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Toward Sustainable Harvests: Designing an Automated Picking Robot for Peaches

Parameters Analysis and Theoretical Robot Design for Peach Variety Baby Gold 9

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Abstract

The high prices of fruit and the hard work of the pickers create a need for automation in the fruit picking process. In this paper, a solution for the harvesting of the BabyGold9 peach variety is proposed. For this purpose, the main characteristics on which a correct automation depends are analysed and different solutions for the three main systems are discussed. According to the identification system, the YOLOv8s-P software is proposed, which will capture images using Real Intel Sense D43Di cameras. The navigation system is divided into two sub-systems, one in charge of mapping the environment and knowing the location and the other one who plans the routes to the peach. To tackle both tasks, the Gmapping software has been proposed with the T265 camera that will map the environment and the RRT* algorithm which is in charge of creating routes avoiding obstacles. A cost estimation and a performance evaluation will be presented in order to know what minimum requirements the robot should have in order to be able to replace human beings. Finally, a commercial end-effector and manipulator have been chosen for the picking system. These are a three-finger soft end-effector developed by the company SoftGripping and the UR5e robotic arm developed by Universal Studios. Finally, an explanation of how it should be tested and the necessary parameters to be analysed is given.

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Acronyms

AGG Adaptive Genetic Grouping. 24

AI Artificial intelligence. 9

DoF Degrees of Freedom. 35, 42

EAPs Electroactive Polymers. 28

EMM Efficient Multiscale Module. 21

EU European Union. 7

FPN Feature Pyramid Networks. 21

FW Fresh Weight. 17

GA Genetic Algorithm. 24, 25

GDP Gross Domestic Product. 7

GPS Global Positioning System. 10

HSI Hue, Saturation, Intensity). 18

HSV Hue, Saturation, Value. 18

IoU Intersection over Union. 20

IPMC Ion-exchange Polymer Metal Composite. 27

ISPAG International Society of Precision Agriculture. 8

LCEs Liquid Crystal Elastoemers. 28

LiADAR Light Detection and Ranging. 10, 42

NIR Near InfraRed. 17

OMPL Open Motion Planning Library. 24

OMS Word Health Organization. 7

PA Precision Agriculture. 8

PAN Path Aggregation Network. 21

PSO Particle Swarm Optimization. 10, 24–26

RGB Red-Green-Blue). 10, 18

RI Ripening Index. 17

ROI Region Of Interest. 11, 19, 37

ROS Software Robot Operating System. 36, 37, 39, 42

RRT Rapidly-exploring Random Trees. 24, 25

RRT* Rapidly-exploring Random Trees improved. 10, 24–26, 37, 40, 42

SA Simulated Annealing. 24

SLAM Simultaneous Localization And Mapping. 10, 24, 37, 40, 42

SMA Shape Memory Alloy. 27

SMMs Shape Memory Materials. 28

SOTA State Of The Art. 20

SPPF Spatial Pyramid Pooling-Fast. 21

SSC Soluble Solid Content. 17, 18

SVG Soft Vacuum Gripper. 27

T-RRT Time Rapidly-exploring Random Trees. 24

TA Titratable Acidity. 17

Introduction

Society’s growing interest in a healthy lifestyle is directly linked to the consumption of fruit. Scientific sources confirm that a diet rich in fruit helps humans to avoid multiple heart diseases or to prevent cancer and diabetes, among others. The OMS recommends the consumption of 5 pieces of fruit per day. However, in the EU only 12 % of citizens consume this amount. Despite society’s social awareness of healthy eating, can BE observeD a downward trend in fruit consumption at European level [54].
To take Spain as an example, fruit consumption has fallen by 14% in the last 10 years [48]. Several reports have analysed the possible causes of this decline. Mainly, they focus on two; the first one deals with how the consumption of fruit as a dessert is being supplanted by dairy products or ice cream, which do not rot so quickly. The second hypothesis is price growth. To quote the words of Carlos Fernández, a specialist in public health at the Carlos III University:
”The price of fruit has risen by 12% from 2013 to 2019, more or less the same as its consumption has fallen” [48].
Not only is there a problem with price, the other major issue is working conditions.There are a number of significant risks that are detrimental to the health of the worker, in most cases a migrant worker.The action of picking involves awkward postures and the movement of heavy loads, which can damage the health of the person. Moreover, must be added the harsh weather conditions to which they are subjected to. In addition to physical overexertion, there are low wages. The vulnerable situation of the workers evokes an acceptance of these harsh and low-paid working conditions [2].
This situation poses a number of challenges in society. Considering that Spain is the leading exporter in the EU and the second in the world [64], it is a problem that must be solved. The importance of the agricultural sector in Spain is also reflected in the national GDP, where the Fisheries and Agriculture sector plays an important role with 2.5% of the total [59].The most exported fruit is the orange, followed by the mandarin. Immediately below, can be found the lemon, melon and strawberry. Lastly, in seventh and eighth place are nectarines and peaches [76].
The aim of this article is to carry out an analysis of the parameters necessary for the automation of fruit picking and the design of the main systems of a robot capable of picking peaches, in particular the variable BabyGold 9 . The main parts of the robot are: Navigation System, Identification algorithm and Picking system. The reason for focusing the study on the peach fruit is due to the challenges involved. There are difficulties in harvesting them due to the fact that they grow in a changing and dynamic environment . Moreover, it is needed a precise selection, due to their fragility and their point of ripeness. The final aspect of why research is focused on peaches is the opportunity for innovation in the sector. There are numerous studies on automatic harvesting many different types of fruit, however there is a gap in the peach sector.In order to develop an accurate and efficient robot, the paper will be focused on the BabyGold 9 variable. This specific approach will allow to quantitatively detail the variables that characterise this type of peach. BabyGold 9 is a very popular variety due to its high yields and good taste. The large presence of this peach in the markets adds another incentive to develop an automatic harvesting system.
The article will look at the creation of an automaton by addressing the following questions:

- Qualitatively, which parameters are important for automation in fruit picking?
- What are the challenges in automating this process?
- What are the essential physical and software components needed for the successful implementation of automation in fruit harvesting?
- Which parameters characterise BabyGolg 9, evaluated quantitatively?
- What elements are necessary to ensure the efficiency and correct functioning of the automaton?
- What are the criteria and ranges used by the software and elements to success in peach harvesting?
- How will the robot be evaluated? Which are the parameters analyzed?

The methodology followed consists of a review of the literature on the parameters needed to self-match the fruit picking. Subsequently, a specific study will be carried out on the peach, by reading up on the

characteristic aspects of the fruit. These extensive literature research have been found in the platforms ResearchGate,Semantic Scholar and ScienceDirect. Finally, a documentation of all the research work previously carried out will be done.
The article follows an orderly and clear structure. The first chapter will give the reader a theoretical background on the evolution of fruit picking methods, an overview of robot architecture and softwares and a description of the harvesting process. The following section will be carried out a study of parameters influencing automation. Inside the third chapter, can be found the limitations that currently exist in automated fruit picking. The fourth chapter will be discussed the practical case of study: Designing an autonomous Peach Picking Robot. In this section, a brief explanation about the robot architecture will be done, moreover will be gone into detail on the parameters that define the BabyGold 9 variable and will be proposed various software and components that will carry out the third main functions of the robot: identification of the fruit , navigation and the fruit picking system. It will be also found an analysis of costs and minimum services. Finally, it is included an evaluation of the theoretical performance of the robot proposed.The last chapter will be the conclusion. A compilation of the main ideas of the article together with a critical analysis of the feasibility of implementing such a robot will be carried out.

1 Backgrounds

1.1 Types of automatising

Mechanisation in fruit process began to develop in the 1907s with the introduction of monitoring and control methods [39] . However, it was not until the 1990s that PA (Precision Agriculture) appeared. According to ISPAG [62] ,this term is defined as:
"Precision Agriculture is a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production".
The creation of robots that can use this strategy helps to increase the efficiency of the process giving society a solution to high fruit prices.In addition, labour shortages in developed countries due to harsh conditions and low wages mean that automation in fruit picking is increasingly in demand [6].
However, the automation of this process is not entirely straightforward. The high investment cost, the numerous types of crops that exist, the ripening point of the fruit and the possibility of damaging the fruit during harvesting make this practice a difficult task. All these impediments will be developed in the following.
The mechanisation of fruit processing has evolved slowly over the years. Initially, harvesting was carried out without any help, only with the manual labour of the workers. Progressively, mechanical elements appeared that facilitated harvesting, such as ladders with three supports that facilitated access to the highest parts of the trees. Forklifts for transporting fruit also underwent an evolution. The first ones only transported a certain amount of fruit from one point to another, while the current ones are able to detect the amount of fruit picked and automatically fill pallets. Today, lifting platforms can be seen in most orchards.Platforms are used to transport users and facilitate access to high areas of the trees. They reduce operator fatigue and increase productivity. They are composed of cabin at the end of a hydraulic arm.Can be found single and multiple platforms [65].

1. Individuals are used for high trees but cannot transport a large number of boxes. They are usually self-propelled.

2. Multi-platforms can be operated by several people, thus increasing picking efficiency. They consist of two platforms, a fixed platform and a rear platform that can vary in height.

3. Multiple platforms with conveyor belts. The main difference with the multiple platforms is the incorporation of conveyor belts.

Apart from platforms, there is an element widely used in greenhouse, the conveyor belts. They simply help the operator to place the fruit on the conveyor belt, which transports it to the desired location. In some occasions, they can be used in orchard or open field.

(a) Individual Platform

(b) Multiple Platform

Image 1: Platforms as an aid for fruit picking. Source [65]

Nowadays, thanks to the advancement of technology , can be found mainly two methods of automation: bulk harvesting and selective harvesting [11].

Bulk Harvesting is applied when the objective is a massive harvesting of fruit, i.e. harvesting in large quantities. This method is based on shaking the trees to loosen the fruit from the tree and then harvesting it. It is a very efficient technique that reduces the cost of the fruit. However, the main problem is the damage caused to both, the trees and the fruit [11]. For this reason, bulk harvesting is commonly used to pick fruit for being used in juices, jams or sauces. In addition, fruits that are not yet at the point of ripening also fall with this vibration method. This process is commonly used with oranges, apples or olives.

Selective harvesting is a method that is based on the individual harvesting of fruit that is in perfect condition for picking. With AI this machinery has the potential to completely replace humans.

	Bulk harvesting	**Selective Harvesting**
Technique	Shaking	Picking one by one
Fruit Damage	High	Low
Efficiency	High	Low
Application	Juice, jams or sauce productions	Fruits in pallets

Table 1: Comparison between types of automation. Source Author.

After analysing both methods, the following conclusions can be drawn: the bulk harvesting method has many advantages, especially its efficiency, as it harvests an enormous amount of fruit in a short period of time. However, its disadvantages are very noticeable. The damage to the fruit means that the fruit can only be used for processing into juice or jam. It is not only the damage done to the fruit but also to the trees. Finally, this technique is very limited.The amount of damage done to the fruit can be reduced by controlling the shaking force , however there is no way to control which fruit fall from the tree and which do not.

Selective harvesting is not as efficient as the method mentioned above. Moreover, the economic investment in these machines is higher due to their complexity.Adding that the problem of damaging the fruit does not disappear, although it is less than in bulk harvesting. Other factors such as the low cycle time and success rate prevent these techniques from revolutionising the market.Despite this, the idea of a robot being able to harvest the desired fruit means that this technique has a very high potential for improvement. The rise of AI and more precise sensors means that the future of automation in harvesting is increasingly heading in this direction.

1.2 Overview of Robot Architecture and Softwares

The complexity of these robots is high. Nevertheless, this section will try to give a brief overview of the design strategies for these robots. The design of these machines is based on three systems: (i) navigation, (ii)identification and (iii) picking system. [43].

(i)Navigation system

The navigation system allows the robot to know its location and create a 3D map of the environment . The other task is creating paths for harvesting fruits. Therefore, navigation system can be dived into SLAM algorithm that manages the first two task and path planning algorithm that is in charge of creating routes to the fruit avoiding obstacles. Depending on the cultivation system, the robot will have to deal with different difficulties. To cope with these challenges, numerous SLAM systems help these machines to avoid collisions and trace the correct route.

- LiADAR (Light Detection and Ranging)
  System based on the emission of lasers in order to create a 3D model to choose the correct route.
- GPS and GPS:
  Robots use satellite signals to create a route. GPS (Real-Time Kinematic) technology is used to know the situation of the robot in the field and to be able to act according to its position
- Ultrasonics:
  Sound waves measure the distance to objects to intercept possible collisions.
- Visual Navigation:
  Use of cameras to detect possible obstacles. This system also gives you an advantage in that you can observe the ripening point of the fruit.
- Impact navigation:
  Sensors that act by touch. They detect collisions and correct the route.
- AI-based autonomous navigation:
  This is the most comprehensive. It integrates all the above-mentioned types of sensors and makes decisions for fruit picking or route traceability.

Path Planning are the systems responsible for designing the routes to the fruit. There are different algorithms to avoid obstacles and reach the target: A*, PSO, RRT, RRT*, AG... The selected algorithm must be a balance between speed to be able to act in real time and pressure to avoid collisions.

Identification System

The identification system is in charge of detecting the fruits.A variety of technologies, including cameras and sensors, are used to deetct the fruit.

- RGB (Red-Green-Blue) cameras
- Multi-spectral cameras
- 3D sensors

Picking System:

This system takes care of picking the fruit from the tree. It can be divided into two parts, manipulator and end-effector. The creation of these grippers is complex due to the number of factors that must be taken into account: Adaptation to different shapes, minimum force exerted so as not to damage the fruit, good grip, low weight, easy extraction of the fruit...Taking into account this series of requirements, there are mainly three grippers available in the industry:

- Electric grippers
- Pneumatic grippers
- Hydraulic grippers

In addition, apart from taking into account how to pick the fruit, in some occasion there is the need of incorporating a cutting system. There are several cutting systems:

- By Laser: A laser diode makes the cut.
- Thermal cutting: By means of a voltage difference, an electric arc is created that cuts the stalk.
- Mechanical cutting: A simple blade separates the fruit from the stem.

