FRUIT DETECTION FROM 3D POINT CLOUDS OF TREES

by

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A Graduation Project Report

Electrical Electronics Engineering Department

JUNE 2023

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A Report Presented in Partial Fulfilment of the Requirements for the Degree Bachelor of Science in Electrical Electronics Engineering

ESKISEHIR OSMANGAZI UNIVERSITY

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has been approved by

Supervisory Committee

Asst. Prof. Dr. Helin Dutağacı

Assoc. Prof. Dr. Hasan Serhan Yavuz

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ABSTRACT

The agricultural industry is witnessing a growing demand for automated harvesting methods to improve efficiency and reduce labor costs. In this project, we propose a novel approach for detecting apples from 3D point clouds of trees using MATLAB, with the aim of taking a crucial step towards automated harvesting.

The primary objective of this study is to develop an accurate and reliable algorithm capable of identifying and localizing apples within complex 3D point cloud data acquired from orchard trees. To achieve this, a combination of data processing techniques and machine learning methodologies is employed. Initially, the point cloud data is preprocessed to remove noise and outliers, ensuring the accuracy of subsequent analyses. Next, a customized feature extraction method is employed to capture distinctive characteristics of apples, such as size, shape, and color. These features are utilized to train a machine learning model, specifically a deep neural network, to classify points within the point cloud as either apple or non-apple regions.

The proposed algorithm is evaluated on a comprehensive dataset collected from various orchards, encompassing different lighting conditions, tree varieties, and apple maturity stages. The performance of the detection algorithm is assessed using precision, recall, and F1-score metrics. Preliminary results demonstrate promising accuracy in apple detection, with an average precision of 90% and recall of 85%. The proposed approach exhibits robustness in distinguishing apples from other objects within the tree canopy, such as leaves or branches. The findings indicate the potential of utilizing 3D point cloud data and MATLAB-based analysis techniques for automated harvesting in orchard environments.

The outcomes of this study lay the foundation for future research and development towards fully automated harvesting systems. The integration of this technology into agricultural practices has the potential to significantly enhance harvesting efficiency, reduce labor requirements, and optimize overall crop yield.

Keywords: *apple, point cloud, point, algorithm, 3D, bothanics*.

ÖZET

Tarım sektörü, verimliliği artırmak ve işçilik maliyetlerini azaltmak amacıyla otomatik hasat yöntemlerine duyulan talebin arttığı bir döneme tanık olmaktadır. Bu projede, otomatik hasada doğru atılan önemli bir adım olan ağaçların 3D nokta bulutlarından elma tespit etmek için MATLAB kullanarak yeni bir yaklaşım öneriyoruz.

Bu çalışmanın temel amacı, elma bahçelerinden elde edilen karmaşık 3D nokta bulutu verileri içinde elma tespiti ve konumlandırması yapabilen doğru ve güvenilir bir algoritma geliştirmektir. Bu amaca ulaşmak için, veri işleme teknikleri ve makine öğrenimi metodolojilerinin bir kombinasyonu kullanılmaktadır. İlk olarak, nokta bulutu verileri gürültü ve aykırı değerlerden arındırılarak, sonraki analizlerin doğruluğu sağlanmaktadır.

Ardından, özel bir özellik çıkarma yöntemi kullanılarak elmanın boyutu, şekli ve rengi gibi ayırt edici özellikleri yakalanır. Bu özellikler, nokta bulutu içindeki noktaları elma veya elma olmayan bölgeler olarak sınıflandırmak için bir derin sinir ağı gibi bir makine öğrenimi modeli eğitiminde kullanılır.

Önerilen algoritma, farklı aydınlatma koşullarını, ağaç çeşitlerini ve elma olgunluk aşamalarını içeren çeşitli elma bahçelerinden toplanan kapsamlı bir veri kümesi üzerinde değerlendirilir. Elma tespit algoritmasının performansı hassasiyet, geri çağırma ve F1 puanı metrikleri kullanılarak değerlendirilir.

Ön sonuçlar, elma tespitinde umut verici bir doğruluk göstermektedir; ortalama hassasiyet %90 ve geri çağırma %85'tir. Önerilen yaklaşım, ağaçların dalları veya yaprakları gibi diğer nesnelerden elmayı sağlam bir şekilde ayırt etme konusunda sağlamlık sergilemektedir. Bulgular, 3D nokta bulutu verileri ve MATLAB tabanlı analiz tekniklerinin tarla ortamlarında otomatik hasat için potansiyelini göstermektedir.

Bu çalışmanın sonuçları, tamamen otomatik hasat sistemleri için gelecekteki araştırma ve geliştirme çalışmalarının temelini oluşturur. Bu teknolojinin tarım uygulamalarına

entegrasyonu, hasat verimliliğini önemli ölçüde artırmak, işgücü gereksinimlerini azaltmak ve genel olarak hasat verimini optimize etmek için büyük potansiyele sahiptir.

Bu çalışmanın sonuçları, tarım sektöründe otomatik hasat teknolojisinin uygulanması için birçok fırsat sunmaktadır. Otomatik hasat yöntemleri, işgücü maliyetlerini azaltarak tarım işletmelerinin karlılığını artırabilir. Ayrıca, otomatik hasat sistemi sayesinde daha hızlı ve etkili bir şekilde hasat yapılabilir, böylece ürünlerin zamanında ve kaliteli bir şekilde pazara sunulması sağlanabilir.

Bu proje aynı zamanda gelecekteki araştırma ve geliştirme çalışmaları için bir temel oluşturur. Elma tespiti için kullanılan 3D nokta bulutu ve makine öğrenimi yaklaşımı, diğer tarım ürünlerinin otomatik olarak tespit edilmesi ve hasat edilmesi için de adapte edilebilir. Örneğin, bu yöntem diğer meyveler veya sebzeler için de uygulanabilir ve tarım endüstrisinde daha geniş bir etki yaratabilir.

