once Algorithm in Molds Detection

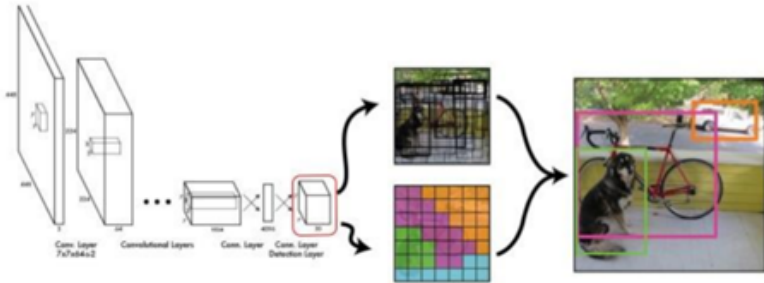


Figure 4. You Only Look Once Algorithm.

The You Only Look Once (YOLO) algorithm is a popular object detection algorithm that can be used in various applications such as computer vision and image processing. It is also known for its real-time object detection which makes it suitable for applications that require fast and efficient processes. YOLO algorithm's key advantages include its real-time performance, as it can process images or video frames very quickly, and its ability to capture objects with different scales and aspect ratios effectively [14].

Moreover, the YOLO algorithm is better suited to the researcher's application as this has better performance, compared to other CNN algorithms, when used in edge devices like mobile devices. The researchers used Ultralytics to train the model and export the file model which then is embedded in the Cao-analyzer application.

2.5 System Architecture

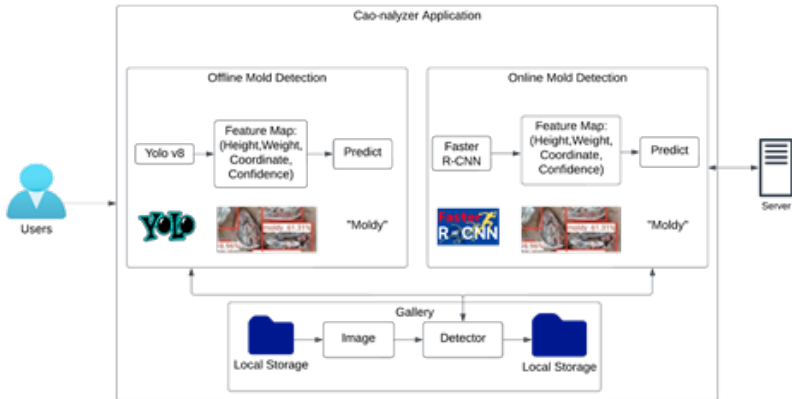


Figure 5. Cao-nalyzer System Architecture.

Figure 5 illustrates the system architecture that visualizes the overview functionality of the system. It consists of different features, hardware, software, and user interfaces that are important in developing the application. The Flutter SDK is used to communicate with the Android mobile device's hardware, such as CPU, GPU when available, and camera. The real-time camera UI is responsible for displaying the real-time image, with the output of the object detection, from the camera and capturing an image from the streamed image to the file storage.

The gallery UI is responsible for displaying the stored images from the file storage. It can also tally the moldy cacao beans detected from the pictures. The input process of the system is the image that comes from the image stream or the static image, then preprocessed to ensure the format is compatible with the TensorFlow Lite Model. The TensorFlow Lite Interpreter handles the process of the TensorFlow Lite Model with the processed input as a parameter and producing the output.

RESULTS AND DISCUSSION

3.1 Training

Training is the process of instructing an algorithm to identify patterns and correlations in data, enabling it to make precise predictions or decisions [15]. After the process, the trained Artificial Intelligence (AI) offers valuable understandings, make well-informed choices, automates tasks, and enhances overall efficiency and effectiveness in numerous practical situations [16].

Faster R-CNN Algorithm

The researchers used the TensorFlow pre-trained model Faster R-CNN with Resnet-50 version 1 for the Faster R-CNN algorithm. They used their custom distinctive dataset, produced by Roboflow, to further refine this model. The free and constrained GPU processing environment offered by Google Colab was chosen as the training platform since it speeds up the training process and cuts down on learning time.

YOLO Algorithm

In order to access the pre-trained YOLO model, the researchers used the Ultralytics library. The researcher's custom dataset, which was produced with the aid of Roboflow, was then used to retrain the model. In keeping with their strategy for Faster R-CNN, Google Colab was chosen as the training environment of choice because of its advantageous free GPU processing capabilities.