1.3 Harvesting Process

Now that the three main systems are known, this sub-section will describe the collection sequence in a clear and summarised way.

1. The robot with its software and localisation sensors starts to navigate its environment, **Navigation system**.
2. While it circulates through the columns, the **identification system** works detecting possible targets by cameras.
3. The **identification algorithm** recognises a region of interest (ROI) where it seems that there are fruits in the optimal state for picking.
4. The robot thanks to the **navigation system** approaches this region.
5. Possible routes to reach the fruit with the arm are created thanks to the **navigation system, path planning algorithm**, the **picking system** is activated by moving the robotic arm.
6. Once the sensors detect that the end-effector is at a short distance from the target, it acts and picks the fruit.
7. The fruit is deposited in a storage system and the process is repeated for the next fruit.

2 Identification of main parameters

The automation of fruit picking is a complicated task, requiring meticulous study of the variables that influence the process. These factors cover multiple areas, from the environment in which the fruit is grown to the physical attributes of the item. This section will examine the importance and impact of each of the parameters necessary to develop an efficient, accurate and safe automated system.

2.1 Cultivate system

One of the main factor to develop automated robot is an analysis of the environment. It is necessary to know under which conditions robots must work. Can be classified the different environments into three cultivation systems: open field , greenhouse and orchard.
In open field, vegetables are grown in rows from the ground 2(a).
An orchard environment is a fruit tree plantation where there is no control on soil surface and possible obstacles 2(b).
Greenhouse, it is an installation where the fruit grows under controlled parameters and the infrastructure allows easy access to the fruit 2(c).
Not taking into consideration, advantages and disadvantages in terms of colour, taste and quality of the fruit, mechanisation in the harvesting of fruit in greenhouses is much simpler than in open fields or Orchard. Elements such as uneven ground, branches, leaves and trunks mean that accessibility to the fruit is not the best, making the robot's work difficult [8]. The crucial aspect in addressing this issue is to enhance the navigation patterns.

(a) Open field photography. Source [63].

(b) Orchard photography. Source [52].

(c) Greenhouse photography. Source [73].

Image 2: Production environment. Source Author.

Not only the type of crop is important, but also the distribution of the plantation. The distribution of trees in the rows affects the quality of the fruit and the accessibility of the robot. Therefore, the efficient implementation of an automatic fruit picking robot must be carried out in a field with sufficient tree and row spacing to allow the robot to perform its functions optimally.
It is important to mention that there are also different patterns, in addition to the well-known straight line pattern, there are also grid or trellis patterns. The specific characteristics of the trees must also be taken into account in order to ensure a high success rate in fruit picking. Possible interferences due to the shape of the trees must be carefully analysed. There are numerous geometrical shapes of trees: conical, cylindrical, irregular, spherical, etc. Depending on the geometry, a fruit picking system will be created that is able to adapt to the geometry without damaging either the tree or the fruit.
The height of the trees and their fruit is another characteristic parameter in their harvesting. Must be known under which range our robot should operate, being able to reach the fruits in higher positions and those growing at the bottom of the trees.

2.2 Type of fruit: Size and geometry

The shape and geometry is a crucial factor in automating this process as it directly affects the accuracy, success rate and efficiency of the robot. The geometry will determine the gripper of the robot. The design must be made in such a way that it ensures fast picking, gripping the fruit without damaging it.
Fruits do not have perfect geometries, however, it is possible to model their shape in a perfect geometry to design the gripper and make simulations. The table 2 will show the different shapes of fruit that can be modelled.
Not only the shape, but also the texture is a parameter that must be taken into account. There are fruits such as peaches, which have a rough skin that favours adhesion. However, fruits such as bananas or mandarins have a smooth surface, which can make it difficult to grip.

Shape	**Examples**
Spherical	Apples, Oranges
Elongated or Conical	Bananas, Cucumbers
Irregular or Asymmetric	Strawberries, Avocados
Flat or Oblong	Cherries, Grapes

Table 2: Fruit Shapes and Examples. Source Author.

2.3 Movement carried out

Another key factor is the movement exerted to separate the fruit from the tree. Depending on the cultivation system, different type of harvesting will be carried out . Mainly, fruit harvesting is carried out either by twisting or pulling with the wrist or with the help of some mechanical element such as blades. It is important to be clear about what type of fruit it is and how it is picked manually to simulate the movement with the robot. For fruits that require an auxiliary element, such as peppers, the type of tool used must be chosen. While the fruits to be picked without the need for any tools, the robot must possess sufficient degrees of freedom to perfectly mimic the movement of a human, taking into account the movement exerted and the pressure applied.

2.4 Point of ripeness

The organoleptic quality of peaches is determined by factors such as climate, soil or variety. All these characteristics determine the moment when the fruit is harvested, that is to say, its ripeness.
Ripeness is the factor that most determines the commercial life and final quality of the fruit. Immature fruits are more prone to mechanical damage and are of poor quality, while overripe fruits become too soft and tasteless.
According to the study [28], the ripening point of fruit depends on external aspects such as colouring or firmness and internal aspects such as the amount of sugar and acidity.
Firmness is a key characteristic for fruit picking. Damaged foodstuffs are destined for the creation of juices and jams, losing part of their economic value. This fact means that the force exerted and the movement carried out is of great importance in the automation of the process. Traditionally, firmness measure has been done with instruments and destructive tests in the factories themselves. However, nowadays there are non-destructive techniques: by acoustic sensors [45] and by vibrational spectroscopy [40], capable of analysing the firmness in real time. The aim of the robot will be to pick the fruit with the lowest rate of damage to the fruit.
Colouring is the parameter by which the operators are guided. Depending on the condition of the fruit, the workers decide whether to pick it. In red fruits, an optimal colouring is related to low chlorophyll content.
Sugar and acid levels can help to know the quality of the fruit and its taste once it has been harvested.

3 Limitations in Automated Fruit Picking

The reason why these robots are not yet collapsing agricultural markets is due to three factors: harvest success rate, cycle time and damage rate. In order to be able to define these problems this study will rely on the paper [11] where he mainly analyses the results in orchards and open field. The data used in the analysis of the performance of robots in greenhouses is provided by the study [8]

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- **Harvest success rate**
  Quantifies the number of correctly harvested ripe fruits per total number of ripe fruits on the tree. This parameter is mainly influenced by two factors. Cultivate system and fruit type. On average, harvesting robots have a hit rate of 66 %. These low hit rates are mainly due to the high slight of occlusion. Another factor is the collisions of the end- effector with the plant. Regarding orchard picking, more advanced studies can be found in fruit and apple picking.An apple robot designed by [44], has a hit rate of 84%. A significant increase compared to the other studies. This increase in the success rate is due to the improved end-effector.

- **Cycle time**
  It measures the fruit picking time, from the time it recognises the fruit, picks it up and moves on to another fruit. The picking time is relatively short, i.e. it is comparable to manual picking time. The leaders in achieving short times are Octinion company (2019), HarvestCROO Robotics (2020), and Abundant Robotics (2019). Adding multiple mechanical arms to the robot further reduces this time, depending on the type of fruit, and the ease of damage, fruits such as apples have a shorter cycle time than strawberries. Talking about real cases, according to FFRobicts argues that thanks to its robot's

12 arms, picking is faster than a human being [56]. The Xiong company has achieved times of 4.6s per fruit and Harvest CROO's company has developed a robot capable of picking 3 fruits every 10s of seconds.

- **Fruit damage rate**
  This parameter quantifies the number of damaged fruit. A wide dispersion of percentages can be observed, some of them alarming, 32.30% in the harvesting of apples or 25% in kiwis, and others encouraging, such as 5% damage in the harvesting of kiwis or apples in some companies. Another form of damage during harvesting is the damage caused by the robot hitting the trees. Moreover, the possibility of damage to the robot due to the terrain must be taken into account.

4 Practical Case Study : Autonomous Peach Picking Robot

There is a wealth of literature with studies detailing the operation of robots that automatically harvest apples [89], oranges [85],pear [88], kiwi [23], bananas [82].... However, there is a gap in knowledge when it comes to peaches. This lack of documentation can be justified by the delicacy of the fruit, i.e. the difficulty in handling and transporting it. Can be found some identification methods [17] [25] and characteristics parameters documents [27] [33] [32], however it has only found a paper that describe in detail the recognition system used and in a very brief way the systems of a robot capable of picking peaches [84].
The peach is a fruit of Chinese origin. It is characterised by a fleshy flesh and a stone inside. Usually, identified by its reddish tones. Its shape is practically spherical, it has a cleft in the centre that gives it its characteristic geometry [33]. The peach can be classified according to flesh colour: Yellow or White.

	White flesh	**Yellow flesh**
External color	Yellow and red	Yellow and red
Internal color	White	Yellow
Texture	S oft and juicy	Firm and juicy
Taste	Sweet	Not so sweet, more acidic

Table 3: Peach Variety. Source Author.

Another classification is done by flesh hardness: melting flesh and non-melting-flesh.
Depending on the area in which they are cultivated, there are different varieties. Some of them are common all over the world and others are specific to each region. In the case of Spain, some of the best known varieties are: Babygold, Redhaven, Springcrest, Calanda, Cherryred, Sudanell, Golden Queen, Jungerman, San Lorenzo, Dixon, Vivian....
The objective of this study is to try to identify the necessary parameters for peach automation and to propose an identification, navigation system and the gripper used. The different types of peaches have a large number of similar characteristics, however, there are small differences that will make the success rate low if It is developed a common robot for all varieties. Therefore, this scientific paper will focus on the variable BabyGold 9.
This variety belongs to the yellow flesh family. It has its origins in the United States. The choice of this variable is due to its popularity thanks to the productivity of its tree, as well as its resistance to pests. As for the fruit, it is characterised by a yellow/golden colour with reddish tints. The taste quality is quite good, with very juicy flesh [5].

Image 3: Baby Gold Peach. Source [74]

4.1 Hardware Platform and System Architecture

It is a fully autonomous vehicle, with no need to be pulled by a tractor. It has its own integrated motorised system with caterpillar wheels (a) to ensure stability and traction in uneven environments. It must have a battery with a minimum battery (c) life of 6 hours [84], which powers all systems. In addition, the GPU (b) shall also be located in the vehicle itself. Equipped with a manipulator (d) and end-effector (e) to reach peaches from different angles. To ensure the reach to the highest fruit, a lifting platform will be installed underneath the manipulator. The maximum height of the end-effector and lift platform is 5 m to ensure reaching the top of the tree. The total number of cameras is 4. Three of them are in charge of the identification and detection of the fruit (f) and one of them is in charge of mapping the environment (g). The camera placed on the end-effector will improve precision, the one placed on the mobile platform will help to optimise the identification process, searching for peaches at different heights and the one positioned at the base of the robot will have the function of detecting possible obstacles. The camera in charge of the mapping should be installed above the power supply and computer systems, to prevent these from blocking its view and to allow it to map the environment in an optimal way. It can be seen that each camera has its own coordinates which differ from the robot's central coordinates. It is necessary to apply different coordinate matrices to relate the different axis systems.
The robot will stand in front of a tree and extract all the peaches that belong to it. Once finished, it will move to the next tree.

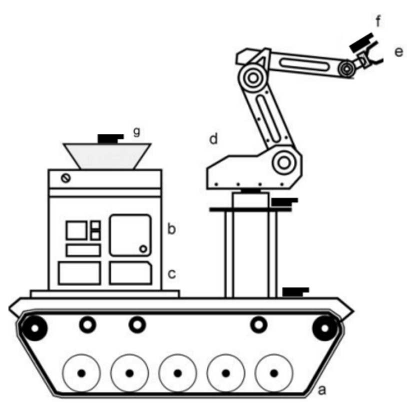


Image 4: Robot Architecture. Source [84]

4.2 Analysis of Fruit and Cultivation System Characteristics

4.2.1 Fruit Characteristics

In this section an analyse both the internal and external characteristics of the BabyGold 9 variable will be carried out. The factors will be analysed quantitatively giving numerical values, in order to automate the process accurately.
The study carried out and presented in the previous section identifies the main characteristics : weight, shape , dimensions, colouring, firmness and chemical levels .
Weight:
This variety has an average weight of 160g to 185g, an elevated weight compared to other variables [5].
Regarding the shape of the fruit, there is a length/width ratio (L/W) which is used to classify them (figure 5). Depending on the ratio, a distinction can be made between flattened, rounded or oblong. The BabyGold family is characterised by a slightly flattened to oval shape, i.e. similar to a sphere. The BabyGold 6 variant has an index of $0,9 < L/W < 1$ and BabyGold 7 $1 < L/W < 1,02$. No precious data has been found for the BabyGold 9 variable, however all sources describe it as spherical in shape, so it is inferred that it possesses a $L/W \approx 1$.
Colouring:
The colouring is used to evaluate its maturity. It has yellow and orange tones that allow an easy distinction with the green of the leaves.According to [27], for wavelengths between 680 nm and 450 nm, *"High reflectance at 680 implies low chlorophyll content, i.e. maturity in the fruit. High reflectance at 450 nm implies low pigment content, i.e. immature fruit.*

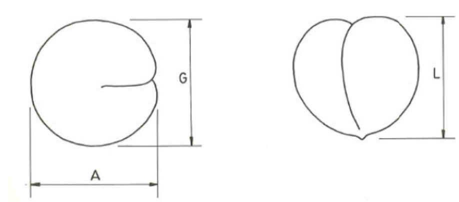


Image 5: L/W index. Parameter "A" is the so-called "L" throughout the article. Source [32].