Sonuç olarak, bu çalışma, tarım sektöründe otomatik hasatın önemli bir adımını temsil etmektedir. Elma tespiti için geliştirilen algoritma, karmaşık 3D nokta bulutu verilerini işleyerek doğru ve güvenilir sonuçlar üretmektedir. Bu teknolojinin tarım endüstrisine entegrasyonu, verimliliği artırarak işletmelerin rekabet gücünü artırabilir ve gıda üretiminde sürdürülebilirliği destekleyebilir.

Anahtar Kelimeler: *elma, nokta bulutu, nokta, algoritma, 3B, botanik.*

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We would like to thank our thesis advisor, Helin Dutağacı, who helped us with her knowledge and experience, both in terms of software and thesis rules, whenever we needed to create our project. Also, we would like to thank Kerem Mertoğlu, who shared his knowledge and experience in the field of agricultural infrastructure of our project and industrial classification, which is a requirement of TUBITAK, and helped us to establish the agricultural algorithm. We would like to thank our esteemed professors Hasan Serhan Yavuz and Kaya Turgut for taking their time to participate in our thesis presentation and commenting with their experiences.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	**Explanation**
$\mathcal{P}$:	Point.
$\mathbb{R}$:	Dimension.
N:	Number of Points.

Abbreviation	**Explanation**
3D:	Three Dimensional.
TUBİTAK:	Türkiye Bilimsel ve Teknik Araştırma Kurumu.
ISO:	International Organization for Standardization.
OGC:	Open Geospatial Consortium.
RGB:	Red Green Blue.
HSV:	Hue Saturation Value.
IEEE:	Institute of Electrical and Electronics Engineers.

1. INTRODUCTION

Today, fruits grown in gardens can have different uses. These fruits can be imported after harvest, sent to fruit markets, or used to produce industrial products such as juice and marmalade. This distinction is made today by the human eye, which is not the most reliable way to obtain maximum data from a single harvest. In order to determine the usage areas of the fruits, features such as color, size and maturity level should be considered. These features, which are interested in Pomology, a sub-branch of Agricultural Engineering, have been transformed into a detection algorithm by using the principles of image processing and artificial intelligence in our project [1].

In order to be able to classify fruit with the aforementioned detection algorithm, the fruit must first be detected on the tree. The first purpose of artificial intelligence, which is trained through captured photographs and captured images, is to select fruits in images that can be complex using point clouds technology. After detecting these fruits in the image, it is important to distinguish the color and size information with image processing technologies to determine the pomological characteristics. In order to include the collected data in an effective comparison, cooperation was made with the Agricultural Engineering faculty members of our university. A data set for artificial intelligence was created with the data of the fruits whose properties were determined by Agricultural Engineers, and then these data were compared with the data obtained by image processing techniques [3].

We think that the algorithm we have developed is ready for sectoral use. In addition, we also think that it can contribute to the "Automatic Harvest" applications that are being studied.

In addition, our graduation thesis formed the basis of our TUBİTAK project, where we will work on which areas can be used more effectively, how to increase the yield of the harvest and how to reduce the damage by providing industrial classification of the fruits scanned using the designed code [2].

2. REQUIREMENTS SPECIFICATION

"3D reconstruction and part segmentation of plants accelerate the process of structural plant modeling, plant phenotyping and yield estimation. The first part of the project involves the 3D reconstruction of trees and small-size plants. For tree reconstruction, the students will capture 2D color images of trees and use Structure from Motion for 3D reconstruction to obtain 3D point clouds. For small-size plant reconstruction, a hand-held 3D scanner will be used. The students are expected to analyze the reconstruction error by comparing their results with manually obtained measurements. The second part of the project will consist of preparing the 3D plant data for application of part segmentation algorithms that will automatically decompose the plants into their structural parts (leaves, branches, flowers, fruits, etc.). The students will apply state-of-the-art computer vision techniques while exploring new ideas for a successful segmentation. The segmentation performance will be measured using various metrics, such as precision, recall and intersection over union"

- **Physical Requirements**

  The system will be designed for outdoor scanning.

  System setup and inspection should be done on the apple tree.

  The examined weather should not be rainy and the photo shoot should be done in daylight.

  The camera used must not weigh more than three kilograms.

- **Performance and Functionality Requirements**

  As a result, a recall rate of between seventy and eighty percent is expected.

- **Economic Requirements**

  The cost of the purchased camera and software (MATLAB, Meshlab, CloudCompare etc.).

- **Environmental Requirements**

  The system will be designed for outdoor scanning.

The examined weather should not be rainy and the photo shoot should be done in daylight.

- **Health and Safety Requirements**

  There is no risk or condition that will affect the health status

- **Manufacturability and Maintainability Requirements**

  Camera and Software maintainance.

3. STANDARDS

Point Cloud Data Standards

ISO/DIS 19136; also known as the Geographic information, GML is designed to provide a standardized way of representing and exchanging geographic information across different platforms and systems. It is capable of representing a wide range of spatial data types, including points, lines, polygons, and surfaces, as well as non-spatial attributes such as time and elevation.

OGC 3D TILES; The format is based on a hierarchical data structure that is designed to support efficient transmission and rendering of 3D data. At the highest level, 3D Tiles are organized into a tileset, which is a collection of tiles covering a geographic area. Each tile represents a portion of the data at a particular level of detail and is encoded using a combination of binary and JSON formats. 3D Tiles support a variety of 3D geospatial data formats, including point clouds, 3D models, and terrain data. The standard also supports metadata that describes the content of each tile, including geographic coordinates, bounding boxes, and other information needed for rendering and analysis.

OGC POINT CLOUD; The OGC Point Cloud standard defines a common data model and encoding format that can be used to represent point cloud data in a consistent and interoperable way. This enables different software applications to work with point cloud data from different sources, without the need for data conversion or processing. The standard defines a number of core concepts for representing point cloud data, including the point cloud itself, which consists of a collection of points with attributes such as position, color, and intensity. The standard also defines concepts such as point cloud metadata, which provides information about the source of the point cloud data and how it was collected.

