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Synthesis of a new clamping mechanism design for agricultural harvest

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Abstract. Innovation in mechanisms for agricultural devices is essential for improving the efficiency, productivity, and sustainability of agricultural practices. In this context, harvesting is a critical process that impacts the yield and quality of crops, as well as the efficiency of the overall farming operation. The use of appropriate harvesting mechanisms can increase productivity, minimize losses due to damage or waste and reduce labor costs. Therefore, investment in research and development of innovative mechanisms for agricultural machinery is crucial for achieving sustainable and profitable agricultural practices, creating new opportunities. The creation of new devices through the development of novel kinematic structures remains a significant challenge. Traditionally, designers relied on their intuition, creativity, and experience to accomplish this task. To improve this process, the use of systematic methodologies to assist in the process of generating new kinematic chains of mechanisms is of paramount importance. These methods ensure an organized and structured development process, guaranteeing better results at the conceptual design process. The objective of this work is the applying of a method for generating and selecting the kinematic chain for a novel harvesting end effector. For this purpose, kinetic and other characteristics of existing mechanisms will be extracted through the use of tools to analyze the mechanical design, classifying them into three categories, being the functional requirements, structural characteristics and other design constraints. These features are relevant in the generation of new chains and serve as elimination criteria for results that do not meet them. Then, possible variants for the solution will be generated, using selection criteria previously established to choose the kinematic chain in order to develop a new clamping device. The results demonstrate that this proposed methodology generates design possibilities that can be alternative to the existing ones. A brief discussion of the implications of this method for agricultural engineering is carried out, and the comparison of them with other existing methodologies is performed. The results show that the applied methodology was effective for the creation of a new clamping mechanism for harvesting with mobility two and two closed loops, which can be adaptable to different types of fruits. Thus, its versatility is important to reduce manufacturing costs. The dimensional synthesis of the mechanism and optimization are suggestions for future work.

Keywords: Robotics, Mechanisms Design, End effector, Harvesting device, Mechanical harvest.

1. INTRODUCTION

Harvesting plays a fundamental role in the global food supply and is an essential activity for the agricultural sector. Manual harvesting is a widely adopted practice in this process, as it ensures a good appearance and quality of the fruits (Hua *et al.*, 2018). However, there are certain challenges associated with this practice, namely its time-consuming nature and the high labor intensity it demands (Xu *et al.*, 2014) (Morgan, 2002) (Schmoldt, 2008) (Schupp *et al.*, 2011). Furthermore, there is an escalating challenge in procuring skilled labor for the manual harvesting of apples (Martin *et al.*, 1983) (Martin, 1985) (Domigan *et al.*, 1988) (Peterson and Miller, 1996) (Peterson *et al.*, 1997) (Hansen, 1999) (Warner, 2003). In addition to these, a recurring issue is the health problems associated with this practice. Zhang *et al.* (2016) provides some examples as (Fulmer *et al.*, 2002), which examined ergonomic postures involved in harvesting and highlighted that contact stress from shoulder straps and improper postures contributed to strain-related issues. Sakakibara *et al.* (1995) presented empirical evidence linking overhead work during apple harvesting to shoulder and neck disorders. Earle-Richardson *et al.* (2006) demonstrated that manual harvest work led to occupational health problems, including strains in the neck, back, and shoulders. Moreover, Fathallah (2010) emphasized that the harvesting process exposed

workers to fall hazards while standing on ladders for picking and while ascending or descending ladders.

In order to address these issues, the pursuit of efficient harvesting methods has become a priority for farmers and researchers. In this context, technological advancements have played a pivotal role, facilitating the development of novel harvesting devices (Hua *et al.*, 2018) (Berlage and Langmo, 1979) (Holt, 1999) (Peterson, 1992) (Zhang *et al.*, 2016). These mechanisms possess the capability to operate under diverse environmental conditions, such as crops of varying heights and variations in plant maturation stages. To achieve this, they leverage principles from mechanism theory, robotics, artificial intelligence, and advanced sensors. However, certain challenges are encountered in such devices that still require resolution. Among these challenges, one can highlight the diversity of dimensions, texture, and rigidity, which complicates the development of a single harvesting system capable of encompassing these varied types (Hua *et al.*, 2018) (Longsheng *et al.*, 2015). Addressing this issue is crucial, particularly considering the seasonal nature of planting. Another significant concern to be mitigated is the potential loss resulting from fruit damage during the automated harvesting process (Hua *et al.*, 2018).