The CIELAB method is the most commonly used technique to assess the colour of the epidermis. It uses three values L^*, a^* and b^*. L^* represents lightness and brightness. It varies from 0 to 100, where 0 represents black and 100 white. Therefore, fruits with a high L^* index will have a bright pigmentation. The parameter a^* indicates the reddish or greenish shade. This value can be positive or negative.Values $a^* > 0$ will indicate reddish tones while $a^* < 0$ will be greener tones. Finally, b^* represents the tendency towards yellow ($b^* > 0$) or blue ($b* < 0$). The [38] study argues that the BabyGold 9 peach should possess the values of: $L^* = 43.62 \pm 0.17$; $a^* = 3.39 \pm 0.06$; $b^* = 24.09 \pm 1.40$.
Size:
In Spain, the size of peaches is marked according to Commission Regulation (EC) no. 2335/1999 of 3 November 1999. This legislation dictates that the size depends on:

1. Circumference
2. Maximum diameter of equatorial section

Depending on these two variables, peaches are classified:

Diameter	Caliber Indication (Code)	Circumference
> 90 mm	AAAA	> 28 cm
80 mm $\leq$ 90 mm	AAA	25 cm $\leq$ 28 cm
73 mm $\leq$ 80 mm	AA	23 cm $\leq$ 25 cm
67 mm $\leq$ 73 mm	A	21 cm $\leq$ 23 cm
61 mm $\leq$ 67 mm	B	19 cm $\leq$ 21 cm
56 mm $\leq$ 61 mm	C	17.5 cm $\leq$ 19 cm
51 mm $\leq$ 56 mm	D	16 cm $\leq$ 17.5 cm

Table 4: Peach Size Classification. Source [34]

BabyGold 9 can be classified with codes of A-AA [57] or with bigger dimensions, AAA [1]. Thus, can be concluded that they have a diameter between 67mm-90mm and a circumference of 21cm-29cm.

Firmness:

Firmness is directly related to the rate of damage, so one must be accurate in determining this characteristic to minimise damaged fruit. Traditionally, firmness is measured with the destructive Magness-Taylor method, which consists in making a 1 mm indentation with a sphere of a diameter determined (Studies checked used $\varnothing = 8mm$). After a review of the literature, can be found a relationship in the firmness data (all value measured by Magness-Taylor method) . According to the data of [27], peaches must have a firmness higher than 2 kg/cm^2 otherwise the transport and mechanical handling will be complicated. Neither, they approach values of 6.12 kg/cm^2. Another study [26], states that they should not exceed 4.59 kg/cm^2. The study [38] classifies peaches according to the colour of their flesh (yellow or white) and according to their firmness (melting or non-melting). BabyGolg 9 is a yellow-fleshed, non-melting peach, which makes it easier to transport and handle. According to the grading, non-melting peach has a hardness of 3.98 kg/cm^2 and according to the flesh colour grading, the yellow flesh has a hardness of 3.88 kg/cm^2. In other words, firmness can be approximated to 3.5 kg/cm^2 and 4.2 kg/cm^2. During *Picking System* section, some estimates will make in order to calculate the force required to achieve a successful picking rate.

Post-harvest Parameters: SSC, RI and TA

Traditionally, only physical or external variables were evaluated by the picker to determine the ripeness point of the fruit. In post-harvest treatments, chemical variables such as soluble solids content (SSC), acidity or ripening index (RI) were evaluated in laboratories. This last index is an indicator of peach flavour ($RI = SSC/acidity$). These measurements used to be achieved by destructive methods. However, thanks to NIR (near-infrared) technology can be analyzed this chemical composition quickly. *Near-infrared (NIR) spectroscopy is an accurate and nondestructive technique, which can be used to quantify molecules containing hydrogen atoms such as water, alcohol, and other compounds formed by $C-H$, $N-H$, and $O-H$ groups* [35]. Articles such as [24]demonstrate their effectiveness in detecting SSC in pears, [30] explain the method used to analyse the inert qualities of apples. Moreover, can be found documentation related to peach [31] [42] which clearly shows the capability of using this technology for SSC analysis. The challenge in implementing a NIR system is that the spectrometer picks up too much unneeded information and noise from the environment, making internal analysis of the fruit difficult, as well as the high cost [24]. In some cases, the appearance of the fruit does not provide correct or sufficient information about the state of maturity, so an infrared system could significantly increase the success rate of harvesting. However, the implantation of these measuring methods in real time is difficult, high-cost and would slow down the identification system. Moreover, BabyGold 9 has a characteristic color, which is sufficient information to determine the collection point. Therefore, It has been decided that NIR system will not be implented in the robot.

Soluble solids are measured on the ˚BRIX scale. This measure, which assesses the sugar concentration, ranges from 0 to 100 degrees Brix (one degree Brix is equivalent to 1 gram of sucrose in 100 grams of solution). Baby Gold 9 has an SSC amount of 11.14 ± 0.18 Other attributes such as titratable acidity (TA) which serves as an indicator of bitterness or the ripeness index (RI) which indicates taste can also be analysed. TA is measured by malic acid concentration per 100 g FW (g malic/100 g FW). The variable Baby Gold 9 contains $TA = 6,49 \pm 0,02$ $RI = 4,03 \pm 0,07$ according to [38].

As a summary, the following table shows the internal and external parameters of the Baby Gold 9 peach.

Parameter	Value
Weight (g)	160-188
Shape (L/W)	Spherical ($L/W \simeq 1$)
Size (mm)	Circumference: 210-290; Diameter: 67-90
External Colour	Yellow-orange ($L^* = 43.62 \pm 0.17; a^* = 3.39 \pm 0.06; b^* = 24.09 \pm 1.40$)
Firmness (Kg/cm^2)	3,5-4,2
SSC (°BRIX)	11.14 ± 0.18
TA ($g\ malic/100\ g\ FW$)	$TA = 6,49 \pm 0,02$
RI (SSC/TA)	$RI = 4,03 \pm 0,07$

Table 5: BabyGolg 9 Parameters. Source Author.

4.2.2 Environmental Characteristics

In order to develop an efficient harvesting system, not only an approach based on the characteristics of the fruit but is needed, also on the environment in which they grow should be focused.
Peach trees are grown in an orchard system and are arranged in such a way as to optimise space and allow the tree to develop optimally, using a row system. The spacing between rows can vary between 3 and 5 metres. As well as the spacing between trees. Some of the most commonly used configurations are: 3x5 or 5x5. This means 3 m between trees in the same row and 5 m between two rows.
As for the tree, its shape is conical and its height is between 3m-4m [32]. The distribution on the fruit of the tree is also of vital importance. No specific source has been found that details the spatial distribution of peaches on trees. However, fruit trend to grow in the middle and lower part of the trees because they receive less direct sunlight, reducing the rate of transpiration and resulting in more uniform peaches. This information is relevant for the development of the detection and picking software.

4.2.3 Harvesting Process

The BabyGold variable is harvested at the end of August/beginning of September. It is a late ripening variable. The harvesting period is usually carried out in one, two or three passes [5]. Picking is carried out according to the point of ripeness, the first harvesting the ready fruits, leaving for the following harvests the fruits that still lack a point of maturation.
The movement described for harvesting consists of a downward rotating movement, with a very slight tug. This is a careful movement so as not to damage the fruit. There is no need to use any tools to help, so the implementation of a cutting system is not necessary.

4.3 Identification System

4.3.1 Classification Identification Methods

The peach detection and identification system is a very important part of the harvesting process. Although the concept of automatic fruit detection sounds very recent, the first data on this technique dates back to 1968 [41]. Since then, the technique has evolved considerably. Traditionally, identification was based on the processing of a digital image. For this, machines were developed to evaluate colour, texture and geometry. However, these methods had their limitations. Colour-based recognition analysed pixel-by-pixel parameters such as RGB,HSI and HSV. The problem is that, due to weather conditions, the brightness of the fruit affects these systems, reducing their hit rate. In addition, if the colour of the fruit is similar to that of the branches and leaves, this technique reduces its efficiency considerably. Geometry recognition solves the problem of colour or light changes. However, the change in fruit shape during development and the existence of occlusions mean that the accuracy of this method is not the best. Another detection technique is based on the texture of the fruit, which is generally softer than the surrounding environment. Not only have methods based on a single characteristic been used, there are also multi-functional systems that take into account texture, colour and geometry and improve the performance considerably. Numerous examples of these traditional methods can be found in [13]. Currently, systems based on deep learning are very popular. Within these systems can be found three approaches: Target Detection Techniques, Target Segmentation Techniques and Vision-Based 3D Reconstruction Technology of Fruit.

Target Detection Techniques:
Algorithms based on Deep Learning-Based Target Detection Techniques can be classified into two: one-stage and two-stage. Both techniques use neural networks (CNN) to analyse and identify images. The difference between the two is that the one-stage technique performs object analysis in one pass. The advantages provided are its speed and efficiency, which are perfect for real-time analysis. The major disadvantage is its lack of accuracy compared to two-stage models, due to occlusions and fruit size. The two-stage algorithms first generate a set of proposals where the fruit could be found (ROI) and then analyse each region, classifying the object. The advantages provided are their high accuracy despite occlusions and their major disadvantage is their speed. Moreover, it is more complicated to implement. The most popular algorithms are listed in the table 6.

One-Stage	**Two-Stage**
R-CNN	YOLO family
Fast R-CNN	RetinaNet
Faster-CNN	SDD
SSPNet	

Table 6: Deep learning-based target detection algorithms. Source Author.

Semantic Segmentation Technique:
The deep-learning-based semantic segmentation technique seeks to delineate the exact shape of fruits. While object detection systems analyse the location and presence of fruits, these systems separate the fruit from the background and are able to distinguish the volume. The most commonly used algorithms are FCN, SegNet, DeepLab and Mask R-CNN.

3D Identification Systems:
Finally, 3D identification systems. These are based on stereo vision or RGB-D Vision. The major difference is that stereo vision uses different images to calculate depth while RGB-D vision uses infrared light to measure distance. These systems can be combined in order to create the most accurate algorithm possible.

4.3.2 Sensors Used

Having explained the different types of algorithms, it should be known which systems are used to obtain information.The algorithm captures signals from sensors or cameras. The most common systems used in that camaras are: monocular vision, stereo , structured camera and multispectral .

- **Monocular camera**. This type of system is able to extract colour, shape and texture. The main advantage is the low cost and the ability to create a multi-camera system. The disadvantage is its poor performance in environments with low visibility or occlusions.
- **Stereo system:** They are capable of detecting the same features as the monocular camera and in addition, by means of image triangulation, they obtain the coordinates of the position of the fruit (including its depth). Their advantage is their 3D analysis of the environment. Their limitation lies in the need for a high degree of sensor calibration and their slow position processing.
- **Structured system:** These cameras obtain 3D information by reflecting light off objects. They have high accuracy and occlusions do not limit efficiency much. Their high cost and reflections due to the brightness of the sun are their main disadvantages.
- **Multi-spectral system:** They are able to obtain information thanks to the differences in radiation of certain characteristics of the fruit. It emits waves that are not affected by the environment. However, they are not currently used for real-time detection.

These systems are integrated into cameras, either individually or in combination (monocular + stereo), creating sensors that are able to capture images and depth.According to [12], these sensors are classified as 2D and 3D. Monocular camera belongs to the two-dimensional category. While stereo camera, multi-spectral camera and structured camera belong to the three-dimensional sensor family. The most widely used system is the structured camera, followed by stereo, monocular and multi-spectral cameras.

4.3.3 Selection Software

Once the physical systems and algorithms have been identified, it must be decided which one to introduce in the proposed robot. The literature is very varied, ranging from proprietary neural networks, YOLO software, Mask R-CNN segmentation systems and combinations of several. These algorithms have different sensors and cameras. All the information is summarised in the table 7.

Fruit	Algorithm	Sensors/Cameras	Reference
Peach	Yolov7-Peach	Not defined	[25]
Okubo Peach	Yolov8s-P	Not defined	[17]
Pear	Yolov5-s	Real Sense D435i	[88]
Kiwi	Faster R-CNN	Stereo camera	[23]
Banana	YOLOv5-B	Stereo camera	[82]
Apple	O2RNet (Fast R-CNN)	Real Sense D435i + Laser camera Scanning	[89]
Orange	CNN	Kinect RGB-D camera	[85]

Table 7: Different algorithms and sensor in harvesting robots

Taking into account the above-mentioned precedents, can be observed that the algorithm used in peaches belongs to the YOLO family. The integrated model will be YOLOv8s-P. It is an open source code developed by Ultralytics. The choice is based because is a "State of the Art" (SOTA) model, i.e. one of the most advanced and developed models. Another determining factor for its choice is its success in identifying "Okubo" peaches. Okubo peaches have similar colouring characteristics to the BabyGold 9 variable. Both species are yellow peaches with similar size and geometry. The efficiency of detecting this type of peaches is shown in the article [17]. The comparison table between different models of the YOLO family will demonstrate the good results obtained. Accuracy (P) determines the percentage of successful detections, being YOLOv8s-

Models	P(%)	R(%)	AP0.5(%)	F1(%)	Parameters(M)	FLOPs(G)	Model Size(M)
YOLOv3-tiny	91.31	75.69	84.60	82.77	8.67	12.9	16.5
YOLOv4-tiny	90.89	76.84	84.85	83.28	5.87	16.2	22.4
YOLOv5s	91.60	79.56	88.81	85.16	7.01	15.8	13.7
YOLOv6s	91.53	79.66	88.74	85.18	16.31	44.2	36.6
YOLOv7-tiny	91.53	79.56	88.99	86.02	6.01	13.0	11.7
YOLOv8s	91.29	81.02	89.01	85.85	11.13	28.4	21.4
YOLOv8s-P	92.80	81.36	90.86	86.70	8.32	21.8	16.1

Table 8: Comparison of the detection effects of different models on the test set of "Okubo" peach young fruits. Source [17].