3.2 Compatibility Assessment

The process of Compatibility assessment involves analyzing and comparing the application and its functionalities across various mobile devices, browsers, operating systems, and platforms to

identify any possible variations or inconsistencies. To simplify, it takes the results or data gathered from the initial assessment and uses that information to generate further insights or conclusions [17].

This study involved conducting a series of tests to assess the efficiency of the developed system. The evaluation encompasses various aspects such as testing the Android operating system, camera resolution, measuring capture distance, and assessing lighting conditions. The outcomes of the conducted conformity assessments are presented in the provided tables.

Table 3. Android Testing

| Device | Android OS Version | Remarks |
|----------------|--------------------|---------|
| POCO X3 pro | Android 12.0 | Passed |
| Redmi K20 | Android 11.0 | Passed |
| Realme 6 pro | Android 10.0 | Passed |
| Redmi Note 9s | Android 9.0 | Passed |
| Huawei Nova i3 | Android 8.0 | Failed |

Table 4. Camera Resolution Testing

| Device | Camera Resolution | Remarks |
|----------------|-------------------|---------|
| POCO X3 pro | 48 - Megapixel | Passed |
| Redmi K20 | 48 - Megapixel | Passed |
| Realme 6 pro | 64 - Megapixel | Passed |
| Redmi Note 9s | 48 - Megapixel | Passed |
| Huawei Nova i3 | 16 - Megapixel | Failed |

Table 5. RAM Testing

| Device | RAM Capacity | Remarks and Performance |
|----------------|---------------------|--------------------------------|
| POCO X3 pro | 11gb RAM | Working |
| Redmi K20 | 8gb RAM | Working |
| Realme 6 pro | 8gb RAM | Working |
| Redmi Note 9s | 4gb RAM | Working |
| Huawei Nova i3 | 4gb RAM | Working |

Table 6. Capture Distance Testing

| Distance | Remarks |
|-----------------|----------------|
| 3 inches | Passed |
| 4 inches | Passed |
| 5 inches | Passed |
| 6 inches | Passed |
| 7 inches | Passed |
| 8 inches | Passed |
| 9 inches | Passed |
| 10 inches | Passed |
| 11 inches | Failed |
| 12 inches | Failed |

Table 7. Light Testing

| Types of Light Distance | Remarks |
|-------------------------|---------|
| Natural Light | Passed |
| Controlled Light | Passed |
| Hard Light | Failed |
| Dim Light | Failed |
| Low Light | Failed |

The evaluation of the application involved testing it on five (5) different Android phone models, each having different camera resolutions and memory sizes. The results indicate that it is recommended to install the application on phones equipped with a camera of at least 48 megapixels and a RAM capacity of 4GB or higher. Furthermore, when capturing an image, it is advised to maintain a distance of no more than 10 inches from the cacao bean. It is also suggested that the user takes the photograph in a well-lit environment as illustrated in table 6.

3.3 Usability Assessment

Usability assessment helps ensure the application meets the users' needs. By carrying out rigorous usability tests, developers may learn a great deal about how users interact with the application, perhaps finding pain points, and seeing potential improvements [18]. It has a critical aspect of user experience, conducting both initial and derived usability assessments can lead to more successful and satisfying user interactions with the product or system [19].

Table 7-8 presents the results of the usability test, specifically focusing on the application's features and modules. The tables showcase the findings derived from the test in relation to these aspects.

Table 8. Function Analysis Testing

| Objective | Findings |
|---|-----------------|
| Detect moldy beans using real-time(online mode) | Passed |
| Detect moldy beans real-time (offline mode) | Passed |
| Capture image (online mode) | Passed |
| Capture image (offline mode) | Passed |
| Display the confidence of moldy beans | Passed |
| Count the detected moldy beans | Passed |
| Store the captured image to the gallery | Passed |

Table 9. Module Testing

| Objective | Findings |
|---|-----------------|
| Detect moldy beans using real-time(online mode) | Passed |
| Detect moldy beans real-time (offline mode) | Passed |
| Capture image (online mode) | Passed |
| Capture image (offline mode) | Passed |
| Display the confidence of moldy beans | Passed |
| Count the detected moldy beans | Passed |
| Store the captured image to the gallery | Passed |

The results affirm that the application aligns with the designated objectives. Most of the Android devices passed the module test. However, the Huawei Nova i3 failed to detect the moldy cacao beans due to poor camera resolution.

3.4 VALIDATION

Table 10. Sample Data

| Moldy Beans Test | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 |
|---|--------|--------|--------|--------|--------|
|  | ✓ | ✓ | ✓ | ✓ | ✗ |
|  | ✓ | ✓ | ✓ | ✓ | ✓ |
|  | ✓ | ✓ | ✓ | ✓ | ✓ |
|  | ✓ | ✓ | ✓ | ✓ | ✓ |
|  | ✓ | ✓ | ✓ | ✓ | ✗ |

A validation assessment is conducted to establish whether a specific process, system, or methodology that manages particular criteria or requirements. The goal is to validate and verify the accuracy, effectiveness, and compliance with the standards of the subject being examined [20].