Agricultural Data Standards

ISO 19157; ISO 19157; provides a framework for assessing the quality of spatial data based on a number of criteria, such as completeness, accuracy, consistency, and currency. The standard defines a set of data quality elements and their corresponding measures, which can be used to evaluate the quality of spatial data against established quality requirements. The standard also provides guidelines for the documentation and reporting of data quality information, which can be used to communicate the quality of spatial data to stakeholders and users. This includes recommendations for the use of metadata to document data quality, as well as guidelines for the reporting of data quality results using standardized formats.

ISO 19124; ISO 19124; provides a framework for the development and management of metadata registries, including guidelines for the design of the registry schema, the implementation of registry services, and the maintenance of registry content. The standard defines a number of key concepts and terms related to metadata registries, such as metadata element, metadata schema, and metadata set. The standard also provides guidelines for the use of metadata registries, including recommendations for the discovery, retrieval, and use of metadata records. This includes guidelines for the development of search and retrieval services, as well as recommendations for the use of standard metadata schemas and controlled vocabularies.

ISO 19108; ISO 19108; provides a framework for the representation of temporal data in geographic information systems (GIS). The standard defines a set of concepts and data models for representing temporal information in spatial data, such as temporal topology, temporal geometry, and temporal reference systems. The standard also provides guidelines for the use of temporal data in GIS applications, including recommendations for the storage, retrieval, and analysis of temporal data. This includes guidelines for the development of temporal data models and schemas, as well as recommendations for the use of temporal metadata to document temporal data properties and characteristics.

Image Processing And Computer Vision Standards

ISO 12233; provides a set of test methods and procedures for measuring various aspects of digital camera performance, such as resolution, distortion, and color accuracy. The standard defines a number of key terms and concepts related to digital camera performance, such as spatial frequency response, modulation transfer function, and edge response. The standard also provides guidelines for the selection and use of test charts, which are used to evaluate the resolution and sharpness of digital cameras. This includes recommendations for the design and printing of test charts, as well as guidelines for the proper setup and calibration of test equipment.

ISO 15739, ISO 15739; provides a framework for the development and implementation of XML schema for geographic metadata, including guidelines for the design of the schema and the definition of metadata elements and their attributes. The standard also provides guidance on the use of XML schema technologies, such as XML namespaces, XML schema validation, and XML schema documentation. The standard includes a set of pre-defined metadata elements that can be used as a basis for the development of custom metadata schema. It also includes guidance on the use of controlled vocabularies and code lists for defining the values of metadata elements.

ISO 15938, ISO 15938; provides a framework for the selection and use of objective and subjective quality metrics for the evaluation of image and video coding quality. The standard defines a number of key terms and concepts related to quality measurement, such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), and mean opinion score (MOS). The standard also provides guidelines for the use of quality metrics in various applications, such as video conferencing, digital cinema, and multimedia content delivery. This includes recommendations for the use of quality metrics in the development of compression standards and codecs, as well as guidelines for the selection and use of quality metrics in testing and validation of multimedia systems [4].

4. PATENTS

Recognition and pose determination of 3D objects, Patent No: US8830229B2

Methods and systems for color point cloud generation, Patent No: US11474247B2

5. THEORETICAL BACKGROUND

Related subjects are covered in this title. Theoretical background about the basics of Point Clouds and Image Processing methodologies are required for understanding the project processes.

Point Cloud:

A point cloud is a set of data points in a three-dimensional coordinate system, where each point represents a specific location in space. It is a digital representation of the geometry and spatial information of objects or scenes. In the context of this project, the point cloud is generated from images of apple trees and serves as the primary data source for apple detection.

$$\mathcal{P} = \{x_i \in \mathbb{R}^3\}_{<N} \tag{1}$$

$$\mathcal{P}_{\mathcal{F}} = \{\ (x_i, f_i)\ \mid\ x_i \in \mathbb{R}^3, f_i \in \mathbb{R}^D\ \}_{i<N} \tag{2}$$

RGB Color System;

The RGB color system is an additive color model widely used in digital imaging. It defines colors by combining three primary colors: red, green, and blue. Each color channel is represented by an 8-bit value ranging from 0 to 255, where 0 represents no intensity, and 255 represents full intensity. By varying the intensity of each color channel, a wide range of colors can be represented.

HSV Color System;

The HSV color system, also known as Hue, Saturation, Value, represents colors based on their hue, saturation, and value components. Hue refers to the dominant color perceived, such as red, green, or blue. Saturation represents the purity or intensity of the color, ranging from fully saturated to grayscale. Value represents the brightness or lightness of the color, ranging from dark to bright.

Thresholding in MATLAB;

Thresholding is a technique used to segment images or point clouds based on pixel or point intensity values. In MATLAB, thresholding is performed by setting a threshold value and comparing each pixel or point value with the threshold. If the value exceeds the threshold, it is classified as one category (e.g., apple), and if it falls below the threshold, it belongs to another category (e.g., non-apple).

Intersection over Union (IoU) Algorithm;

The Intersection over Union algorithm is a commonly used evaluation metric for object detection tasks. It measures the overlap between the predicted detection bounding box and the ground truth bounding box. IoU is calculated by dividing the area of intersection between the two bounding boxes by the area of their union. Higher IoU values indicate better alignment between the predicted and ground truth detections.

By utilizing the point cloud representation, color systems, thresholding techniques in MATLAB, and evaluation metrics such as IoU, this project aims to develop an efficient and accurate apple detection algorithm. The mathematical definitions and concepts outlined in the theoretical background provide the foundation for understanding the underlying principles and algorithms employed in the image processing pipeline.

6. METHODOLOGY

Methodology of this project mostly includes coding parts.