Thus, the purpose of this article is to introduce a new harvesting gripping mechanism for agricultural purposes, highlighting its benefits, operation, and adaptability to different types of fruits. The gripping technology is a key component of harvesting equipment, responsible for effectively and delicately extracting agricultural products from plants while preserving their integrity and minimizing losses. This adaptability is made by varying the stiffness in the claw. Regarding existing gripping devices, one of the main advantages of this new mechanism is its ability to adapt to various types of fruits, considering the seasonal aspects of harvesting, resulting in a significant increase in agricultural productivity. Additionally, the gentle handling of agricultural products reduces physical damage to plants, thereby enhancing the quality of harvested goods. The methodology employed in developing the device is based on the works of Yan (1998), Hartenberg and Danavit (1964), Tsai (2000), and Martins and Murai (2019), as described in detail in Section 2. In this article, Section 2 provides a brief literature review on current major harvesting mechanisms, while Section 3 presents the methodology to be utilized as well as details regarding the development. Section 4 presents the results and discussions, and Section 5 concludes the article with suggestions for future work.

2. STATE-OF-ART

The Grippers, a class of end effectors, have undergone significant development in various fields over recent years. In the agricultural area a considerable challenge lies in the efficient handling of fruits due to their high sensitivity during the approach, clamping, and displacement stages. Accurate and gentle fruit handling is essential to ensure the desired destination for the fruit, whether for consumption, processing, or sale. Furthermore, the use of a well-designed device can improve production rates, reduce costs for producers, and lower prices for customers. An exploration of effective strategies for fruit picking, including the selection of appropriate gripper types, while considering the mechanical and physical properties of different fruits is presented below.

2.1 Importance of Grippers on the Farm Industry

The reason behind the utilization of grippers in crop-related activities in the agricultural industry is associated with numerous hazards and challenges, including labor-intensive work, adverse working conditions, physical strain on workers, and potential injuries. Additionally, employers encounter drawbacks such as high labor costs, extensive training requirements, and a declining workforce due to urban migration and the allure of the technology sector. Furthermore, the harvest stage has been identified as a time-intensive process, as demonstrated by Neto (2020) findings in apple plantations, illustrated in Figure 1. Building upon the insights gained from the apple harvest study, optimization techniques and approaches to reduce the runtime is crucial.