P the highest among all software. Another noteworthy feature is its high AP@0.5. This is the portion of the predictions that it considers positive with a degree of certainty greater than 50% (IoU) of all the positive predictions made by the model (including correct and incorrect detections). A high AP is therefore synonymous with high accuracy. The F1 score is calculated by $F1 = 2\frac{P}{P+R}$, having a range from 0 to 1, being 1 a model whose identifications are perfect and 0 a software where all detections are wrong. Another important parameter is its speed and efficiency, which is linked to the size of the software. It can be seen that it is not the lightest, its Model Size is 16.1 MB. Despite a reduction of 75 % compared to YOLOv8s, it still has a considerable weight compared to other models such as YOLOv3-tiny and YOLOv7-tiny. This will have an impact on detection speed. Identification time and accuracy are inversely correlated. If we are looking for a highly accurate model, the speed will be lower. It has been decided to go for a more accurate process as the

BabyGold9 peach is only picked in two or three passes. The robot can work from the beginning of the day until it starts to pick, so the number of hours it can work is high, reducing the importance of picking peaches in the shortest possible time (as long as it finishes the day with the target number of peaches picked).
YOLOv8s-P performs better than its predecessors thanks to the incorporation of modules in the three parts that make up a CNN: Backbone, Neck and head.
The backbone is responsible for extracting features. The built-in enhancement is a C2f module that optimises the extraction of effective features from the image. It also incorporates the Efficient Multiscale Module (EMM) to improve the extraction of tiny features. The Spatial Pyramid Pooling-Fast SPPF) module is also used to increase the accuracy of the model.
In the neck, it uses a combined Feature Pyramid Networks (FPN) and Path Aggregation Network (PAN) structure similar to YOLOv5s. FPN is responsible for improving the identification of smaller objects and PAN optimises the flow of data throughout the network.
While in the head it uses the YOLOX innovation. This improves detection speed.
This model like all those based on a neural network, needs prior training. The software can be trained according to: *”labeled dataset was randomly divided into three subsets: train, validation, and testing sets, according to the division ratio of 7:2:1, respectively”* [17]. It is beyond the scope of this article to go into detail about the training procedure.

4.3.4 Selection Hardware

The inputs received by the model would be through an RGB-D camera. The images captured would be processed by YOLOv8s-P, which would evaluate them in real time, determining by their colour and geometry whether they are suitable for harvesting, i.e. the parameters that will be used to determine the maturity of the melon is its flesh colour ($L^* = 43.62 \pm 0.17; a^* = 3.39 \pm 0.06; b^* = 24.09 \pm 1.40.$) and geometry shape ($L/W \simeq 1$). The depth information will be used to evaluate the distance and position of the peach. Therefore, this robot will use a recognition method that will combine 3D information for the positioning of the fruit with 2D images to detect its ripeness point.
The proposed camera is the Intel RealSense D43Di. According with the state of art analyzed in table 7, ensure an integration with YOLO software and has been used in diffrent types of fruit. This camera is integrated with two infrared cameras, an infrared projector and an RGB camera. The two infrared cameras and the projector obtain the 3D information, while the RGB camera will be used to evaluate the colour of each fruit. Spherical shape ($L/W = 1$) of BabyGold9 must be also analyzed, serving as a parameter for its detection, improving its accuracy with spherical adjustments. The price for each camera is 131 € [60]. Table 20 shows the total price of all sensors used for identification and navigation.

Image 6: Intel RealSense D43Di. Source [60].

The option of placing 2 fixed cameras at the base of the robot has been chosen. In this way will be achieved a fixed coordinate systems and a matrix that remains unchanged, making it easier to find their relationship. It is required an other one mounted on the arm to improve the precision of detection and grasping of the fruit.
The identification sequence is summarised in the diagram 7. The IntelReal D43Di cameras will capt peaches images. Yolov8s-P will analyse these pictures: Does the fruit have the desired shape ($L/W = 1$)?. If this condition is not met, it is an obstacle to avoid or an unripe peach. In case the condition is true, fruit ripeness is evaluated according to the previously defined colour parameters (($L^* = 43.62 \pm 0.17; a^* = 3.39 \pm 0.06; b^* = 24.09 \pm 1.40$). If it does not meet these colours, it is an unripe fruit and should not be harvested. In case peach meets with these values, must be picked.

Features	Description
Use Environment	Indoor/Outdoor
Image Sensor Technology	Global Shutter
Ideal Range	0.3 m to 3 m
Depth Technology	Stereoscopic
Minimum Depth Distance (Min-Z) at Max Resolution	28 cm
Depth Accuracy	$< 2\% at 2m$
Depth Field of View (FOV)	$87°x58°$
Depth Stream Output Resolution	Up to 1280 x 720
Depth Stream Output Frame Rate	Up to 90 fps
RGB Frame Resolution	1920 x 1080
RGB Frame Rate	30 fps
RGB Sensor Technology	Rolling Shutter
RGB Sensor FOV	69˚ x 42˚
RGB Sensor Resolution	2 MP
Camera Module	Intel RealSense Module D430 + RGB Camera
Vision Processor Board	Intel RealSense Vision Processor D4
Form factor	Camera Peripheral
Camera Dimension (Length × Depth × Height)	90 mm × 25 mm × 25 mm
Connectors	USB-C 3.1 Gen 1
Mounting Mechanism	One 1/4-20 UNC thread mounting point, two M3 thread mounting points

Table 9: Main features of Intel Real Sense D43Di. Source [60]

Features	Description
Product Collection	Intel® RealSense™ Cameras
Code Name	Products formerly Banner Ridge
Marketing Status	Discontinued
Launch Date	Q1'19
Depth Technology	Tracking
Depth Resolution and FPS	848 x 800
Depth Field of View	D:163
Datasheet	View now
RGB Sensor	No
Tracking Module	Yes
Dimensions	108 mm x 24.5 mm x 12.5 mm
Power	1.5 W
System Interface Type	USB 3

Table 10: Main features of Intel RealSense Tracking Camera T265. Source [61]

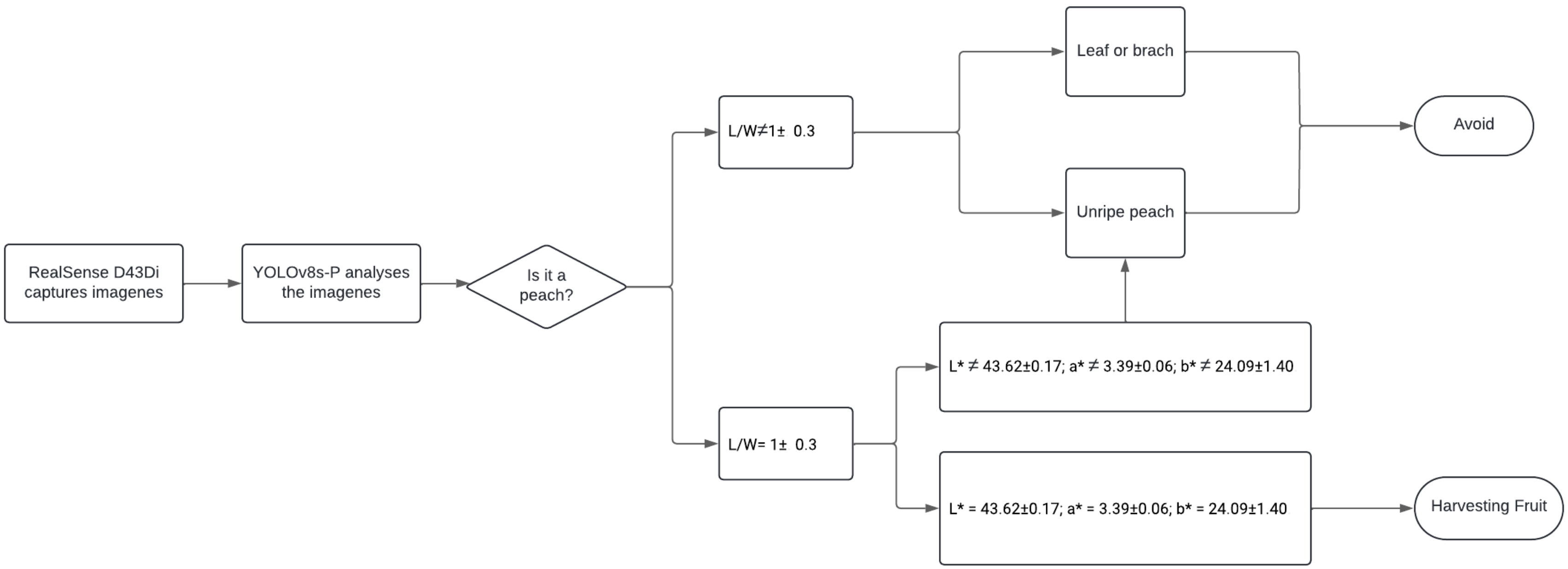


Image 7: Flow-Chart Identification Process. Source Author.

4.4 Navigation System

4.4.1 SLAM Algorithm

The robot must know its location and the environment in which it will work before it can create a route to the fruit and avoid obstacles. These functions are provided by the SLAM technology. According to the article [14], it is defined as *in an unknown environment, a robot starts from an unknown position and, during its movement, generates real-time state estimates through sensor feedback to determine its own location. Simultaneously, it constructs an incremental map based on its self-localization.* To apply SLAM technology, an algorithm must be developed. Numerous algorithms have been developed, such as Extended Kalman Filter (EKF), Fast SLAM 1.0 or Fast SLAM 2.0. The Gmapping algorithm has been chosen for the design of the robot. It is a system that performs an estimation of the robot's position and builds the map. To perform this task it is used Intel RealSense Tracking Camera T265 will be installed to map the environment in real time to avoid large obstacles [3]. Its operation is based on stereoscopic images that create a 3D environment. The camera itself uses a Movidius Myraiad 2 processor running SLAM algorithms [61]. That is to say, with the integration of this camera, the robot knows its location and is able to navigate between the rows and columns of the field avoiding obstacles. Camera characteristics summarized in 10.

4.4.2 Planning Path System

Classification Path Algorithms

During this section, will be analyzed in detail how the robot creates the movement towards it. That is, the choice of the algorithm that allows the robot to create a trajectory to the fruit, avoiding obstacles. After a literature review, a large number of systems have been identified: A*, RRT*, GA,AGG. OMPL is an open source library that offers several algorithms for route planning such as RRT*. The choice of software depends mainly on three factors:

- Dynamics of the environment
- Accuracy
- Speed

In terms of accuracy and speed, must exist a balance between the two to ensure its efficiency. It must be fast enough to achieve small picking times but at the same time accurate enough not to damage adjacent fruit and avoid collisions.
A study of the applied route planning algorithms used in fruit picking has been carried out.

Fruit	Algorithm	Reference
Apple	PSO	[7]
Apple	OMPL	[20]
Orange	RRT*	[85]
Apple	GA	[89]
Pears and Apple	T-RRT	[83]
Pear	SA	[88]
Banana	AGG	[82]
Strawberry	OMPL	[36]

Table 11: Path Algorithm. Source Author.

The navigation algorithms are divided into global path planning based on prior knowledge of the environment map and local path planning based on information provided by sensors. The main algorithms that integrate the global path family are: A*,RRT,GA. While the local path planning include also A* and PSO algorithm [19].

A*
"A algorithm, a heuristic search method with high search efficiency, can solve the shortest and most effective path in static environments"* [19]. That is, it searches for the shortest path between two points. The main advantage is that it always finds the shortest solution. Whereas main disadvantage is the memory consumption and therefore it is not ideal for very large environments.
GA
The GA algorithm uses artificial intelligence, not a heuristic function. Inspired by biological evolution and natural selection. There is a problem and several solutions called chromosomes (sequence of directions to follow). These chromosomes are subjected to operations: crossover, mutation and selection, generating new solutions [13]. In the context of peach picking, possible movement sequences (chromosomes) are created. These are crossover, i.e. it is chosen the part of one solution and mix it with the second half of the pathway of another chromosome. This generates a new, potentially more efficient solution. Then come mutations, where exist a randomly swap one part of the pathway for another, helping to explore new solution areas. Finally, selection is the process of choosing the fittest. It evaluates how efficient the path is in terms of time, distance and energy. The main advantage lies in good performance in large and complex spaces. However, it does not guarantee the optimal solution and there may be convergence problems.
PSO
"The idea of PSO comes from the study on birds' foraging behaviour, and birds can find the best destination through collective information sharing" [19]. It finds the best solution through iteration. The solutions are called particles (the generated routes). The initialisation phase starts, a swarm of particles (random paths) is generated. Then, the fitness evaluation phase begins. Each particle is evaluated according to its appropriateness. The shorter the path or time, the higher the fitness. The next phase is the update of speed and positions. It consists of adjusting the routes according to the positions of the fruits. That is to say, which fruit is best positioned for picking. Then, the iteration process begins. The evaluation and updating process is repeated until a stopping criterion is reached, such as a minimum improvement in fitness or a maximum execution time. Finally, the best path is selected. The advantages provided by this method are fast convergence, a simple, easy to implement and memory efficient algorithm that is very beneficial for real-time application. The main disadvantage is that it can easily fall into local optima, i.e. it does not improve the route, as there are several better solutions.
RRT*
RRT* is an improved RRT algorithm. The basis of this algorithm is to create branches from the growth tree to possible targets [85]. The difference between the two is that the RRT* actively modifies the tree, improving the paths found while in RRT, the tree is limited to finding new paths. In the context of peaches the algorithm works as follows: It starts a node at the starting point of the robot, generates random points in the orchard, then identifies the nearest node (peach) and creates a branch (direction). Once in front of the peach tree, it realises that by varying the branch of a previous node (the trajectory towards the previously identified peach) it will pass through a new node, making this trajectory more optimal. This process is repeated by expanding the tree and optimising the branches. Its advantages are its ability to avoid obstacles, its flexibility which allows it to adapt to different geometric shapes and it has a fast convergence for high dimensional spaces. It can reach a slow convergence when spaces are very dense.

