Holographic-based design, building, and testing of an RRP spherical robot for olive fruits harvesting

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ABSTRACT

A revolute-revolute-prismatic (RRP) spherical robot has been designed, simulated, built, and tested. The robot is intended to perform olive fruit harvesting tasks. The design simulation is done using hologram tools. The design factors considered include reach, dexterity, accuracy, and productivity. Based on the results of the holographic simulation, a prototype was built and tested on real olive fruits. The end effector is equipped with a rake tool so that the robot can harvest multiple fruits in each stroke. The robot is controlled by Raspberry Pi while a stereovision camera enables 3-D vision. Once the camera detects the fruits, an inverse kinematics algorithm is initiated to find the location of the fruits. The fruit coordinates are commanded to the manipulator to perform the harvesting. The field tests showed that the manipulator is successful in performing the harvesting operations. To increase the harvesting efficiency, it is recommended to build a larger prototype.

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1. INTRODUCTION

The traditional task of manual olive fruits harvesting is tiring and time consuming. In addition, in some cases, it may pose health risks for the workers; Korenevskiy *et al.* [1] proposed a method to determine the influence of risk factors on health. Furthermore, mathematical models for diagnosing occupational diseases of workers in contact with pesticides were presented by Al-Kasasbeh *et al.* [2], while pesticide-induced diseases were early diagnosed by Al-Kasasbeh *et al.* [3] and Korenevskiy *et al.* [4] using decision support systems and fuzzy logic rules, respectively. In order to combat these issues, various solution are adapted; such as the deployment of farming mechanical equipment. For harvesting in particular, while mechanical harvesters are used in many scenarios, they cannot be used in difficult terrains or in farms with dry soils, as they can harm the roots. In addition, canopy acceleration resulting when harvesting by trunk shakers is correlated with fruit damage, Castro-Garcia *et al.* [5]. Therefore, this work introduces a robotic arm that is designed, built, and programmed to perform olive-harvesting task in these difficult situations. The expected saving is substantial since harvesting represents most of the work required for the olive plantation, Hidalgo *et al.* [6]. On average, a ton of olive fruits is worth US$550-900, while to harvest the same quantity, it costs US$350, Oliveoilsource [7].

Many farming robots have been developed to perform agricultural operations and replace human workers, Vougioukas [8]. Tang *et al.* [9] discussed the integration of robotic systems in agricultural practices to enhance efficiency and accuracy. The study by Wang *et al.* [10] combined image processing and odor sensing to improve mango ripeness classification. Luo and Tan [11] presented a deep learning model for estimating mango yield, aiming to automate and optimize production planning. Zhang *et al.* [12] used color sensors to accurately determine the ripeness of oil palm fruits, improving the harvesting process. Onishi *et al.* [13] reported the progress of robotics and vision technology in fruit harvesting. The size of lime fruit was graded by Chimlek *et al.* [14] based on image comparison ratio of the pixel radius. In this work, a rake is fixed at the end-effector to facilitate the harvesting process. Rakes have been used in agriculture for a variety of tasks, and new ones are being developed; one of them is a robotic rake implemented by Abana *et al.* [15] for mixing paddy in sun drying.

The feasibility of a harvesting robot was investigated by Saputra *et al.* [16] using virtual simulation. A peduncle locking harvester was simulated by Wang and Zhou [17] using Adams software; the design was based on crank rocker mechanism. A synergistic robotic harvester was designed by Calvo *et al.* [18]; the prototype features deep learning-based fruit detection using an RGB-D camera. A robotic arm was proposed by Thamboon *et al.* [19]; where the manipulator harvests the fruit by twisting the hand axis. Al-Hababheh *et al.* [20] employed an algorithm to determine the accuracy of geometrical approach for 2DOF manipulator. Ahmad and Ayoub [21] presented a dynamic robot path planning system using neural network. A study was performed by Castillo-Ruiz *et al.* [22] to examine different types of olive harvesters, where one operator was involved with four types of harvesters, which lead to extremity disorders. However, this problem can be mitigated using active vibration isolation based on electromagnetic spring developed by Brown and Sukkarieh *et al.* [23].

2. METHOD

This work builds upon the previous work performed [20], where they presented a smart robotic manipulator for harvesting olive fruits. However, in this work, the design of the robotic arm was improved which resulted in more efficient harvesting. For example, a rake was added to the end-effector to increase the harvesting efficiency. The new design was simulated, built, programmed, and tested. The proposed harvesting system is illustrated in the block diagram shown in Figure 1.