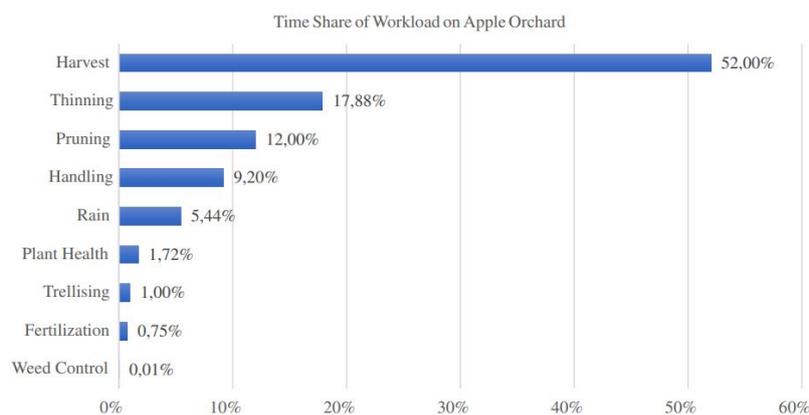


Figure 1: Time expending of each activity on apple orchard

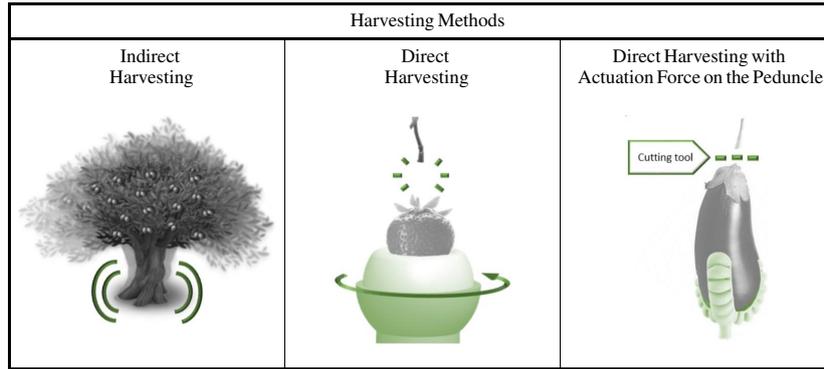


Figure 2: The main aspect and consideration in pipe inspection robots

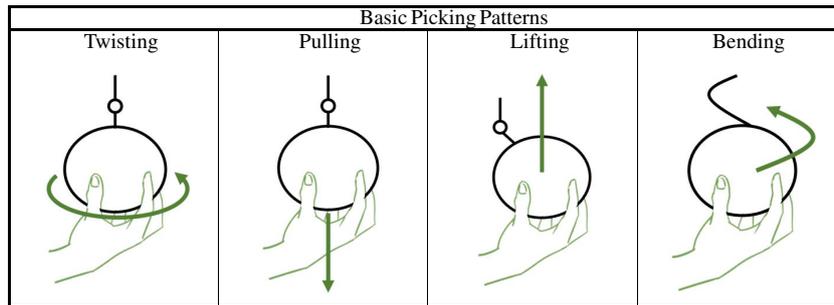


Figure 3: Patterns to grab fruits

2.2 Fruit Picking

On the harvest, a crucial aspect is the selection of the most effective method for fruit picking. Multiple approaches exist, and it is important to carefully assess and determine which method best serves the intended purpose. According to Navas *et al.* (2021), there are three automatic harvesting methods to gather fruits. The first method is called indirect harvesting, where a machine grad a trunk and shakes the tree to cause the fruit detachment, then, it's collected on the ground or a specific machine surface. The second method is direct harvesting where a machine grabs the fruit and picks it up one by one. The third method is direct harvesting with actuation force on the peduncle, where machines grab the fruit and then cut the peduncle above one by one, as shown in Figure 2.

In this article, the method which will be used is direct harvesting. Inside the approach, there are some subcategories on the way to proceed with the harvest. According to Navas *et al.* (2021), there are four picking patterns: twisting (twisting the fruit till the peduncle brake), pulling down the fruit, lifting up the fruit up to detachment, and bending, where twisting toward some direction to brake the peduncle, Figure 3. Here, will be used the pulling pattern, where the machine and the gripper can be simplified using fewer actuators (drive motors) to do the action. Focusing on harvest fruit grasp, it's noticed that some aspects are representative, such as dexterity, low power input, and a wide range of dimensions of the grippers. To accomplish the task with low bruise fruit rates the paramount importance is the right choice about which kind of end effector is selected. According to Zheng *et al.* (2011) for more precision and dexterity, prismatic grippers as 2, 3, and 4 fingers are the best choice due a high dexterity and a great performance on detailed objects, as shown in figure 4.

2.3 Analyzing grip modes

It's possible to find various kinds of grippers for any proposal. From suction grippers for picking and placing industrial goods to multi-finger grippers for special needs. Figure 5, adapted from Zhang *et al.* (2020), presents a brief overview of grippers' characteristics. And according to figure 4, it's possible to understand the use of grippers with fingers is suitable to accomplish the harvest due to a high level of dexterity and the ability to deal with small objects. The actuation of the mechanism is essential, as well, to minimize the number of components. Gripping mode is defined according to the handle object, in this case, fruits are objects, and it doesn't have an internal area to be gripped, the only possible mode is the external gripper, where the contact area of the fruit is on the external surface. Another factor is which mechanism will transmit power for actuators. In this context, it is important that forces are applied toward the fruit center of gravity, in this way, doesn't need to apply thrust on the opening of the mechanism.

An additional aspect to be analyzed is the object being handled. Fruits are not ordinary industrial components; they possess certain distinct characteristics. Figure 6 illustrates some of the specificities that must be taken into consideration during the development of a novel grip device for fruits. This paper will only enumerate the attributes pertinent to fruits,