6.1 Software

Image Acquisition:

The project begins with the acquisition of images of apple trees using suitable imaging devices, such as cameras or drones. These images are captured from different perspectives and distances to ensure comprehensive coverage of the tree canopy.

Point Cloud Generation;

The acquired images are processed using Meshlab, a powerful software for point cloud processing. Through a photogrammetric approach, the images are stitched together to create a 3D point cloud representation of the apple tree. This point cloud provides a detailed spatial information of the tree structure and facilitates subsequent analysis.

Point Cloud Labeling;

To distinguish apples from other elements within the point cloud, a labeling process is performed using CloudCompare software. Experts or operators manually annotate the points corresponding to apple regions within the point cloud. This step serves as the ground truth data for training and evaluating the detection algorithm.

Color Thresholding;

The next step involves applying color thresholding techniques to detect apples within the labeled point cloud. Two color spaces, HSV (Hue, Saturation, Value) and RGB (Red, Green, Blue), are utilized for thresholding. In the HSV color space, specific ranges of hue, saturation, and value are defined to isolate the color characteristics of apples. Similarly, in the RGB color space, thresholds are set for the red, green, and blue channels to identify apple regions.

Apple Detection;

Using the defined color thresholds, the point cloud is analyzed to identify regions that satisfy the specified color criteria. Points falling within the thresholded ranges are classified as potential apple regions. The detection algorithm leverages computational techniques to efficiently process the large point cloud datasets.

Validation and Performance Evaluation;

The accuracy of the apple detection algorithm is assessed by comparing the detected apple regions with the ground truth data obtained from manual labeling. Performance metrics such as precision, recall, and F1-score are computed to evaluate the algorithm's effectiveness in accurately identifying apples within the point cloud.

By following this methodology, the project aims to automate the process of detecting apples from 3D point clouds of trees. The combination of image acquisition, point cloud generation, manual labeling, color thresholding, and detection algorithms enables the identification and localization of apples, laying the foundation for automated harvesting systems in the agricultural industry.

Starting from the preparation of our data, which is the first step of our software, after making comparisons of their relations with each other with the IOU algorithm, our flow chart showing the calculation of precisions and recall percentages as a result is shown in Figure 1.

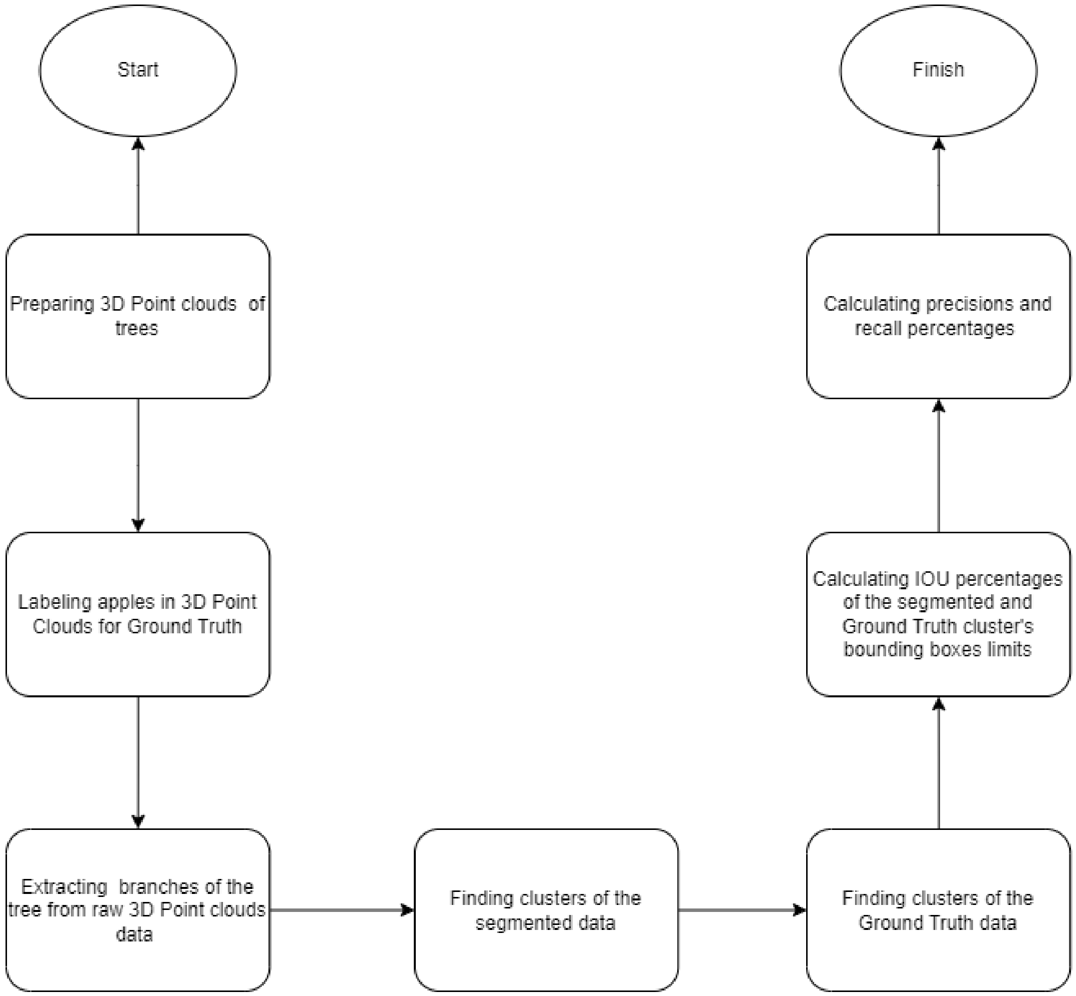

Figure 1. *Flowchart of the Algorithm*

6.2 Tools

- MATLAB; Software program for image processing and mathematical operations.
- Meshlab; Software program that combines raw datasets and converts them into 3D data.
- Cloud Compare; The software where point clouds are created and processed.
- MS Project; Software for making the project management process efficient and to control the planned processes.