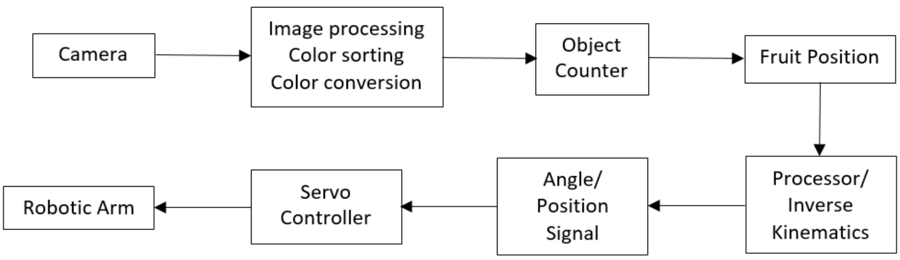

Figure 1. Harvesting system operation

The picking process is conducted using the rake tool positioned at the end of the robotic arm. The effectiveness of pneumatic comb harvesting machine in comparison with traditional methods of olive harvesting was evaluated by Patel and Bhavsar [24]. Olive fruit detachment force for different stalk twisting angles was measured by Al-Hababheh *et al.* [25]. A platform for robotic harvesting was presented by Ibrahim [26]; it was used to test specific design choices on different conditions. The best harvesting rate of 42% was observed when using soft gripper combined with target tracking. However, in this work, by using the rake tool, a higher harvesting rate is expected. The proposed system comprises a motorized 3DOF robotic manipulator, an RGB stereo vision camera, and a velocity control algorithm installed on Raspberry Pi. In order to control the robot, the Raspberry Pi is connected to the computer using VNC software.

2.1. Conceptual design

The proposed olive-fruit robotic harvester is shown in Figure 2. It is based on an RRP spherical manipulator design. Above the base there is a rotary motor-1 with vertical axis. It enables the horizontal motion of the robot. Another rotary motor-2 with horizontal axis is fixed on top of the first motor, which enables the vertical motion of the robot. Finally, a prismatic motor is fixed to the second motor, which enables the depth motion of the robot. This design enables the robot to reach the fruits position and perform the harvesting process.

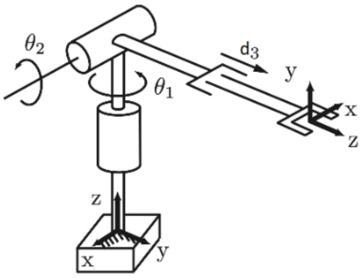

Figure 2. A schematic diagram of the robotic manipulator [27]

2.2. Holographic simulation

Based on the preliminary conceptual design, the next step is to perform kinematic and dynamic analyses. However, the design functionality should be verified first. This is best done using an effective simulation technique. Since holographic simulation can clearly represent the 3-dimensional functionality of the robot, it is selected in this work. It will help to visualize the various movements and processes conducted by the robot. After verifying the effectiveness of the model and making the necessary modifications, an experimental prototype will be built. To proceed with this approach, a holographic model based on the conceptual design is developed. The holographic model serves as a prototype which can be modified in order to achieve the required tasks. Hologram technology enables three-dimensional visualization of the robot and the tree together. First, the three-dimensional model of the robot is designed using Maya software, 3D Max, and Adobe Premiere. After constructing the model, it should be inspected for the suitability of using it in harvesting. This is done by moving it horizontally by 360° and vertically by 90°. The simulated movements ensure that the robot can perform the picking stroke. Holographic technology relies on displaying the content using light reflections on a display surface, where the viewing angle of the displayed content can reach 180°.

The hologram display comprises several components including a specially-designed black box or hologram case with the following dimensions: 55 cm width × 43 cm height × 34 cm depth. The rest of the components are assembled inside the box. These components include a transparent plastic sheet measuring 51.5 cm width × 42 cm height, and installed at an angle of 45°. This sheet is used to reflect the light of the contents produced by a 22" LG display screen. All components are integrated together using a Raspberry Pi-4, where the displaying process is streamed through it using the operating software. The 3D content is saved on a Flash memory. When the simulator is turned ON, the data on the SD card will identify the required files on the flash memory, and the process of streaming the video on the monitor begins. Next, the light reflection of the video appears on the plastic plate fixed at an angle of 45°. The assembled hologram case is shown in Figure 3 and the front view of the case is shown in Figure 4.