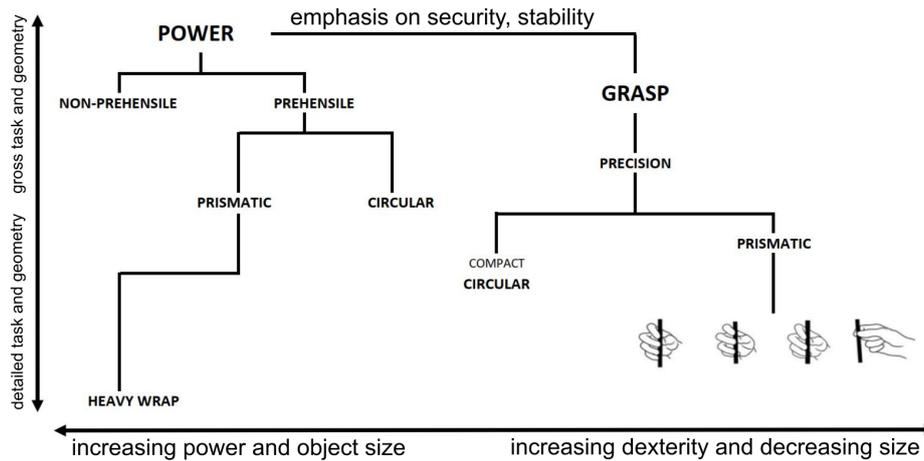


Figure 4: Adopted gripping category

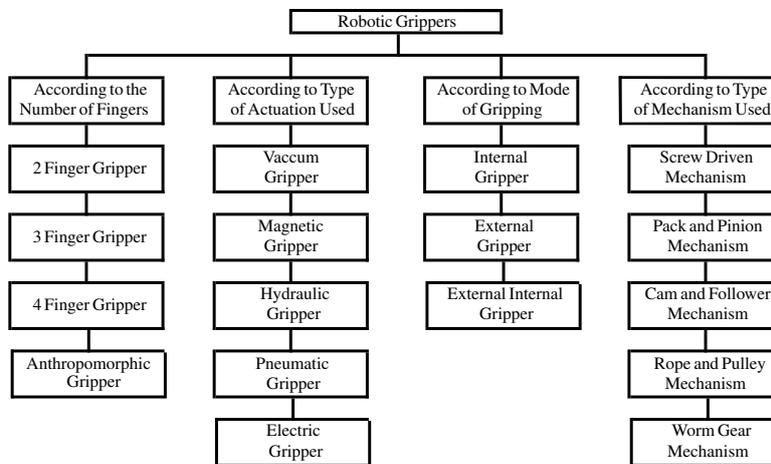


Figure 5: Gripper Properties

as mass, material properties, and geometry. The remaining aspects will be deliberated in a subsequent publication.

The initial topic in the list pertains to the mass and diameter of the fruits. Each type of crop possesses distinct specifications and a range of variations. In accordance with Markovic *et al.* (2014), table 1 presents average measurements for these mass and size parameters. It is important to note that due to the circular shape of fruits, dimensions such as height, width, and length will not be explicitly mentioned, only the diameter.

Among several parameters to evaluate such as friction, hardness, humidity levels on grab moment, a significant aspect to discuss is the mechanical properties of the fruit, specifically Young's Modulus. This parameter plays a pivotal role in determining the forces required for fruit handling. Insufficient force application would result in an unsuccessful grip, while excessive force application would lead to premature fruit bruising. Table 2, as reported by Russo *et al.* (2017), provides mechanical property data for the corresponding crop varieties. In order to assess the pronounced susceptibility of fruits, Li *et al.* (2016) conducted an experimental study wherein varying forces were applied to the finger of an end effector, and subsequently, the resulting percentage of bruised fruits was analyzed. The study findings, Table 3, indicated that the two highest applied forces resulted in bruising of 46.7% and 60% of the gripped fruits, underscoring their inadequacy for apple harvesting applications. Consequently, the identification of the optimal force necessary for fruit grasping emerges as a crucial objective for manipulator systems.

2.4 Actuator with Adjustable Stiffness

The utilization of Actuators with Adjustable Stiffness (ARV) constitutes an additional topic to be explored in this paper. As outlined by Rosa (2018), this concept refers to actuators that combine both rigid and compliant elements within the same device. To facilitate comprehension, the ARV is primarily based on rigid actuators, which maintain their position independently of the applied force, and compliant actuators, which exhibit the capacity to adjust their equilibrium position in response to external forces. The equilibrium position represents a state in which the actuators generate zero forces or torques. Hence, the distinguishing characteristic of ARV lies in its ability to modulate stiffness and thereby enhance or reduce compliance by modifying its own configuration. The overarching goal is to facilitate adjustments in gripper forces