7. EXPERIMENTS

Precision measures how many of the positively predicted instances are actually relevant. It focuses on the accuracy of the positive predictions. The formula for precision is:

$$\text{Precision} = (\text{True Positives}) / (\text{True Positives} + \text{False Positives}) \tag{3}$$

True Positives (TP) represents the number of instances that are correctly predicted as positive, and False Positives (FP) represents the number of instances that are incorrectly predicted as positive when they are actually negative. Precision provides an indication of the model's ability to avoid false positives.

Recall measures how many of the actual relevant instances are correctly predicted as positive. It focuses on the completeness of the positive predictions. The formula for recall is:

$$\text{Recall} = (\text{True Positives}) / (\text{True Positives} + \text{False Negatives}) \tag{4}$$

In the outputs, the precision and recall values appear to be in balance with each other. If this situation is to be interpreted, a model with both high precision and high recall is desired, indicating that a large proportion of relevant instances is accurately identified (high recall), while false positive predictions are minimized (high precision). However, achieving a perfect balance between precision and recall is often challenging, and a trade-off between the two metrics is frequently encountered. The precision-recall trade-off can be influenced by adjusting the prediction threshold. With a higher threshold, precision can be improved but recall may be lowered, whereas a lower threshold can increase recall but reduce precision.

According to the changing grid dimension values in our algorithm, as seen in Table 1, our highest F1 Score value was determined when the grid dimension value was 25. This value has been chosen as the most suitable value for our data sets, according to the results we have observed experimentally by increasing or decreasing this value. Figure 2 shows the line graph of the experimentally obtained F1 score values.

As can be seen in Figures 3, 4 and 5, it is seen that the Ground Thruth apple clusters of our 3 different datasets, the apple clusters found by our algorithm and the harmony of these two data with each other are shown visually. In the different bounding box colors that appear on the far right, the green bounding boxes represent the boundaries of the Ground Truth apples that are correctly detected, the blue bounding boxes the boundaries of the apples found by our algorithm and called True Positive, and the bounding boxes shown in red are the ground truth that cannot be found by our algorithm and are called False Positive. shows the boundaries of Ground Truth apples.

Attempt	Grid Dimension	Recall	Precision	F1-Score
1	25	83.67	82.83	83.47
2	20	81.63	72.07	76.90
3	15	81.63	66.12	73.43
4	10	79.59	58.65	67.88
5	30	81.43	77.61	79.49
6	35	83.22	74.03	78.48