Figure 3. The assembled Hologram case

Figure 4. Front view of assembled Hologram case

The holographic model of the robot harvester is shown in Figure 5. Since the robot must pick the fruits, it must be elevated by a platform as shown in Figure 6. The holographic model facing a fruit cluster is shown in Figure 7. The harvesting mechanism performed by the holographic model is shown in Figure 8. Consequently, the operational principle of the harvester is verified using holographic simulation. Based on the holographic simulation, the conceptual design seems to be effective in the harvesting process. Next, the dimensions of the links are adjusted so as to perform the harvesting process successfully.

Figure 5. Holographic model of the harvester

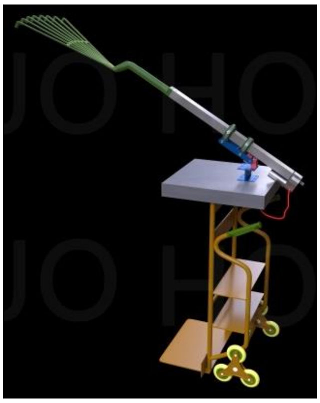

Figure 6. The harvester model positioned on the platform

Figure 7. The harvester model handling a fruit cluster

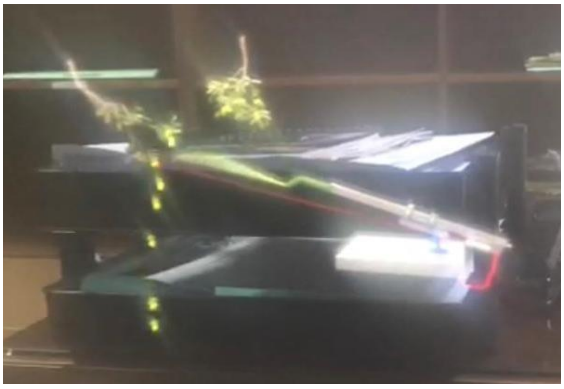

Figure 8. The holographic model performing harvesting

2.3. Recognition system

The recognition system was presented in a related work [20]. Robotic harvesters are normally moved based on algorithms trained to identify and locate the fruits, Mavridou *et al.* [28]. Therefore, in this work, image processing algorithms are employed for this purpose. Furthermore, instead of identifying a single fruit for each stroke, a modification is done to identify the center position of each fruit cluster, then the rake will be moved there to pick it up.

2.4. Picking system

The picking system performs grasping and cutting operations using the rake fixed at the end effector. The detachment force was found for Grossay olive trees as 6.8 N. The rake tool used in this work is made of reinforced plastic. In order for the harvester to reach for the fruits, it is supported by a platform. In addition, the trolley-like platform provides mobility to move in the field.

2.5. Kinematic and dynamic analyses

Inverse kinematics analysis is needed to ensure that the manipulator can reach the fruit cluster position and perform the picking process. A schematic diagram of the robot design is shown in Figure 2. The robot is designed based on the requirements of the harvesting process, where the average weight of olive fruit is 8 grams. In order to measure the force required for harvesting, a balance was attached to the rake while pulling the branch. For ten fruits, the force was 80 gm. The dimensions of the harvester are assigned as shown in Table 1. Based on the aforementioned characteristics, the DH parameters of the robot are shown in Table 2 and the transformation matrix for each joint is determined using (2).

Table 1. Dimensions of the harvesting robot

Part	Parameter	Value
Link-1	Length (L1)	50 cm
Link-2	Length (L2)	30 cm
Link-1	Angle range (α_1)	75°
Link-2	Angle range (α2)	120°
Link-3 (prismatic joint)	Length (L3)	40 cm
Vertical joint	Range of motion	(0-180)°
Horizontal joint	Range of motion	(0-45)°
Prismatic joint	Range of motion	40-80 cm

Table 2. DH parameters of the manipulator

Link	a_(i-1)	α_(i-1)	d_i	θ_i
1	0	0	0	θ_1
2	50	-90°	0	θ_2
3	30	90°	40	0

The maximum torque is calculated using (1):

$$\begin{aligned} \textit{Max Torque} &= \textit{Max olive weight} \times \textit{Max arm length} \\ &= 0.012\ kg \times 0.8\ m \\ &= 0.0096\ kg\cdot m \end{aligned} \quad (1)$$

$${}^{i-1}T_i = \begin{bmatrix} cos\theta_i & -sin\theta_i cos\alpha_i & sin\theta_i sin\alpha_i & a_i cos\theta i \\ sin\theta_i & cos\theta_i cos\alpha_i & -cos\theta i\ sin\alpha_i & a_i sin\theta i \\ 0 & sin\alpha_i & cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