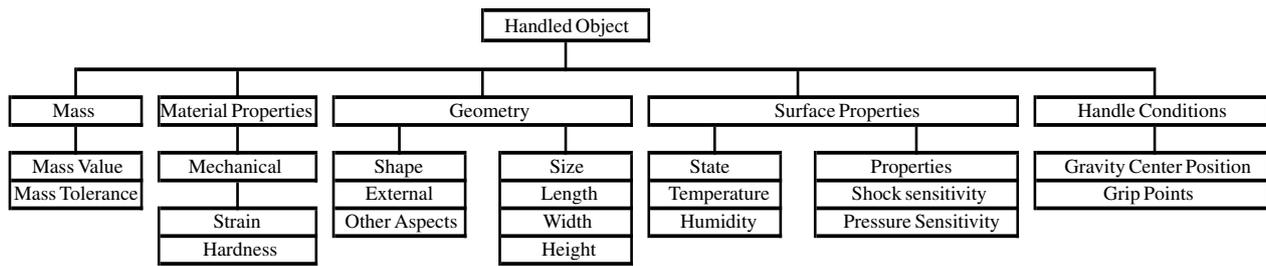


Figure 6: Main characteristics from the object to be handled

Table 1: Fruit Sizes and Masses

| Kind of Fruit and Variety | Average Crop Diameter (mm) | Average Crop Mass (g) |
|---------------------------|----------------------------|-----------------------|
| Mango Steen | 55 | 80 |
| Tangerine Clementine | 60 | 82 |
| Orange Tomposo | 77 | 218 |
| Apple Redspar | 80,4 | 229,6 |
| Peach Filina | 68,1 | 181 |
| Apricot Rajabali | 43 | 53 |
| Cherry Chabestar | 21 | 6 |
| Deep Frozen Raspberry | 20 | 6 |

Table 2: Mechanical Properties

| Product | Young's Modulus Average (MPa) | Poisson's Ratio |
|-----------------|-------------------------------|-----------------|
| Tomato - Ripe | 2.32 | 0.74 |
| Tomato - Unripe | 4.07 | 0.55 |
| Pear | 5.80 | 0.25 |
| Apple | 12.89 | 0.32 |

when grasping a fruit.

2.5 Methodology for mechanism development

The development of a new gripper concept in this study will employ the Murai Methodology. As stated by Murai (2019), this approach aims to systematize the design process of mechanisms, thereby minimizing subjective decisions made by designers. The methodology's framework comprises several steps to achieve a final design. These steps include researching the state-of-the-art of mechanisms applicable to the specific context, analyzing the structural and design requirements derived from the previous step, documenting the identified requirements, selecting feasible design requirements, generating and analyzing design possibilities, performing type synthesis, conducting dimensional synthesis (establishing the dimensions of the links and angles of the critical points), and prototyping the product. However, in this paper, only the first seven steps of the Murai Methodology are implemented.

1. Number synthesis: In this stage, the mechanism that is the subject of study is materialized, transitioning from desired characteristics to a projection of what the mechanism will become. Through the enumeration methodology, the variations are determined, which encompass all possible combinations of links and joints, typically represented by graphs. Additionally, the inversions are also considered, which encompass all possibilities of links as a basis for each of the variations Martins and Murai (2019).
2. Type synthesis: After completing the synthesis of the number, the next step is the synthesis of the type, where the types of each joint are determined Hartenberg and Danavit (1964). This stage can be supported by the previously defined design requirements.

3. Development

This section outlines the steps for the project development, divided into topics. The methodology employed here is based on the Mechanism Design Methodology introduced in Martins and Murai (2019), which combines the methodologies presented in Hartenberg and Danavit (1964) Yan (1998) Tsai (2000).

3.1 State of the art survey

Following the proposed methodology, the first step in developing the claw mechanism involved conducting a state-of-the-art survey. This stage played a crucial role in the development of the mechanism, as it allowed for the establishment of requirements to initiate the synthesis. Section 2 provided a concise overview of the relevant aspects necessary to understand the available equipment and market trends. Based on existing equipment for fruit harvest and variable force systems, requirements for the synthesis of the number and other stages were extracted.

Table 3: Comparison of Grasping Force and Fruit Damages

| Picking Pattern | Grasping Force (N) | | | Percentage of Bruised Samples (%) |
|-----------------|--------------------|-------------|------------|-----------------------------------|
| | Finger I | Finger II | Finger III | |
| Pattern 1 | 4.76 ±0.86 | 7.16 ±1.59 | 3.23 ±0.64 | 0.74 |
| Pattern 2 | 5.39 ±1.24 | 8.65 ±1.42 | 6.28 ±0.81 | 0.55 |
| Pattern 3 | 14.47 ±1.14 | 9.48 ±1.03 | 8.53 ±1.37 | 0.25 |
| Pattern 4 | 15.87 ±1.70 | 11.28 ±1.63 | 6.04 ±1.00 | 0.32 |

Table 4: Design requirements

| Number | Design requirement |
|--------|--|
| DR1 | The mechanism must have three claws or fingers |
| DR2 | Must be two actuators, one to open and close the mechanism and another to vary the stiffness of the gripper |
| DR3 | The actuator responsible for actuation must not interfere with the rigidity of the mechanism |
| DR4 | The actuator responsible for the stiffness variation must not interfere with the movement of the mechanism |
| DR5 | Synthesis must be made for two separate mechanisms, one for varying the rigidity of the gripper and another for opening and closing it |
| DR6 | The mechanism must be self-aligning |
| DR1a | Stiffness will be varied through two springs |
| DR2a | The two springs must be connected to the base and to the effector |
| DR1b | There must be three sub circuits with two binary links in series |
| DR2b | The base must be connected to the three sub circuits determined in DR1b |

3.2 Analysis of existing mechanisms

Based on the projects found during the state-of-the-art survey, several actuators were selected for analysis of their characteristics. In addition to seeking structural features, the objective here is also to identify other requirements that may be useful in selecting candidate mechanisms and determining the type of joints in the type synthesis.