4.4.3 Algorithms selected

The choice of the algorithm has been based both on the indirect comparison between them and on the presented bibliographical background. The robot will create the map with the selected Gmapping algorithm, this decision is based on the popularity of its use in robots such as the one mentioned in [3]. Whereas, the algorithm for route planning is RRT*.
According to the paper [4], when the environment is complex, RRT* is faster than PSO.In complex cases where more iterations are needed PSO takes 5 to 10 times longer than RRT*, having in time-really less computational time [18]. The documentation mentioned in the table 11, ensure the ability of RRT* to avoid obstacles. The GA algorithm is discarded because it does not ensure the best possible solution. The algorithm selected characteristics suit perfectly with the required: large spacing, fast convergence and flexible to different fruit sizes. The only disadvantage is the possible error at high densities. This could become a

problem, as the BabyGold 9 variable provides a large number of fruits per tree. It should be tested if the RRT* algorithm is sufficient, otherwise, an improved variant is proposed that will solve this problem: RRT*+PSO [15]. This solution will improve the accuracy of the robot with a higher number of peaches. In terms of time, it is only sometimes superior to RRT*. It is a pioneering solution that should be taken into account in the development of our robot.

4.5 Picking Sytem

After learning about detection and movement towards the fruit, in this chapter will be tackled the choice of the tool that our robot will have. It can be divided into two parts: manipulator and end-effector. The structure of this section will follow an explanation of the different movements used for detachment , an explanation of the different types of end-effector according to the different classifications, explaining the need to integrate sensors to monitor some parameters in real time and finally, will be presented the characteristics that an end-effector intended for the picking of BabyGold 9 peaches must fulfil in order to choose an end-effector.

Harvesting fruit in changing environments is a problem to automate agriculture. In addition, the variety in size and shape of different fruits makes harvesting a challenge. It is true that there are end-effectors designed to be used for different groups of fruits such as the one proposed in [22], aimed at picking circular fruits or the one proposed in [29] that adds blades to facilitate extraction. However, the physical differences of each fruit, as well as their different characteristics such as firmness, make the standardisation of a harvesting tool really complicated. Therefore, grippers can be designed only for the harvesting of a particular fruit or designed more commercial that can be used universally. Success rate will be higher for those designed specifically for one fruit, but the cost will be much higher. Our end-effector will be a commercial one that meets the necessary characteristics for our fruit. The aim is to strike a balance between speed and efficiency.

4.5.1 Detachment Method

Developing an end-effector is based on the detachment method. Most known is the pulling method, which involves exerting a large external force to separate the fruit from the branch. Another commonly used method is to rotate the stem to weaken it and then pull. Cutting method is with the use of cutting tools for fruits with a stronger stem, such as peppers. Finally, there is a strategy based on vacuum: the suction method. It consists of creating a vacuum and separating the fruit from the tree.

4.5.2 Grippers Classification

Once the separation methods are known, the different types of end-effectors must be identified. They can be classified, (i) according to the type of detachment, (ii) depending on the number of fingers and (iii) based on the materials they are made of.

Classification based on detachment method
According to the type of separation there are 4 categories [46]:

1. Contact-grasping
2. Rotation Mechanism
3. Cutting Tools
4. Suction devices

The most commonly used type is contact-grasping. They are the most accurate. However, they can interfere with the branches. A strong external force must be exerted creating an upheaval in the tree. This movement damages the plant and reduces the precision in picking the next fruit.
To reduce the external force exerted and to eliminate the agitation of the tree, there are end-effectors with a rotating mechanism. Generally , the picking time in this grippers are longer than by contact-grasping, but

the damage rate is reduced.
The next type of end effectors are called cutting tools. These grippers integrate blades, scissors or edges to separate the fruit. This method is fast, however, the complexity increases significantly. The identification and detection system must be very precise in order to determine where to cut and not to damage the fruit. In addition, the cutting movement must be coordinated with the gripping of the fruit. The spread of pests through contact with the blades is also a problem to be tackled. In order to solve these possible infections, a thermal cutter is used [10].
The last type are suction devices. They are usually designed as a cup that generates a vacuum. This method is limited by the weight of the fruit and possible damage to the skin. The advantage of this method is that it only needs to adhere to a visible part of the fruit in order to extract it.
All types of end-effectors can be combined to develop more precise systems. The table 12 shows an overview of the different types of end-effectors according to the way they are harvested.

End-Effector Type	Advantages	Disadvantages
Contact-Gripping	High precision in fruit handling.	Significant external force required, causing tree agitation
Rotation Mechanism	Lower damage to the plant.	Picking time higher
Cutting Tools	Quick collection	Complex System
Suction	Needs only a small visible part to be able to operate.	Limited by the fruit's weight and shape

Table 12: Comparison of end-effector types according detachment methods. Source Author

Classification based on materials

The other classification is according to the material used. Traditionally, the grippers used were made of rigid materials. Built by rigid joins. These types of end-effectors are precise and can withstand high loads. In addition, they were capable of exerting high pressures. However, they have limitations in adapting to different shapes and sizes, as well as being susceptible to damage to fruit.
Soft grippers are those that replace fixed joints with materials that are hyperelastic and capable of adapting to different shapes and sizes. The materials used are characterised by their good flexibility, adaptability and good interaction with the surrounding environment. Silical gel is the most representative of these materials. Other types of materials can be Hydrogel, Shape memory alloy (SMA) and Ion-exchange polymer metal composite (IPMC) [21]. These materials help to reduce damage to the fruit. Advances in soft robot technology, coupled with the need to avoid damage to the peaches, mean that the soft grippers are perfectly suited to the requirements. Therefore, after giving a brief overview of the two different types of end-effectors depending on the material used, this paper will go into more detail only on the family of soft grippers.

The end-effectors created from soft materials can be classified according to their drive method: (a) Electrically driven and (b) Fluid Variable Pressure Actuator.
(a) Electrically driven actuators. They are based on the principle of converting electrical energy into mechanical energy. There are two types: (i) cable-driven, where the motion is produced by retracting or extending cables and (ii) tendon-driven, which are similar to cable-driven systems but instead of a cable producing the motion, the actuator is an artificial "tendon", designed to better mimic human movement. These systems are good at adapting to different sizes of fruit , performing fast and precise movement. They are lightweight and easy to integrate.
(b) Fluid Variable Pressure Actuator uses fluids to change the pressure of structures that envelop the fruit, allowing for gripping. A brief separation between two methods of performance inside this group can be made: (i) Gas or Liquid as the Driving Medium and (ii) Granular Material as the Driving Medium.
Focusing on the (i) Gas or Liquid Methods, exist the cavity structures , channel and chambers or Soft Vacuum Gripper (SVG). Cavity Structure are based on the principle of applying pressure inside the cavity and producing the required deformations. The other type is formed by channels and chambers, this configuration allows the sound to be distributed through the end-effector by moving the fingers. The other application of power actuators are Soft Vacuum Gripper. They use the vacuum (air) produced by a vacuum cup to exert the grip. They are useful for objects with irregular surfaces and reduced visibility. Hydraulic and

pneumatic actuators are the most commonly used actuators due to their ease of integration. In particular, pneumatic actuators are more widely used due to their simpler design. Although hydraulic actuators are capable of exerting more force, for the agricultural action of picking fruit, the pressure exerted by pneumatic elements is sufficient. The major disadvantage is how air is supplied. Traditionally, compressed air tanks were needed to supply the system. Nowadays, small pumps have been developed to create such air. Another major disadvantage is its longer actuation time compared to cable and tendon systems, as compression and decompression is required.
The other major branch is granular materials as actuators. This type allows to adapt to irregular fruits. Granular materials can shrink and shrink quickly, gripping objects without the need for a sensor. These materials can be combined with previously used actuators. They require careful consideration of the material used in order to provide the maximum possible porous grip and reduce the rate of damage.
In addition to the most widely used methods mentioned above, there is new research in the field of Smart Materials Actuators. This family includes techniques such as Shape Memory Materials (SMMs) that change shape in response to a temperature stimulus, Electroactive Polymers (EAPs), material that change shape when an electric field is applied and finally Liquid Crystal Elastoemers (LCEs) that change shape with electromagnetic fields and temperature.

Classification based on number of fingers

Finally, the qualification by the number of fingers can be classified as two-fingered or multi-fingered. According to the paper [46] where a study of the state of the art of numerous effectors is carried out, it concludes that the most used are those with 3 fingers. The greater the number of fingers, the better the manipulation but the greater the complexity.

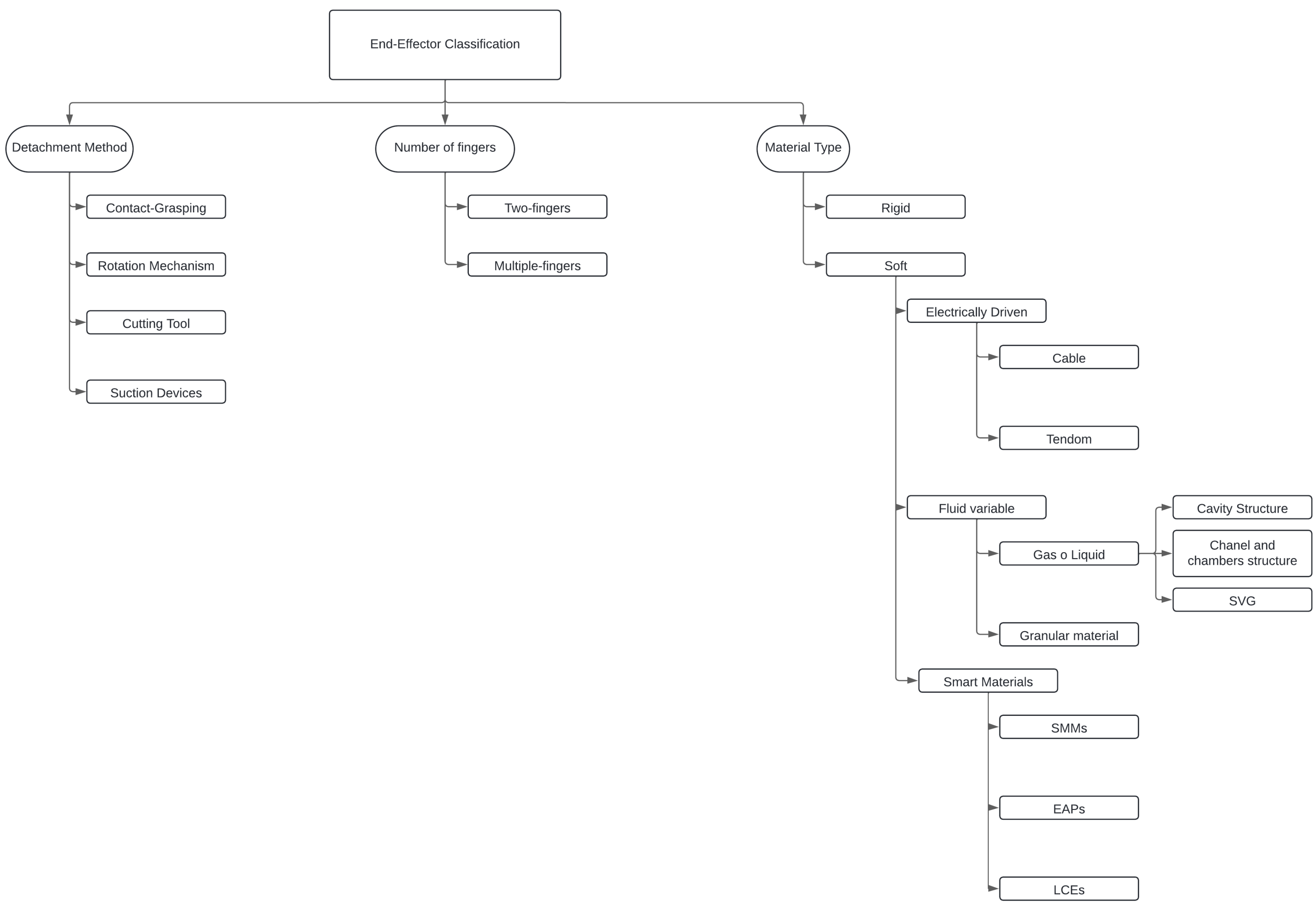


Image 8: Type of End-Effectors. Source Author.

4.5.3 Sensors used in grippers

Humans have inherent sensors that allow us to adjust the force, position and movement of our arm. The integration of sensors is intended to simulate human behaviour as accurately as possible. The sensors related to fruit grasping can be divided into four categories [86].

Switching sensors:
These sensors provide a binary on/off signal. These sensors include proximity sensors that detect proximity to an object (not measuring the distance), reed switch sensors that consist of two reeds that join or separate in the presence of a magnetic field, contact sensors that detect interference with an object by physical contact, and hall sensors that detect the presence of a magnetic field and are used to detect the positions of different mechanical elements due to changes in the magnetic field.

Tactile sensors:
These sensors are responsible for acquiring physical properties of the object by contact. They are used to measure properties such as pressure, grip force, vibration, humidity, torque, temperature... Within these tactile sensors we find the piezoresistive ones that change their mechanical resistance by a deformation stimulus. They are generally used to measure force and pressure. Capacitive sensors measure and detect changes in capcitance caused by contact with an object or by approaching it. Finally, optical sensors detect changes in light to detect the position of objects.

Visual sensors:
These are sensors that incorporate monocular or stereoscopic cameras to provide information about the environment. They help detect obstacles and determine contact points for grasping fruit.

Measuring sensors:
These are used to determine some characteristics of the fruit, such as distance, dimensions or end-effector properties such as speed. These sensors include ultrasonic, microwave or laser triangulation sensors mainly used to measure distances. They also include hall effect, acceleration or torque sensors that give the exact value of the actions that grippers are performing.
Several sensors can be combined, which will provide real-time information and increase the precision and control of our systems.

4.5.4 Identification of parameters that the collection system depends on

The methodology has been as follows: (i) identification of the parameters on which our system depends, (ii) selection of the end-effector that complies with the previously mentioned characteristics, (iii) selection of the manipulator that adapts to the robotic arm, (iv) selection of the necessary adjacent components.