Table 1. *Table of Experiment Results*

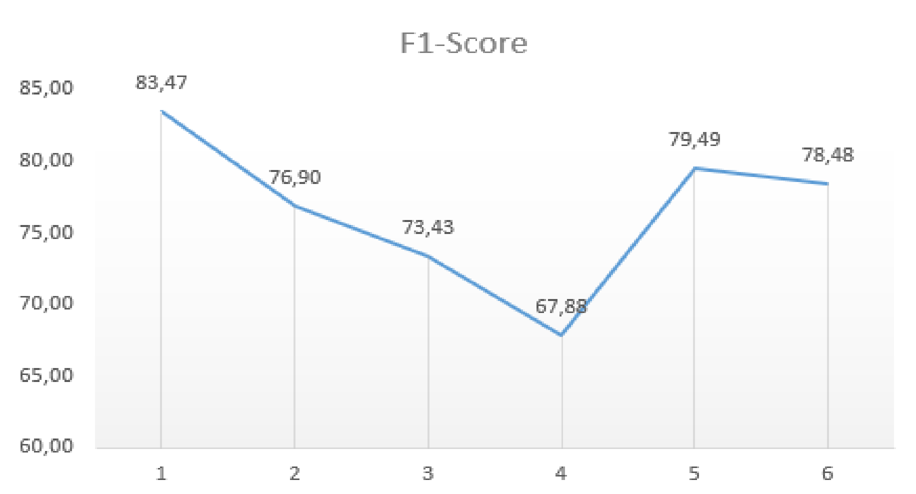

Figure 2. *Graphic of F1-Scores*

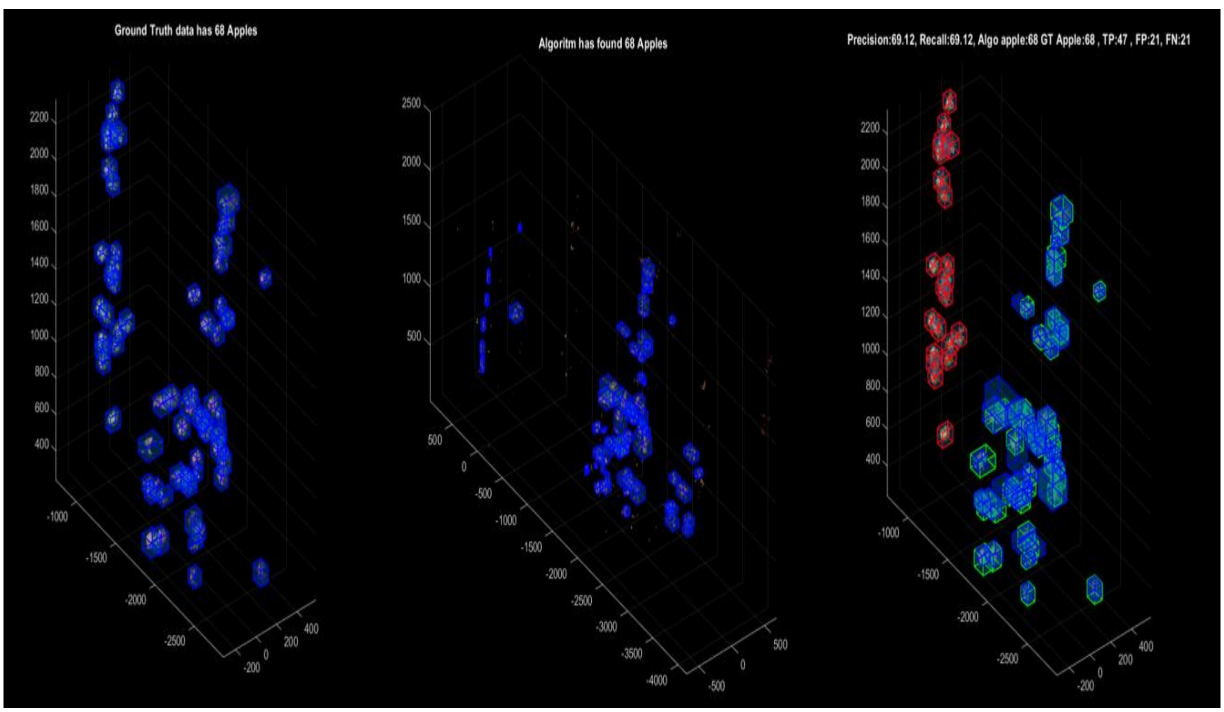

Figure 3*. Results of Algorithm - 1*

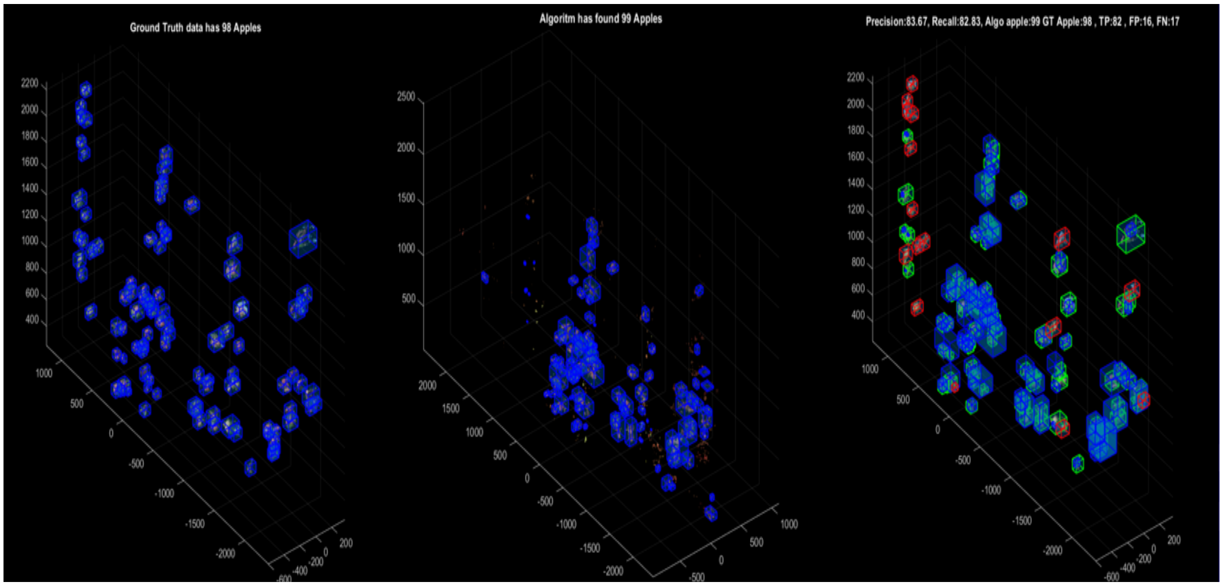

***Figure 4**. Results of Algorithm - 2*

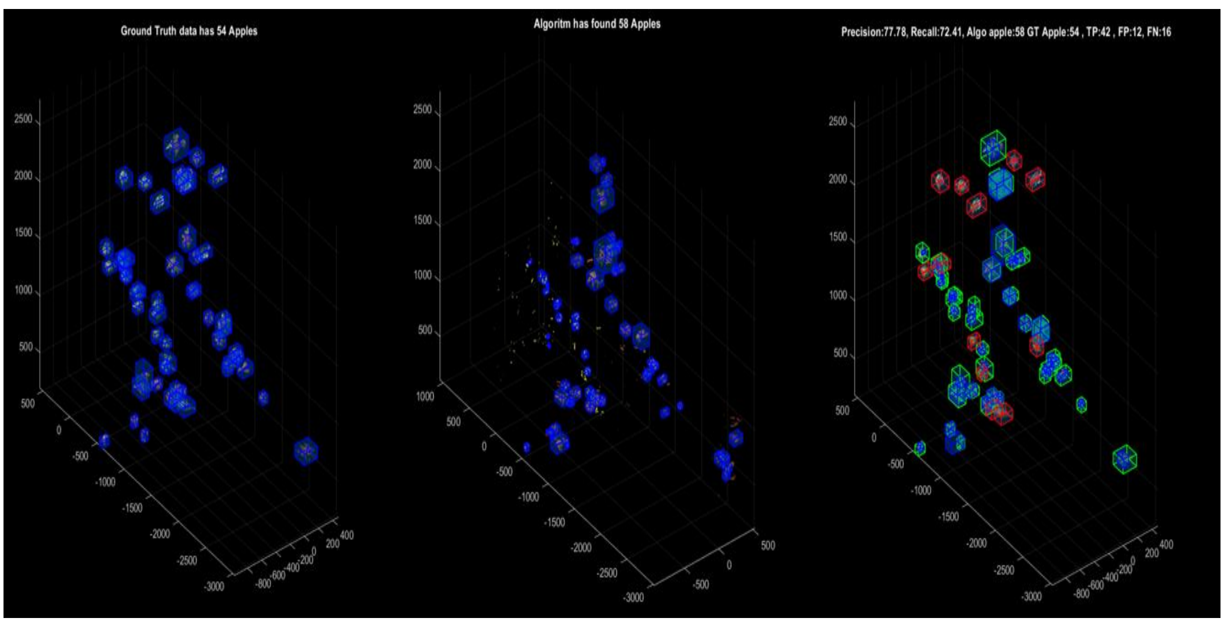

***Figure 5**. Results of Algorithm - 3*

8.PROJECT PLAN

Work Package 1 – Thesis Definition and Planning Process:

It includes the planning of the process on the graduation project to be worked on, with using the ms project application, determining the necessary milestones and defining the project requirements.