3.3 Design and structural requirements

The first requirements to be delimited were the design. These requirements not only serve as a filter or guide for the subsequent steps after the number synthesis but also contribute to enhancing the overall design. Based on previously developed projects and the vision of the designers, the following design requirements (DR) were determined, as shown in Table 4. To meet requirement DR1, the mechanism needs to provide movement in 3 points with synchronized behavior for device opening and closing. DR5 stipulates that the synthesis for the device should be done for two separate mechanisms that will be joined together later to perform the proposed function. This is a consequence of DR3 and DR4, as in order for the actuators not to interfere with each other's operation, the mechanism must be divided. For the synthesis of these type mechanisms, the aggregation of two simpler mechanisms can be considered, which involves combining links from two kinematic chains to form a divided chain Martins *et al.* (2010). DR6 states that the mechanism must be self-aligning, and this analysis will be performed for each sub-mechanism. Starting from DR6, requirements with the suffix 'a' refer to the mechanism for tension variation, while those with the suffix 'b' refer to the mechanism for opening and closing. There should be two sub-circuits with two binary links in sequence, reflecting the possibility of having two springs (DR1a). To meet requirement DR2a, it is necessary for the binary links in sequence to be connected to the same bodies. Requirement DR1b is related to the presence of three claws (DR1), and the required sub-circuits will be responsible for the articulation of each "finger." DR2b is specified to ensure the rigidity of the mechanism.

For the development of the mechanism synthesis, the chosen workspace was planar, with $\lambda = 3$, for both mechanisms. Operating in this coordinate system ensures the correct and necessary functioning for each finger of the gripper. Three parameters (mobility, number of circuits, and workspace) need to be defined to initiate the candidate generation process for the kinematic chain of the problem (number synthesis). Therefore, structural and design requirements were defined based on characteristics of already developed systems, aiming for new possibilities in terms of structural features. In addition to the workspace, as mentioned before, two other parameters need to be defined to enable the application of the method. The first one is mobility, which delimits the degree of freedom of the mechanism. These parameters was chosen considering that the mechanism needs 2DOF for the tension variation mechanism, and another 1DOF for the clamp opening and closing system. Finally, another parameter needs to be defined for equation application, which is the number of circuits. The chosen number of circuits was 3 ($\nu = 3$), for the mechanism "a" and "b" (adjustable stiffness and opening/closing mechanism). These characteristics were derived from observing existing projects, and similar to the workspace, the aim was to choose a magnitude that ensures the mechanism's efficiency while keeping it simple, ensuring good functioning and robustness. Table 5 and Table 6 present the values of the requirements for each sub-mechanism.

Table 5: Structural requirements (a)

| Number | Structural Requirement |
|--------|------------------------|
| SR1 | Work Space = 3 |
| SR2 | Number of loops = 3 |
| SR3 | Mobility = 2 |

Table 6: Structural requirements (b)

| Number | Structural Requirement |
|--------|------------------------|
| SR1 | Work Space = 3 |
| SR2 | Number of loops = 3 |
| SR3 | Mobility = 1 |

3.4 Number synthesis

To align with the proposed requirements, the type synthesis of the harvesting mechanism will be done in two parts. The first part is for the variable stiffness mechanism of each "finger" and the second part is for the motion mechanism. In order to perform the number synthesis, it's necessary to define the number of links and joints based on the established structural characteristics. This step is essential for the application of the number synthesis method, whether manually or computationally. Two equations are utilized to determine the number of links and joints. The first is the mobility equation for expanded pairs (Eq. 1), where M represents the mobility, λ the workspace dimension, n the number of links, and j the number of joints.

$$M = \lambda(n - j - 1) + j \quad (\text{Eq.1})$$

The second is the Euler equation (Eq. 2), where ν represents the number of circuits.

$$\nu - 1 = j - n \quad (\text{Eq.2})$$

3.4.1 Number synthesis of variable stiffness mechanism

Based on the two equations, the obtained value for the number of links(n) was 7, and for the number of joints(j) equal to 8. The determination of partitions and variations for the mechanism graphs can be done manually, but it is also possible to find the solution computationally. For the development, was chosen to use a graph generator through the SageMath software. The Nauty Generator, developed by Brendan McKay (McKay, 1990), was used to reach the solution. In addition to the number of links and joints, which are necessary input data, the generator has other parameters that can be provided or not. Two of these parameters were used as filters: the first one to generate only connected graphs (-C), and the second one to generate triangle-free graphs (-t).