The data under examination for detection is presented in the table above. Using Cao-nalyzer, the proponents validated using five (5) samples of moldy cacao bean images to assess the application's accuracy. Among these images 2, 3, and 4 successfully passed all the tests, while images 1 and 5 encountered a failure during the 5th test. The test cases achieved an overall accuracy of 92%, with only an 8% failure rate as shown in Table 9.

3.5 ALPHA TESTING

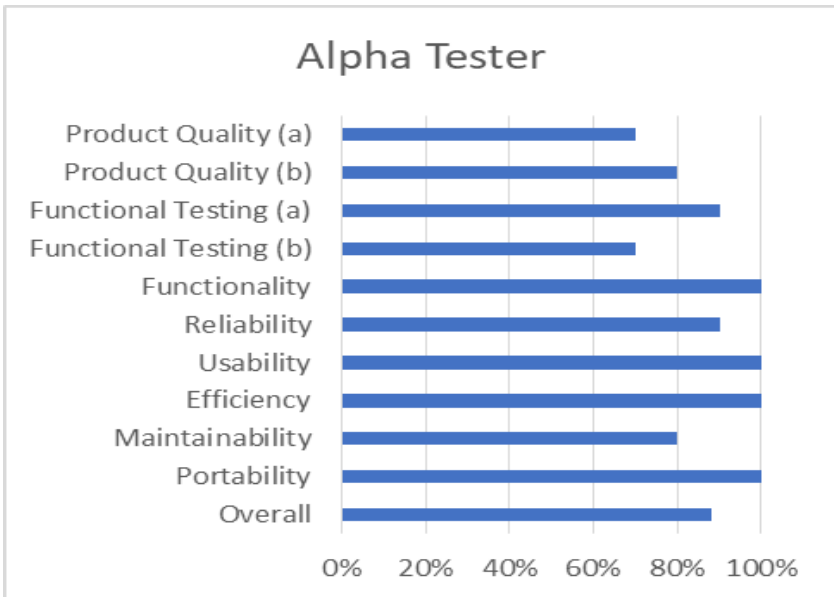


Figure 6. Alpha Testing Result

The researchers used Alpha testing to guarantee the software system's quality prior to its deployment in the production environment [21]. After conducting the tests on various mobile models and performing compatibility assessments, the application entered the first phase of software testing, monitored by the researcher's advisor. The illustration above shows the outcome of the alpha test. The researcher's advisor recommended enhancing the application by incorporating a larger dataset and integrating cloud storage for backup purposes. Therefore, the alpha testing received an overall evaluation score of 88%.

3.6 BETA TESTING

The researchers used Beta testing which plays a crucial role in identifying functional or usability issues that may go in-house testers, designers, or automation [22]. In contrast, the researcher conducted a beta test with 10 participants to evaluate the application's detection functionality among the intended users. This testing approach enabled the developers to identify and address any bugs while also assessing user satisfaction. Consequently, the achieved overall score was 86.60%.

CONCLUSIONS AND RECOMMENDATIONS

During the development process, the developers found that for optimal performance, the application is best suited for smartphones with Android version 9.0 or higher, a camera resolution of at least 48MP, and a minimum of 4GB RAM. The application offers two modes, namely offline and online, with captured images stored in internal storage.

The conducted survey shows that the beneficiaries are satisfied with the application. The application was evaluated based on its functionality, usability, reliability, performance, supportability, and compatibility.

The researchers accomplished the following objectives:

1. Implemented a camera for captured photos and real-time image processing in mold detection.
2. Developed and trained an AI Model that uses the Faster R-CNN algorithm to identify moldy cacao beans for online mode.
3. Developed and trained an AI Model that uses a YOLO algorithm that identifies moldy cacao beans for offline mode.
4. Developed a counter of the number of identified moldy cacao beans based on the image.

The researchers suggested this list of recommendations addressing the limitations and issues encountered during the development of this thesis. Develop the application in native Android or native IOS instead of Flutter:

1. Despite Flutter's efficient performance compared to other cross-platform frameworks, it is not optimized yet for the development of resource-extensive applications such as object detection, and gaming.
2. The mold detection is best used with six beans placed properly in a holder as an input.
3. For the dataset, make sure the image captured should be in close proximity. For example, at least six beans in one image.

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