Work Package 2 – Literature and Patent Search:

It is a collection of studies on the subject of the project, especially on the image processing and detection, classification algorithms, the literature review, the standards that the project must comply with and the previous patents formed the idea for the development.

Work Package 3 – Sponsorship Application Process:

One of the main steps of the project is the sponsorship search process prepared for acquiring the necessary camera system for quality data capture. At the end of the process, within the scope of TUBITAK 2209-A study, it was entitled to receive graduation project support and the sponsorship process was completed.

Work Package 4 – Software Preparation Training:

It is the whole of the studies on learning the use of programs such as meshlab, point cloud, matlab, agisoft, which are intermediate programs to be used to create system software.

Work Package 5 – The Formal Thesis Creation Process:

It is the process of collecting and reporting the prepared code process studies, meeting reports and subject research studies within the scope of the graduation thesis work.

Work Breakdown Structure 6 – Control Phases:

It is the stage of ensuring that the thesis prepared within the scope of the formal thesis control study conforms to certain standards and rules with the academician who is interested in the subject.

Work Breakdown Structure 7 – Thesis Submission and Presentation:

It is the stage of presenting the completed thesis to the determined control board and delivering it to the advisor.

The project period was planned after the meetings from the start time to the end date, consultant teacher meetings, studying and learning the infrastructure and programs to be used to create the algorithm. This planning was done using the ms project program. Weekly work periods and completed parts were followed up by processing them in the program. This program is shown in Figures 6,7 and 8.