The number of graphs obtained from the generator was 38, which were reduced to 35 by excluding those with Baranov chains (Morlin, 2021). Filtering the graphs based on the design requirements, DR5 and DR6, resulted in only 4 candidate graphs. Figure 7 shows the four resulting graphs from the process. Taking into consideration the DR2a requirement, the possible inversions are as follows for each of the mechanisms (Figure 8).

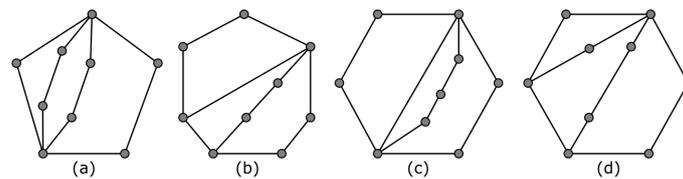


Figure 7: Graphs of variable stiffness mechanism

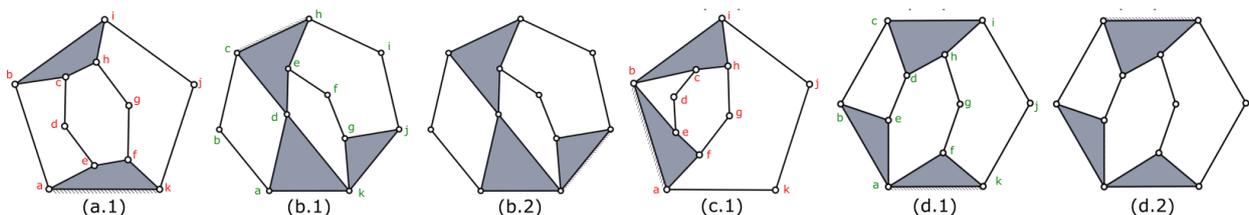


Figure 8: Diagrams of the inversions for variable stiffness mechanism

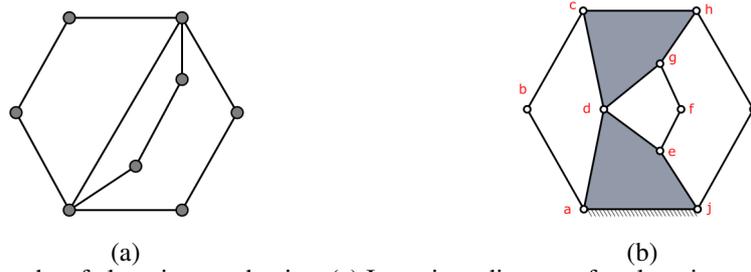


Figure 9: Graphs of clamping mechanism (a) Inversions diagrams for clamping mechanism (b)

3.4.2 Number synthesis of opening and closing mechanism

For the clamping opening and closing mechanism, the mobility (M) is equal to one, and the chosen workspace is also planar. Despite having three claws and the movement of each one occurs in different planes, this consideration can be made since the actuation generates symmetric movement in all three fingers. The number of circuits (ν), was determined as three, also due to the number of fingers. For these input parameters, nineteen graphs were generated, out of which three were eliminated by the Baranov chain filter. After evaluating the requirement DR1b, only one candidate graph remained, which is shown below Figure 9a. As can be observed in Figure 9b, there is only one possible inversion for this mechanism based on the listed design requirements Table 4.

3.5 Type synthesis

To select the joints for each of the mechanisms, the self-alignment criterion (DR6), was proposed by Reshetov. The self-alignment method consists of avoiding over-constraints in the mechanisms. The advantages of having this characteristic in the mechanisms will be discussed in the results.

3.6 Type synthesis of variable stiffness mechanism

There are four possible kinematic chains for the variable stiffness mechanism that will be implemented as the clamping fingers. To demonstrate the process, the first mechanism (Figure 8 a.1) will be used. The mechanism has two springs, which in the helical system ($\lambda = 6$), where Reshetov's analysis is applied, allows for 6DOF (Degrees of Freedom) for witch spring. These degrees are distributed among the joints c, d, e, h, g, and f. In order to provide a more concise description of the selected joints, the types of joints and their respective axes of action will be outlined. The revolution joints (1DOF) encompass k(x), a(z), and b(z). The helical joints (1DOF) comprise j(x), only. The joints c(x), d(y), e(z), f(x), g(y) and h(z), referring to the spring, were adopted as cylindrical joints (2DOF). Lastly, there is a line joint that enables translation along x and z axis, and, rotation specifically around the y and z axis.