Force analysis
To choose the end-effector and manipulator for our robot, firstly must be parameterised the motion performed by a human pick-up previously described . It can be described as a circular motion while a pulling force at a certain angle is applied to the peach.

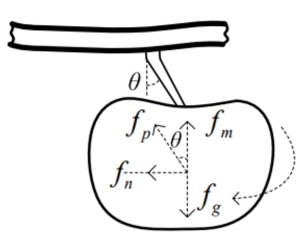


Image 9: Separation method. Source [16].

To better understand the movement, a force analysis on the peach is carried out. The force exerted by the branch (contrary to the pulling force exerted by the human) is called f_p. The force of gravity is shown as f_g. The angle θ is created by the pulling direction (equal to the direction of the stem) and the force f_g. The force f_p can be divided into its vertical component f_m and horizontal f_n.

$$f_m = f_p \cdot \cos(\theta) \quad f_n = f_p \cdot \sin(\theta)$$

The horizontal force f_n is in charge of creating the circular motion, the centripetal force f_c.

To know the value of the forces exerted, empirical tests should be carried out with sensors on the end-effector and monitoring the values obtained. As we are unable to make this measurement, this study will focus on the literature review, analyzing the forces exerted at different fruits by end-effectors.This study will be the base for future experiments. The article [87], shows the forces necessary to hold a cherry tomato. It argues that there are two types of gripping, those on large fruits such as oranges or apples and those on small fruits such as cherry tomatoes. This type of food is grasped by the fingertips, exerting varying pressure according to its size. He concludes that the forces required range from 1N to 4N according to the diameter of the tomato. The article [16] makes a force diagram (as presented above) resulting in a horizontal force of 1N, a vertical force of between 4.6/ 7N and a maximum holding force of 8.5N. In addition, he cites that a total pressure of 20.9 KPa is required. The article [9] distinguishes between two models for harvesting handles. The first one with four fingers requires a gripping force of about 30 N and the second one with six fingers 40N. In addition, it requires a rotational force of 64/74 N . Another document [36] states that the maximum compression force to avoid damaging the fruit is 22.53N. It can be seen that depending on the article different forces are measured.The mentioned articles break down the forces in different ways (horizontal, vertical, rotational and compressive forces) making comparison complex. Therefore, it was decided to choose the model proposed by the article [16] to guide the study of the forces. Based on this study and on farmer experiences, the following conclusion has been drawn:

- The apple stem is stronger than the peach stem.
- Apple is more susceptible to bruising due to the stiffness of its skin but is more difficult to deform because it has more firmness.
- The separation movement of the apple is more violent.

After these conclusions we can estimate some initial forces for future tests. The vertical force should be lower as the extraction is easier. It is assumed a circular movement exerted by a horizontal force similar to that of the apple. Finally, the gripping force should be lower due to the firmness of the peach is lower than that of the apple. It should be noted that this analysis has no scientific evidence, it simply aims to reflect the important parameter of the forces exerted when choosing the end-effector. The estimation of the forces should be governed by the firmness of the BabyGold 9 variable, but tested in a practical way with tactile sensors.

Forces	**Description**	**Value**
F_m	Vertical Force	4 N
F_n	Horizontal Force	1 N
F_g	Gripping Force per finger	5 N

Table 13: Forces Values. Source Author

Number of fingers

After the force analysis, the next parameter to decide is the number of fingers. This choice will be made taking into account the characteristics of: shape, size, structure and mass [46].

Size: Small foods need as little as 2 fingers while large fruits require four or five fingers. The peach with a size of $\varnothing(mm) = 67/90$ can be considered medium sized.

Shape/Structure: Fruits with a clear and simple geometry such as a sphere (it should be remembered that BabyGolg 9 has an index of $L/W = 1$ so it resembles a sphere), require fewer fingers than fruits with more complex geometries such as aubergine or peppers.

Mass: The greater the mass, the greater the number of fingers. The peach, compared to other fruits, can be categorised as medium weight, with a mass of 160/188 g ($Apple \quad mass(g) = 200$ [77], $Orange \quad mass(g) = 250$ [78], $Tomato \quad Cherry \quad mass(g) = 10/15$ [49],$Watermelon \quad mass(g) = 4500$ [79]).

The selection not only will be based on characteristics of BabyGold 9 peach, also on the state of the art collected in the articles [46], [86] where can be concluded that the most used end-efectors are 3-finger end-efectors. There is no mention of a robot designed for peach picking. Approximately, it can be said that the most similar fruits are plums, oranges and apples. The number of fingers of these fruits varies between 3 and 4. The only peach precedent found is [84], which dates back to 2018. It proposes an end-effector of 2 fingers. It can be concluded that the number of fingers should be in the range of 2 to 4. With the example provided by [84], it is sure that the weight of 160/188 g can be supported by only 2 fingers, as well as being able to adapt well to the spherical shape. However, the imitation of the circular movement carried out by an human is complicated to performance with only two fingers, therefore, it has been decided to choose an end-effector composed of three fingers.

Fingers position

Once the movement is known and the number of fingers to be used, the next step is to know how this movement is executed, i.e. the position of the fingers. The procedure to follow would be to test different positions and evaluate parameters such as the maximum force exerted, pressure, holding force and average pick-up time. However, due to the lack of means, this article will propose the solution that theoretically best suits the specifications of the BabyGolg 9 peach. According to the study [16], which evaluates the position of a three-finger end-effector on apples, four gripping positions are proposed (figure 10).

- *"Posture 1 (a):fingertip horizontal centripetal grasp (two adjacent fingers placed at 120° apart near the equatorial surface of the apple)*

- *Posture 2 (b): fingertip parallel grasp on the calyx of the apple stem (two fingers placed parallel to the side of the steam and one finger placed on the base of the apple.*

- *Posture 3 (c): medial finger horizontal centripetal grasp (three fingers wrapped around the apple, fingertips placed at 120○ apart on the calyx side, palm resting on the bottom of the apple)*

- *Posture 4 (d): medial finger parallel to the calyx axis grasp (fingertips oriented in a vertical calyx direction, grasping the waist side of the apple, palm resting on the other waist side) [16]."*

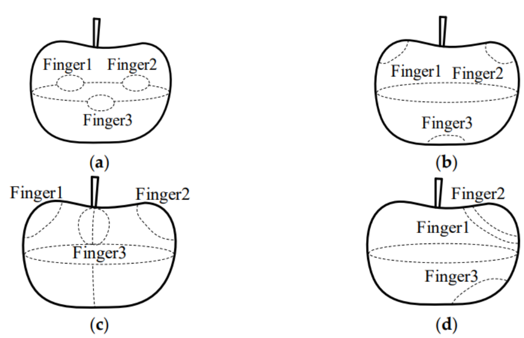


Image 10: Four three-finger grasp postures.Source [16].

The paper studied comes to the conclusion that position (d) is better for apple picking, taking into account the parameters mentioned above. However, based on the traditional movement for picking peaches, can be argued that position (c) is the most similar. Picking apples from the stem, which is more resistant, requires a gripper that provides more angle and pulling force. Moreover, the shape of the apple is more complex than peach structure, so apples require a finger that grasp the waist side of the apple to guarantee stability. Whereas the peach, when it is at its optimum point of ripeness, a slight pull accompanied by a circular twist is enough to lift the fruit off the tree: Adding, its shape is practically spherical ($L/W = 1$). Therefore, position (c) better allows this circular twist and the finger positions are more suitable to the grip of a spherical object. Furthermore, observing the data in terms of forces, pressure and times, can be detected that the two positions (c)(d) do not differ too much, being position (d) better for the case of apples.
In conclusion, **position (c)** is the optimal position for peach picking due to its shape ($L/W = 1$) and circular motion.
The described movement has become clear after the analysis of the forces and the position of the fingers: a pulling movement accompanied by a rotation. To execute it is needed the pull-rotate end-effector type. Vacuum methods are discarded because of the possibility of damaging the peach skin and its rough texture that can make it difficult to make the vacuum. The other type discarded is the cutting end-effectors due to the lack of need to use a tool to separate the fruit from the stem.

End-Effector Material
The firmness of the peach 3.5/4.2 kg/cm^2 and its delicate treatment require a soft end-effector and not a rigid one. This type of grippers will considerably reduce damage to the skin of the peach, as well as perfectly adapting to the different sizes that can develop in the BabyGold9 variable.

4.5.5 End-effector and Manipulator Selection

It remains to describe the drive method required and the sensors integrated in the gripper. After selecting the commercial end-effector, actuator method and the integrated sensors will be described. The only requirement to ensure efficiency is that the drive method will be fast and reliable. Therefore, beforehand electric and pneumatic or hydraulic systems are the most suitable.
To summarize, the table 14 gathers the necessary characteristics to ensure a good harvest of the BabyGold 9 peach by means of an end-effector.

Variables	Characteristic End-Effector	Parameter based
Detachment Method	Pull-Rotate	Simulate traditional method
Type end-effector	Contact-Gripping + Rotate mechanism	According to the detachment method
Number of fingers	Three-finger	$\varnothing(mm) = 67/90$; $Shape : Spherical$; $Mass(g) = 160/188$
Material	Soft Materials	Delicate fruit, $Firmness(kg/cm^2) = 3,5/4,2$

Table 14: BabyGold 9 End-Effector Characteristics. Source Author.

Different gripper manufacturers such as Schonk, SMC Corporation, Festo, IAI, Zimmer, Destaco, Soft-Gripping, Robotiq and SofRobotTech (SRT) were evaluated. Most of the products found were rigid grippers which would not adapt correctly to the shape of the peach. Four products should be highlighted that do meet the specifications: (a) SFG-FNC3-N3034 by SRT, (b) Three Finger SoftActuator developed by Soft-Gripping and (c) 3-finger adaptive robot gripper created by Robotiq (d) Soft Gripper-Flexible Food-Grade Robot gripper by OnRobot. The product developed by SRT imitates the human grip. Composed of three fingers and a flexible material, it adapts perfectly to spherical shapes. Pneumatic actuator.
3-Finger Adaptive RobotGripper by Robotiq has a human hand design with three fingers that allows it to adapt to any structure. Electric actuator. A customised option is available with soft material overlays.
Three Finger SoftActuator developed by SoftGripping is made up of three silicone fingers. It is possible to

(a) SFG-FNC3-N3034 (b) Three Finger SoftActuator (c) 3-finger adaptive robot gripper (d) Soft Gripper-Flexible Food-Grade

Image 11: Different types of grippers. Source (a) [75]; (b) [72]; (c) [71]; (d) [66]

add a plate to increase the grip radius. They are light and allow to adapt perfectly to spherical shapes. The table below shows a comparison of the main characteristics of the three proposed solutions.

	SRT [75]	**SoftGripping** [72]	**Robotiq** [71]	**OnRobot** [66]
Pressure	100 kPa (1 bar)	-0,3/1 bar	-	-
Grip Force	-	5N per finger	30/70N	380 N(spindle)
Object Weight	453 g	450 g	10 kg	2.2 Kg
Diamter max, $\varnothing_{max}$	142 mm	240mm	155mm	75mm
Finger length (gripping length)	25 mm	68 mm	125 mm	38 mm
Drive Method	Pneumatic	Pnematic	Electrical	Electrical

Table 15: Grippers Specifications. Source Author.

Looking at the specifications it can be seen that the solution proposed by Robotiq is not adapted to the type of object to be handled. It is designed to move larger and heavier objects. In addition, the forces exerted are too high and can damage the object. OnRobot gripper works in a different way. A spindle rotates and opens or closes the clamps. The fingers are exchanged for a cup that adapts to different shapes. Despite the high degree of flexibility, some peach sizes cannot be gripped, so this option is discarded. The object The gripper designed by SRT meets all requirements, however, the length of the fingers is too short. Due to the average size of the diameter of the peach, the gripper can only be used with the tip of the end-effector. To ensure a correct grip, the solution proposed by SoftGripping is the right one. Three Finger SoftActuator can exert a force of 5N per finger, which is more than enough to separate the peach from the tree. In addition, the weight of the BabyGold 9 (160/188 g) can handle it perfectly. The actuator is pneumatic, ensuring reliability due to its uncomplicated installation. Thanks to the built-in plate of this gripper, the length of the gap between the grippers can be modified to suit the desired diameter. Tests should be carried out to find the best configuration but it is suggested a maximum gap between the jaws and the centre of the plate of 50 mm ($\varnothing = 100mm$). As for the length of the fingers, can be noticed that on some examples of BabyGold 9 it would not be able to wrap completely around it. However, the grip is not made by contacting the surface of the fruit with the entire contact surface of the jaws. As can be seen in the picture 10 and in the photo of proposed grip, 11(b), the force is exerted primarily by the fingertips with the rest of the surface remaining to ensure stability. The end-effector consists of 3 parts: Fingers,plate Robot Adapter and 3 arm plates.
The fingers have a mass of 40g and an effective length of 68mm.