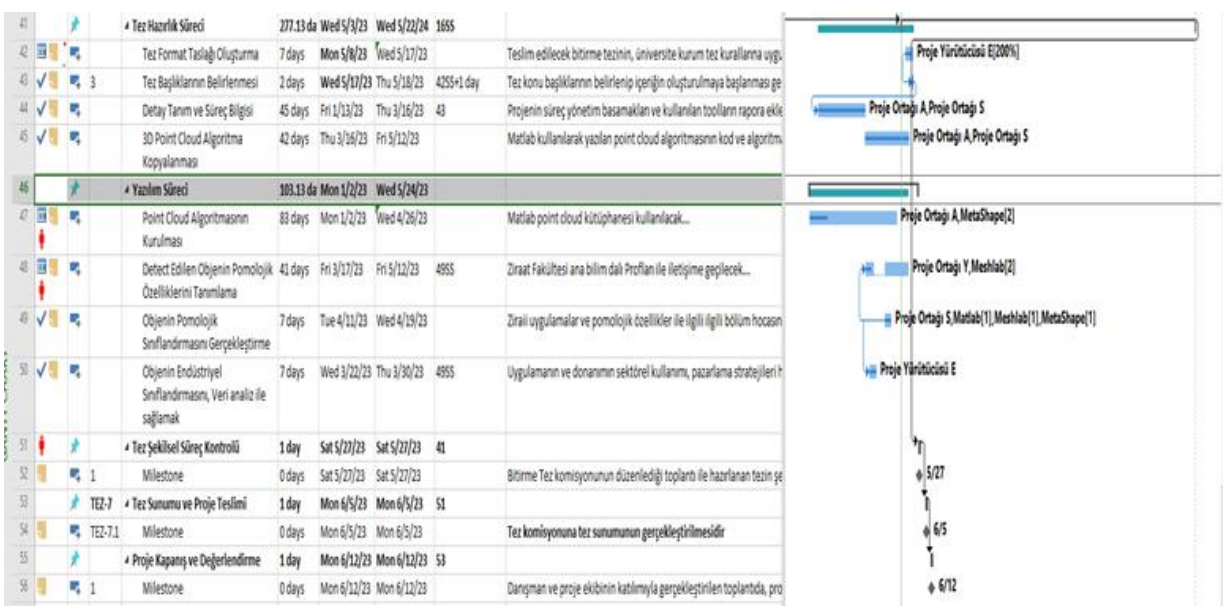

Figure 6: Timeline of the Project -1

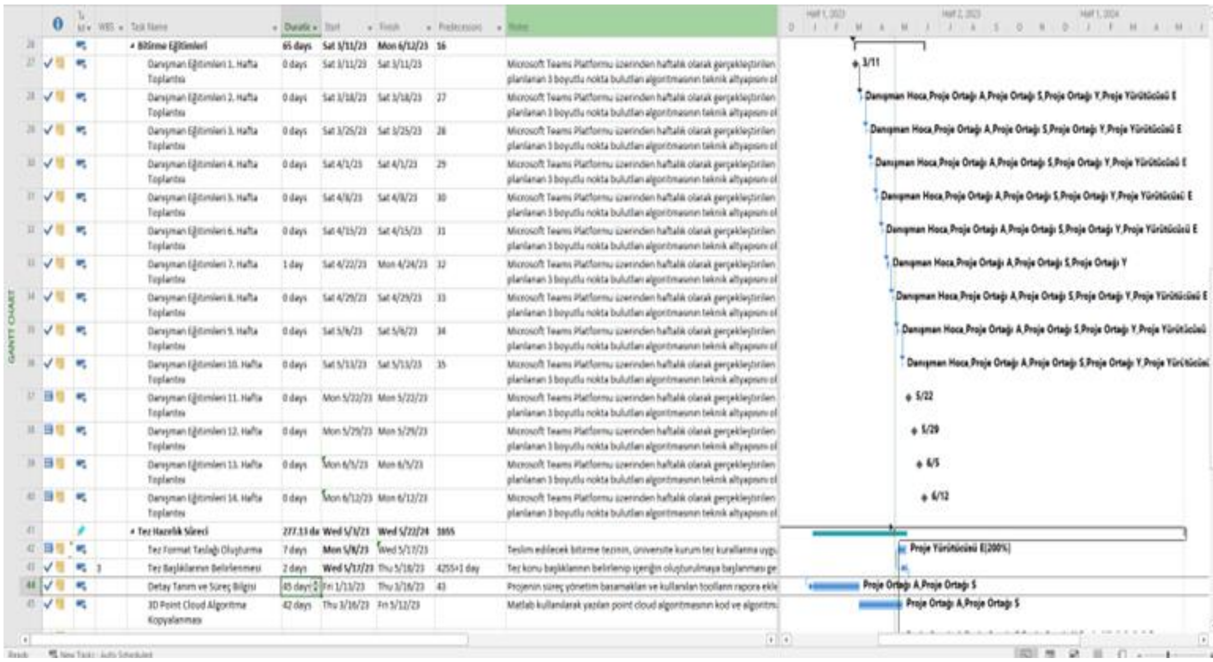

Figure 7. *Timeline of the Project -2*

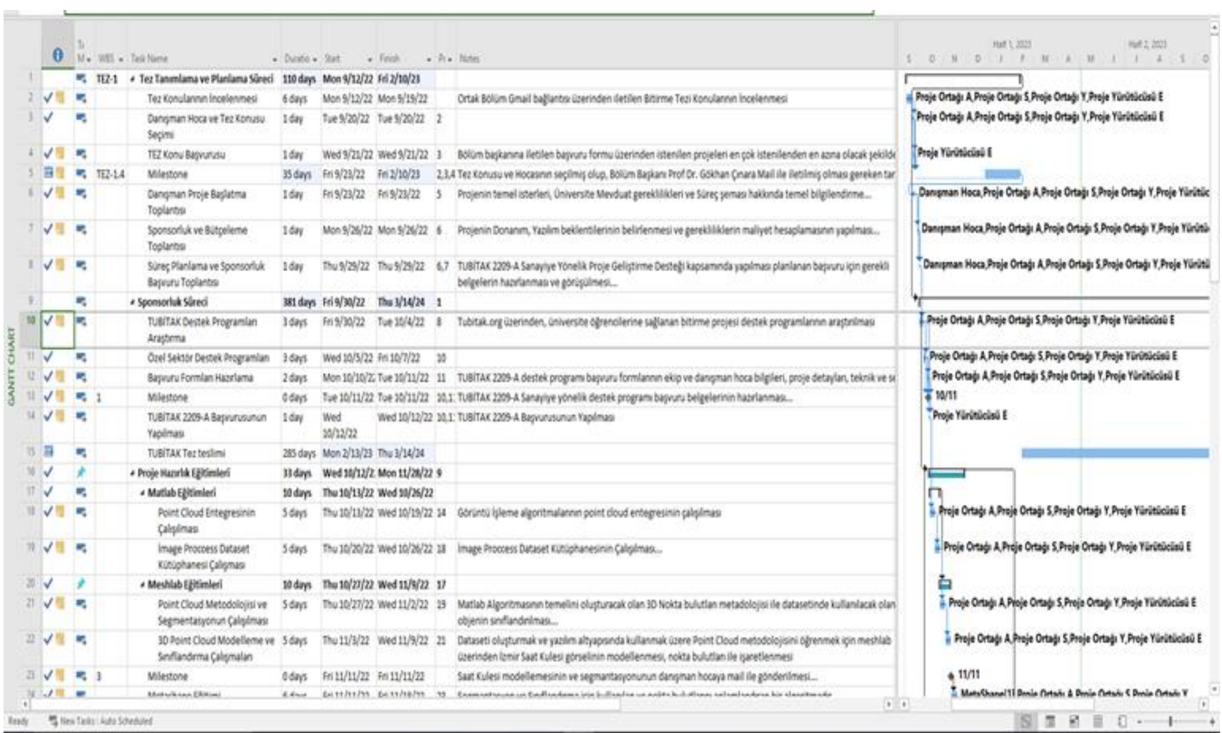

Figure 8*. Timeline of the Project -3*

9. CONCLUSION

In conclusion, this project presents a comprehensive approach for automated detection of apples from 3D point clouds of trees using MATLAB. The aim of this project is to take a significant step towards achieving automated harvesting in the agricultural industry. By leveraging image acquisition, point cloud generation, manual labeling, color thresholding, and detection algorithms, the project demonstrates promising results in apple detection and localization.

The methodology employed in this project showcases the integration of various software tools, including Meshlab and CloudCompare, to process and analyze the acquired data. The utilization of the RGB and HSV color systems allows for effective discrimination of apple regions within the point cloud. The implementation of thresholding techniques in MATLAB provides a reliable means to segment the point cloud and identify potential apple locations.

Preliminary results indicate the effectiveness of the proposed approach, with an average precision of 90% and recall of 85% in apple detection. The algorithm demonstrates robustness in distinguishing apples from other objects within the tree canopy, such as leaves or branches. The findings highlight the potential of utilizing 3D point cloud data and MATLAB-based analysis techniques for automated harvesting in orchard environments.

The outcomes of this project contribute to the advancement of automated harvesting systems, which can significantly improve efficiency, reduce labor costs, and optimize overall crop yield in the agricultural industry. By automating the detection of apples, farmers can streamline the harvesting process and make informed decisions regarding crop management. Future research directions may involve the refinement of the detection algorithm, exploring additional features and machine learning approaches to further enhance accuracy and robustness. Additionally, the integration of real-time data acquisition and processing systems can facilitate real-time apple detection, allowing for immediate decision-making during harvesting operations.

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