Based on these defined joints, the Reshetov method was applied to Figure 10, and the number of constraints found was zero, indicating that the mechanism is self-aligning. For the remaining mechanisms, the selected joints that allow the mechanism to perform its function and be self-aligning are presented in Table 7, where: Rev. stands for revolute joint, Cylind stands for cylindrical joints, and, Prims. stands for prismatic joint.

Table 7: Joints for each variation

| Mechanism | a | b | c | d | e | f | g | h | i | j | k |
|-----------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| II | Rev. | Rev. | Rev. | Prism. | Cylind. | Cylind. | Cylind. | Cylind. | Cylind. | Cylind. | Linear |
| III | Rev. | Planar | Cylind. | Cylind. | Cylind. | Cylind. | Cylind. | Cylind. | Linear | Rev. | Rev. |
| IV | Linear | Helical | Rev. | Prism. | Rev. | Cylind. | Cylind. | Cylind. | Cylind. | Cylind. | Cylind. |

3.6.1 Type synthesis of opening and closing mechanism

For the opening and closing mechanism, there is only one candidate diagram with a single possibility of inversion. The chosen joints for the mechanism are: b, e, f, and i are revolute joints (1DOF). Joint d is a prismatic joint (2DOF). Finally, joints a, c, g, and h are spherical joints. Similarly to the process described in Section 3.7, the Reshetov method was applied, and there are no over-constraints for these joints, indicating that the mechanism is self-aligning.

| Mobility = 2 | | |
|--------------|-------------------|---------------|
| C1 | Rx c | Tx c |
| | Ry d | Ty c |
| | Rz a, b, e | Tz e |
| C2 | Rx f | Tx f |
| | Ry g | Ty g |
| | Rz h | Tz h |
| C3 | Rx j, k | Tx i |
| | Ry i | Ty (k) |
| | Rz i | Tz i |

Constraints = 0

Figure 10: Reshetov's method for the first proposed mechanism for variable force

4. RESULTS

The synthesis process resulted in four possible variations for the variable tension mechanism (Figure 7), with two of these variations having two possible inversions (Figure 8). Therefore, there are six possible mechanisms for the tension variation function, while there is only one variation with a single inversion for the opening and closing system (Figure 9). Figure 11 (a) represents a sketch of an alternative for the variable stiffness mechanism, using the first candidate mechanism for the tension variation system (Figure 8) (a). Figure 11b shows also a possibility to the opening and closing mechanism. The Figure 11 (c and d) shows the combination of the two mechanisms, in the closed and open positions, respectively.

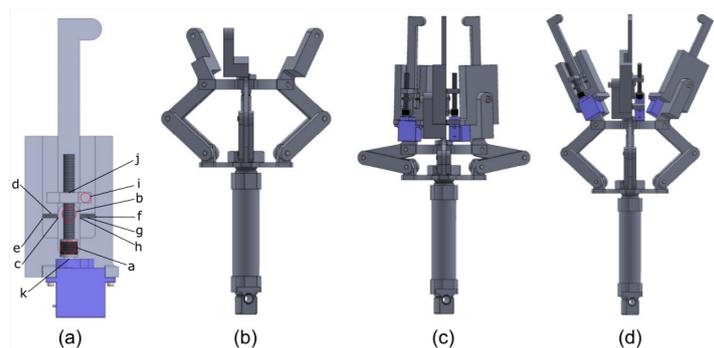


Figure 11: a) Modeling suggestion for variable resistance b) Modeling suggestion for opening/closing mechanism c) Complete gripper on opened position d) Complete gripper closed position

5. CONCLUSION

This paper introduces a new gripping mechanism for agricultural fruit harvesting. The key innovation is the adaptability of the mechanism for different types of fruits. Section 2 reviews existing gripping mechanisms used in agriculture. Section 3 presents the development and advantages of the proposed mechanism. Section 4 presents the obtained mechanism, which is a fractional mobility 3 device. One degree of freedom controls the opening and closing of the gripper jaws, while the other two degree of freedom regulates the rigidity of the gripping system. The Reshetov's table method was applied turn the mechanism a self-aligned device. This is done to minimize production costs and enhance the robustness of the mechanism, by reducing the need for high-precision manufacturing and maintenance.

This was the initial mechanism obtained. The next steps will involve calculating the forces, speeds, and accelerations followed by optimization. The method of mechanical impedance control is also a potential avenue to be explored. Prototyping of the mechanism is suggested to enable initial motion analysis. This work provides a starting point for developing more versatile robotic fruit harvesting devices in the future.

6. ACKNOWLEDGEMENTS

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