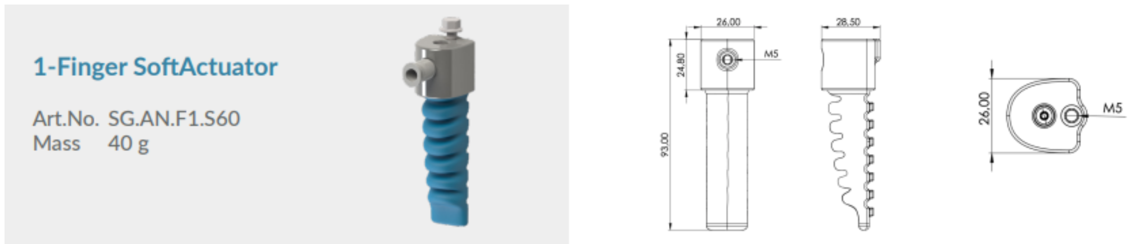
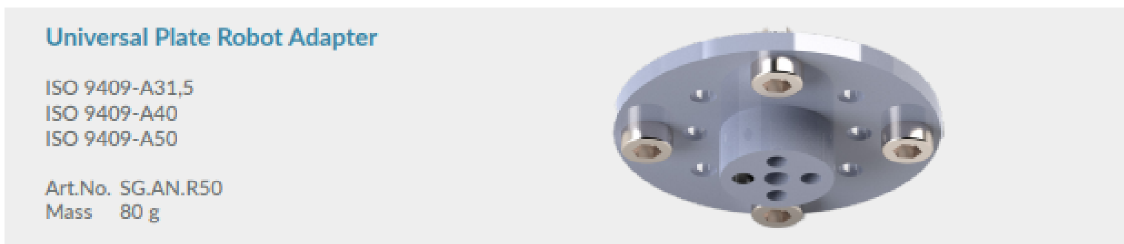
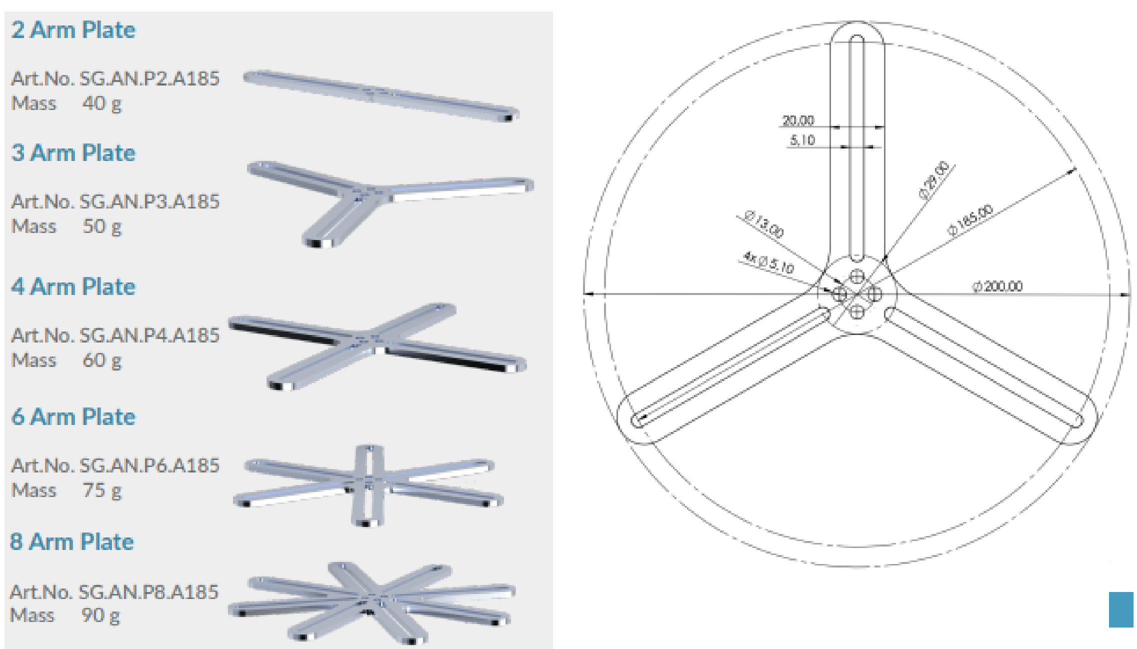


Image 12: Specification of fingers. Source [72]

The universal Plate Robot Adapter is used to attach the end-effector to the robotic arm. It has a mass of 80 g and complies with DIN ISO 9409-A50. This standardisation allows us to know the compatibility of connection with different arms.The arms plate weigh 50 g and allow the gap between the jaws to be adjusted.



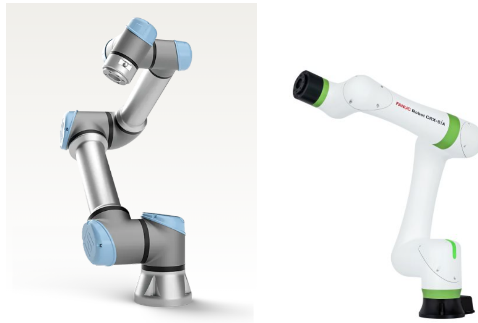
(a) Plate Robot Adapter



(b) Arms plate

Image 13: Specification of plate robot adaoter and arms plate. Source [72]

They have been compared commercially available manipulators that appear in [46] and that the extraction method is by rotation and pulling. Two candidates have been found: UR from Universal Robots [81] and ARC developed by FANUC.
According to the state of the art , the most commonly used are UR family. The UR5e has been chosen because it is the longest in the light arm range (UR10e is longer but heavier). It is not needed holding heavy loads



(a) UR5e (b) CRX-5iA

Image 14: Manipulator options. Source (a) [81]; (b) [55]

(end-effector + peach+ camera), so the maximum load to be supported suits perfectly. The manipulator reaches 200 mm further than a human arm, allowing it to reach the most inaccessible fruits. A design with aluminium and plastic provides lightness and allows 6 degrees of freedom. The power consumption of the arm is 570 W. It fits perfectly to our end-effector due to the connector type ISO-9409-1-50 (in case of incompatibility, a stone would be machined). In the article, an ARC Mate is used, however, the CRX-5iA collaborative robot is better suited to our specifications. This robot meets the required payload requirements as well as being protected against liquids and dust. Its reach is longer than the UR5e and it has 6 DoF. It is heavier than the one proposed by UR.
The UR5e robot has been chosen because of its long history of outdoor fruit robots. It is true that the robot developed by FANUC has a protection to prevent the entry of external bodies, but as have not been found any data on its performance in outdoor environments. Therefore, it has been decided to discard this option. Moreover, the UR5 robot is lighter than the CRX-5ia, making it perfect for mobile applications. Future research should check whether the range of the UR5 robot is sufficient or whether models with a greater range should be selected,

Specification	**UR5e** [81]	**CRX-5iA** [55]
Reach	850 mm	994 mm
Payload	5kg	5 kg
Weight	18,4 kg	25kg
DOF	6	6

Table 16: Specification manipulator UR5e and CRX-5iA. Source Author

For end-effector and manipulator operation , it is needeed two controllers: (i) end-effector control and (ii) manipulator control
. The proposed end-effector controller is SoftGripping Controlbox from Soft Gripping, a robust control box designed to operate pneumatic end-effectors. It has two outputs, one for the robot fingers and one in case we want to add a vacuum cup. It has a fast switching speed (< 20 ms) ensuring efficient control. An external compressor is required. The requirements to be met, according to SoftGripping's brand catalogue, are that the inlet pressure exerted must be 4-8 bar, it must operate at an air flow rate of more than 120 cycles per minute and it must allow for high mobility and continuous operation. The proposed compressor is California Air Tools CAT-1P1060S whose characteristics are summarised in the table 17. It requires low maintenance, does not require oil and it is light, making it perfect for a mobile platform.
As for the actuator that will operate the UR5e arm, it incorporates the Universal Robots Control Box (CB5). Its function will be to manage the movement of the robotic arm. It can coordinate and communicate with the end-effector controller via digital interfaces or an Ethernet network such as RS-485. That is, the CB5 system will plan the movement of the arm to approach the object, while the softGripping controller will activate the actuators to open or close the gripper.

Requirements	Value
Maximum Pressure	8.3 bar (90 psi)
Air Flow	1.2 cfm, 90 psi
Weigth	13 kg

Table 17: California Air Tools Light Quiet 1P1060S Portable Air Compressor. Source [50].

The costs of the main collection systems can be estimated. A table of prices is presented below.

4.6 Different Systems Integration and Harvesting Sequence

4.6.1 Integration Different Systems

The three identified systems communicate thanks to the Robot Operating System (ROS) software. It is a software that facilitates the integration between sensors, actuators and algorithms thanks to a system of nodes. The connections between the different systems can be via Ethernet, USB, cables... In our robot there are four nodes: location and mapping node, fruit detection node, path planning node and the end-effector and manipulator node. To run the ROS software, a computer was required to ensure speed and capacity to support all the systems. For the choice of this computer it has been taken into account which system is the most limiting in terms of processing. This system is the fruit identification and detection system. In some cases, this algorithm requires a specific computer [36], in other examples, only a GPU is needed [89]. Our detection algorithm is from the YOLO family, therefore, a study has been made on what kind of computers were used in different YOLO algorithms (table 18). Must be mentioned that after reading different with a wide variety of processors and graphics cards, there is one option repeated in much of them: Raspberry Pi.

Processor	RAM	Graphics card	Software Frameworks	References
Intel i7-12700H	16GB	NVIDIA GTX 3060, 6GB	PyTorch 1.10.1, CUDA 11.6, Pycharm 2021.3	[88]
AMD Ryzen 7 6800H	16GB	NVIDIA RTX 3070Ti, 8GB	PyTorch 1.13.1, CUDA 11.6, Pycharm 2022.1.4	[17]
AMD EPYC 7351P, 16 cores	Not defined	NVIDIA RTX 3090Ti, 24GB	Python 3.8, PyTorch 1.7, Ubuntu	[25]

Table 18: Computer vision systems comparison. Source Author.

The robot must work with the YOLOv8s-P algorithm, so will be used the hardware proposed in the documentation [17] . An AMD Ryzen 7 6800H processor is required, which offers high performance and the ability to work simultaneously on different tasks. A RAM of 16 GB should have enough capacity to store all the prior learning and ensure fast loading to achieve real-time detections. An NVIDIA GeForce RTX 3070Ti graphics card with 8GB of memory enables fast AI computations. The NVIDIA architecture is commonly used in AI applications. After a market research, it has been found that the AMD Ryzen 7 6800X3D is not currently available in the product line, so the immediately superior AMD Ryzen 7 7800X3D will be chosen. The search for the components of our system will be carried out on the PC components website [70]. The processor chosen as mentioned above is AMD Ryzen 7 6800X3D. The selected RAM memory is Kingston FURY Beast DDR4 3200 MHz 16GB 2x8GB CL16. The choice is based on being the current best-selling graphics card on the web that meets the desired characteristics. Palit GeForce RTX 3070 Ti GamingPro 8GB GDDR6X was chosen for the graphics memory, whose performance offers sufficient power for the correct operation of the identification system. According to the source PC Components, the prices of each part are listed in the table 20.

4.6.2 Harvesting Process

The proposed BabyGold9 variable collection sequence involves the integration of SLAM systems, identification, path planning and the picking system. The sequence that the robot will follow is as follows:

1. The robot starts to move around the orchard using the T265 camera, allowing the automaton to know its location and update the 3D map. The Gmapping algorithm runs in ROS creating the map while the robot is moving (SLAM system).
2. The robot navigates through the rows, the D435i cameras capture images of the environment and the YOLOv8s-P algorithm identifies the areas of interest, ROI , where there are ripe peaches (identification system).
3. Once identified the ROI zone, the RRT* algorithm plans the shortest route to the peach. For the creation of the movement pattern it uses both the map generated by Gmapping and the coordinates identified by the D43Di camera and analysed by the YOLOv8s-P algorithm (path planning system).
4. The controller of the manipulator and the end-effector receive the orders and proceed to pick the fruit (picking system).

This sequence assumes the three systems and the sensors used to capture the information. The integration of the systems is achieved through the use of the ROS which coordinates all the components to ensure accurate picking.

4.7 Profitability of the robot

In order to know the profitability of the project, i.e. whether the traditional method can be replaced by the proposed robot, a cost and performance evaluation must be carried out. The performance evaluation will be carried out by establishing the minimum requirements to be able to state that the robot is more optimal than people. In other words, it will be concluded that the robot is cost-effective if it is able to at least match the performance of a human. The cost evaluation will compare the labour costs of each season with the cost of producing and maintaining the robot. Break-point and tir.parameters will be analysed. To evaluate the yield, we will compare data from a farm harvested by the manual method. The selected orchard is "Giraba" (image 15).
It is located in Fraga, Huesca, Spain. Its climate is characterised by hot and dry summers, with temperatures around 35°. Moderate winters and low rainfall. The soils are characterised by a rich fertility, being a locality known for its extensive fruit fields, especially peach trees. With the help of Google Earth, the coordinates of the orchard have been measured: 41°32'00 "N 0°19'34 "E. The described orchard is located 2 km from the city centre and has an area of 4.5 hectares. The main characteristics of this orchard are summarized in the table 19.

Characteristics	Value
Area (ha)	4.5
Nº Peach trees evaluated	2000
Dimensions Peach tree (m)	3-4.5
Separation between trees (m)	4.5
Separation between columns (m)	5

Table 19: Giraba characteristics. Source Author.

The hypothesis is a season with an average number of peaches. To harvest this traditionally cultivated field of BabyGold 9 peaches, 10 people are needed. Harvesting is carried out in 3 passes. The first pass takes 10 days, the second 8 and the third 6 (24 days in total). The passes are carried out continuously, as soon as one pass is finished the next one begins. It is assumed a working day of 8 hours and a labour force of 10 euros per hour. 6,000 trees (2,000 each pass) are evaluated in 24 days. To find out how long it takes to harvest a tree, the following equation is used:

$$h/tree = \frac{24\ day \cdot 8\ h \cdot 60\ min/h}{6000\ tree} = 2\ min/tree$$

Therefore, the designed robot must be able to harvest a tree in less than 2 min to be profitable. It has been assumed that the workers pick continuously without breaks or breaks. According to the experience of people who perform this task, the estimated time to empty a tree is usually two minutes, but this is highly dependent on the amount of fruit in the tree. In addition, it is argued that a lot of time is lost due to breaks taken by workers to smoke or hydrate themselves.
The labour cost for a whole season tree, with the hiring of 10 employees is:

$$\text{Labour cost} = 10\ people \cdot 8\ h \cdot 10\ e/h \cdot 24\ day = 19.200\ e$$

To estimate the cost of the robot, it is summarised the selected elements in a table and add the costs for the integration of the systems and the costs of the structure. To establish these costs, it has been used the article [37] which details technical assumptions and economic results for the Autonomous Field Scouting system. .

Component	Price	Reference
Three Finger SoftActuator	830,63 $ (764,98 €)	[72]
SoftGripping Controlbox	1.8989 $ (1.745,16 €)	[72]
California Air Tools CAT-1P1060S	182 $ (167,44 €)	[51]
UR5e+ CB5	32.620,20 $ (30.010,58)	[80]
Intel RealSense D43Di (x3)	393 €	[60]
Intel RealSense Tracking-Camera T265 (x1)	571,37 €	[53]
AMD Ryzen 7 7800H	430 €	[67]
RAM 16GB	48 €	[68]
NVIDIA RTX 3070Ti, 8GB	615 €	[69]
Systems Integration	20.000 €	[37]
Architecture	8.000 €	[37]
TOTAL	**63.045,53 €**	

Table 20: Estimation robot costs. Source author.

In order to compare the manual model with the automated model, the following concepts must be defined:

- Initial Cost: It is the initial investment for the robot creation.
- Annual Manual Cost: Cost associated with manual tasks, i.e., workers' salaries.
- Annual Automated Cost: Cost of robot maintenance.
- Annual Savings: It is defined as Annual Manual Cost – Annual Automated Cost.
- Payback Period: The year when the initial investment is covered. It is calculated using this formula, $P = \frac{\text{Initial Cost}}{\text{Annual Savings}}$.

The development cost of the robot is 63.045,53 €. Annual maintenance costs (Annual maintenance costs = annual automated cost) are assumed to be 10 % of the value of the initial cost, i.e. 6.304 €. The annual manual cost is the cost associated with workers' salaries, 19.200 €. Therefore, there is an annual saving of 12.895€. Taking these data into account, it is considered that the investment is recovered in 5 years.

$$\text{Annual Saving} = 19.200 - 6.304 = 12.895, 45\ e$$

$$\text{Payback} = \frac{63.045, 53}{12.895} = 4, 89\ year$$

With this data can be compared the total costs over a period of 10 years. In the manual model the cumulative costs are 192,000 €while in the automated model they are 126,000 €(without taking into account the changing value of the currency).

$$\text{Manual Cost} = \text{Annual Manual Cost} \cdot \text{Number of Years} = 19.200 \cdot 10 = 192.000\ e$$

$$\text{Automated Cost} = \text{Initial Cost} + (\text{Accumulated Automated cost} \cdot \text{Number of Years}) = 63.045,53 + (6.304,55 \cdot 10) = 126.091\ e$$

Image 15: Yellow perimeter limits ”Finca Giraba” .Source [58].

4.8 Performance Evaluation

There is a lack of standardisation in the measurements and procedures for evaluating robot performance [9]. In other words, each paper measures in different ways, different processes. This makes it difficult to compare results. To reflect this problem, an example of pick-up time is given. Some articles define it as the time it takes for the gripper to complete the action of grabbing, separating and placing the fruit in a container. While the vast majority of articles define it as the time it takes for the robot to identify the fruit and complete the picking action. In order to ensure a robust robot and to be able to test in detail its weaknesses and strengths, the three main systems should be tested separately in the laboratory and then all integrated in an orchard environment.In addition, it will be evaluated under different rain, wind and lighting conditions. Despite having chosen a concrete solution for each system, a couple more of the proposed systems will have to be evaluated to corroborate that the theoretically chosen option is the correct one. The results should be quantitatively reflected in tables and graphs.

4.8.1 Before Orchard Testing

Before integrating all our systems into the ROS software, must be checked their individual efficiency.

Identification system:

To test a CNN that uses artificial intelligence to detect objects,the following steps must be carried out : (i) data capture, the device used to take images must be defined and the field in which they are taken must be described. In addition, they should be taken with different perspectives, shooting distances, illuminations and with/without obstacles.(ii) The images should be classified with annotation software. The proposed one is Labellmg [17]. (iii) Training of the network by validation and testing. Finally,(iv) the model is evaluated using accuracy (P), recall (R), F1 score and AP average metrics. Although ,the YOLOv8s-P model demonstrates high accuracy, more lightweight and commonly used models such as YOLOv3-tiny should be tested.

Navigation System:

To test both systems, route creation and SLAM, it is necessary to create a simulated environment. For this task, it is proposed the V-REP software, capable of creating an interactive 3D environment [47]. This model must include trees and fruits. A mobile robot must be configured in V-REP integrated with the RealSense T265 camera. To collect data, the robot must move through the simulated environment and observe how the Gmapping software builds the map in real time. The RRT* algorithm must also be tested in this simulated environment. The parameters to be evaluated are: (i) processing time, (ii) travel time, (iii) distance travelled and (iv) battery consumption. Apart from the proposed software, the option of RRT*+PSO or only the PSO software should be analysed.

Picking System:

Initial tests can be performed by exchanging the BabyGold 9 variable for spherical objects placed on a table surface or suspended. Furthermore, it is not necessary for the manipulator to have all degrees of freedom as we only evaluate the grasping ability of the gripper. However, this model is far from reality. For future tests, a tree planted on a plot of land close to the site will be used. It is only needed the movements of arm extension, opening/closing of the gripper, rotation and retraction of the arm. According with [9], the parameters to be measured should be:

- Picking area: Refers to the two-dimensional surface on which the gripper successfully grabs the fruit. That is, the fruit is placed on a table and the arm is moved over it. The manipulator will try to pick up the fruit. It must be recorded whether the grip attempt from the different positions has been successful. With this data, a 2D plane is drawn with an (x) for success and (o) for failure. The contour that connects all (x) is the picking area. A larger area implies that from different positions the robot is able to pick fruits with a good reach.
- Picking volume: This is the space within which the gripper successfully grabs the fruits. In other words, it is the same test as the picking area but in 3 dimensions. It is used to evaluate the gripper's reach in an environment where the fruits are at different heights and depths.
- Forces and finger position: These are the necessary forces applied to ensure a successful extraction. Using a dynamometer, must be measured the horizontal force that generates the twisting, the gripping force and the vertical force to ensure the lowest possible damage rate. In addition, these forces must also be related to the time it takes to achieve extraction. The different finger configurations proposed should also be studied. The proposed position is the most similar to human action, however, it does not guarantee that it is the best option. It should be checked with which configuration the least force is exerted, the least time is taken and the harvest is successful.

4.8.2 Orchard Testing

Once the robot has been verified that the chosen systems are the correct ones and the best options, its performance must be tested in a real environment. First, the area where the robot will be tested must be described. This includes the location, the weather conditions and the characteristics of the field itself. An example of a proposed field could be "Finca Giraba" (image 15), defined in section *Profitability of the robot*. The evaluation will be carried out taking into account the cycle time, success rate and damage rate parameters. Cycle time is defined as the time it takes for an entire cycle from extraction to extraction during the same tree (Cycle time does not include the movement time between trees). It will be calculated with average of all extractions. Inside this cycle can be dived in different time tasks.

Time task	Description
Detection and Identification Time	Time taken by the robot to detect the fruit to be harvested
Approach to fruit Time	Time it takes for the robot to approach the tree lightly and bring its arm close to the fruit.
Picking System time	Time it takes for the harvesting system to pick the fruit, remove it from the tree and store it.
Order processing time	Time taken by the computer to send commands and by the systems to process them.

Table 21: Cycle time descomposition. Source Author.

Success rate is defined as the percentage of success with respect to the total number of fruits. A right extraction consists of a correct detection of the maturity point of the fruit and no damage to the fruit. Finally, the damage rate will evaluate both the damage on the surface (skin) and the damage inside the fruit (flesh). These parameters will be measured with the following formulas:

$$C = \frac{\sum_{i=1}^{n}(T_{0_i} - T_{1_i})}{n}$$

where C, the average time of picking n peaches,s;T_{0_i}, the moment of time that starts the peach identification action,s;T_{1_i} the time it takes to separate the peaches from the tree,s; n, the total number of peaches

$$\text{Success Rate} = \frac{r}{n} \cdot 100\%$$

Where S, is the success rate; r, the total number of fruits successfully extracted.

$$\text{Damage Rate} = \frac{f}{n} \cdot 100\%$$

Where D, is the damage rate; f, is the total number of damaged fruits.
By means of this evaluation, first individually and in laboratories and then in the field, taking into account the three factors that most limit the application of these robots in real life, we will efficiently check the performance of the designed robot.

5 Conclusion

Hard working conditions and rising prices for fruit products lead to a decrease in consumption. A repetitive task such as fruit harvesting can be automated, reducing labour costs and increasing efficiency. This paper proposes the design of a robot capable of harvesting BabyGolg9 peaches. Three main systems have been identified: Detection, Navigation and Picking system. Different solutions for each systems have been proposed to ensure efficiency in the robot.
The critical characteristics of weight $(160 - 188g)$, spherical shape $(L/W = 1)$ and dimensions $(varnothing = 67 - 90mm)$ will limit the choice of gripper. In addition, its firmness $(3.5 - 4.2Kg/cm^2)$, which despite being categorised as a non-melting variable, the peach is susceptible to damage, reducing its profit margin. This characteristic defines the forces exerted $(F_m = 4N, F_n = 1NandF_g = 5N)$, which have been established by an approximation based on experience and the soft materials used in the end-effectors. Another factor of vital importance for the choice of the gripper is the detachment method, which is to imitate the traditional way of rotation and a slight pull, without adjacent tools. To execute this movement, a three-finger gripper has been chosen, which is positioned according to the posture 3.
The external colour $(L^* = 43.62 \pm 0.17; a^* = 3.39 \pm 0.06; b^* = 24.09 \pm 1.40)$ is the variable on which the robot will base the evaluation of the ripeness point. Thanks to its reddish, yellowish and orange tones, it can be clearly distinguished from the branches and leaves, together with its spherical shape, are the two

characteristics on which the identification system is based.
The parameters of the environment in which the peach grows have also been evaluated. It has been concluded that plantations have a tendency to be distributed in row and column patterns. Peach tree height of between 3-5 m is essential to ensure that the end-effector reaches the highest fruit. The row and column layout determines the choice of our navigation system. It is a structured and dynamic environment as there are slight changes such as growth or detachment of branches, movement of rocks.... Therefore, the chosen algorithm should not be the most complex because it would slow down the computational calculations, neither the simplest because it should be able to adapt to changes.
After identifying which parameters constrain each system, the choice of these was made by comparing different solutions and evaluating the state of the art of previous studies. The proposed identification system was YOLOV8s-P. This choice is based on two pillars: the precedents and the values of precision, recall, F1 and size. After reviewing several scientific articles, it can be seen that YOLOs family are one of the most common. In addition, there are guarantees of their correct use in peaches [17] [25]. Within this family, YOLOv8s-P has been chosen because it is the most updated version, and according to the article [17] which evaluates different models for the detection of the "Okubo" peach, it concludes that this software stands out from the rest in terms of performance, recall and F1. However, it is true that it is not the lightest in terms of weight, which would affect the cycle time.
As for the navigation system, can be divided it into the SLAM system in charge of mapping the environment, whose proposed software is Gmapping, and the RRT** algorithm in charge of route planning. The choice of the Gmapping algorithm is based on precedents such as [3] and on the ease of implementation in the ROS system. The choice of the RRT* algorithm is based on its extensive use in different robots such as [85] [88] and its simplicity. That is, its low execution time can guarantee high success rates.
Finally, the picking system is subdivided into the end-effector and manipulator. Although most of the articles reviewed , propose a customised and proprietary end-effector, has been decided to choose commercial end-effectors that fit our requirements. First, end-effector was chosen and then the robotic arm was chosen. The gripper chosen is a three-finger soft end-effector developed by SoftGripping, which is the best suited to BabyGold9's strength and dimensional specifications. It is a pneumatic actuator that requires an external compressor and control box. The control box provided by the gripper manufacturer, SoftGripping Controlbox, and the compressor is California Air Tools CAT-1P1060S , capable of providing the necessary pressure to execute the gripper and with a light weight to facilitate its mobility. The manipulator is UR5e, developed by Universal Studios. The purchase also includes a control box. It has been chosen because of its compatibility with the end-effector (DIN ISO 9409-A50) and its great popularity in the automation industry. Moreover, among the arms proposed by UR, it is the one that best suits our needs, light in weight and long enough to reach the top of the trees. It has 6 DoF and is able to support the weight of the peach and end-effector.
To implement all three systems, a series of sensors and GPU are required to ensure their correct operation. The Intel real sense D435i camera has been chosen, which combines an RGB camera to detect colours and depth sensors to determine the three-dimensional position. In addition, it is fully compatible with the YOLOv8s-P agortimo. To run the SLAM algorithm, the T265 camera is used, which is less expensive than LiADAR systems and still offers a good solution for mapping the environment. The choice of GPU, AMD Ryzen 7 7800X3D, NVIDIA GeForce RTX 3070Ti, and 16 GB of RAM is limited by ensuring that the systems perform correctly. The system that limits this action the most is the detection system, so a sufficiently powerful GPU has been chosen to support this program.
The robot must be able to harvest a tree in 2 minutes to match the performance of a human. The cost analysis shows that the robot will pay for itself in 5 years. Saving each year 12.895,45 €if the conventional method is replaced by the proposed robot. These numbers demonstrate its profitability over time. Therefore, if the technical requirements of cycle time, success rate and damage rate are matched to those of a human being, the robot for the collection of BabyGold 9 is a good option to automate the process.
This theoretical approach to the robot should be tested according to section 4.6. A preliminary evaluation should be done in the laboratory, studying each system separately. Subsequently, it should be tested in a field as described in the "Finca Giraba" experiment, collecting all the data in tables and graphs. The parameters to be analysed should be those that currently limit the automation of this process: cycle time, success rate and fruit damage rate.
For future research, not only the proposed solutions should be tested, but also the mentioned variables to ensure that the theoretical choice of algorithms and hardware is correct. In addition, empirical tests with

sensors should be carried out to evaluate the forces exerted in a quantitative and accurate manner. In addition, the physical design of the robot, its dimensions and the elements that integrate it must be detailed.

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