Table 2 and (2) allow the calculation of the positions and orientations of all joints, based on the corresponding joint angles. In addition, they enable the determination of the overall transformation matrix for the end effector position and orientation (Frame 3) with reference to the base frame 0 (Frame 0). This transformation must be found in order to solve the forward kinematics of the manipulator, such that:

$$T_3^0 = T_1^0 * T_2^1 * T_3^2 \quad (3)$$

The end effector's position with reference to the base frame 0 can be written as:

$$\begin{aligned} X &= 0.01 * cos(t1) * (0.7cos(t2 + t3) - 0.04 * sin(t2 + t3) + 0.7 * cos(t2) + 0.25) \\ Y &= -(sin(t1) * (70 * cos(t2 + t3) - 4 * sin(t2 + t3) + 70 * cos(t2) + 25))/100 \\ Z &= -(7 * sin(t2))/10 - (1229\hat{}(1/2) * cos(t2 + t3 - atan(35/2)))/50 \end{aligned} \quad (4)$$

For fruits detection and localization, a Kinect camera is used. The camera is fixed to the top of the platform. Open-source libraries provided by Libfreenect enable the camera to be compatible with Windows. In addition, it offers wrappers for languages such as Python and C++. The fruit location coordinates are communicated between the camera and the robot using a Python algorithm, where the pixels are transformed into (X, Y, Z) coordinates. Once the coordinates of the locations of both the camera and the robot are available, the transformation equations can be developed for all axes such that:

$$\begin{aligned} R_x &= S_x * (x + x_0) \\ R_y &= S_y * (y + y_0) * cos(a) + S_z * (z + z_0) * sin(a) \\ R_z &= -S_y * (y + y_0) * sin(a) + S_z * (z + z_0) * cos(a) \end{aligned} \quad (5)$$

where:
R_x, R_y, R_z: robot coordinates
S_x, S_y, S_z: scaling factors for the x, y, and z axes
x, y, z: kinect camera coordinates
x_0, y_0, z_0: displacements
a: angle of the kinect camera with respect to the horizon

Using the above equations, the angles of the Kinect camera can be solved. They only need to be calculated once, then they are usable as long as the positions of the robot and the Kinect camera do not change. The code results obtained for the Kinect camera must be converted to Cartesian coordinates, then a mask is applied to determine the location of the fruits. These coordinates are sent to the robot to move to the specified location and perform the picking stroke. Inverse kinematics is conducted by importing several functions from the robotics toolbox, such as DHR robot, RevoluteDH, and PrismaticDH. On the other hand, the Transformation matrix is defined using petercorke toolbox. By defining the DH parameters of the manipulator, it will manage to reach the fruits position.

2.6. Experimental prototype

After completing the holographic simulation as well as the kinematic and dynamic analyses, the robot design has enough details and ready to be built. The components selected to build the robot along with their inputs and outputs are shown in Table 3. The experimental prototype of the robot is assembled as shown in Figure 9, which illustrates the fully-assembled prototype of the spherical RRP robot. Next, the prototype is deployed for testing in the field as shown in Figure 10; first it was prepared for testing by positioning it next to the tree and facing the fruits. During testing, the robot is fixed to a wheeled platform to enable mobility around the tree. Figure 11 shows the robot while performing the harvesting task.

Table 3. Prototype components

Component	Input	Output/Function
Linear actuator; PFS 300, DC 12 V, 1,500 N, 300 mm	Input voltage, Control signals	Extension/Retraction of linear actuator
Servo motor-1; feetech, 35 kg, rotation range; (0-180)°	Control signals for horizontal movement	Used for vertical axis; Desired angle of rotation for horizontal movement
Servo motor-2: feetech, 35 kg, rotation range; (0-60)°	Control signals for vertical movement	Used for horizontal axis; Desired angle of rotation for vertical movement
Control Box cover- 2 channels with wireless remote control	-	Connection, signal transmission, and robot control
Rake attachment	-	Stroke action for harvesting
Metal Base plate	-	Secure the robot and other components
Step-up voltage	Battery electrical voltage	Suitable voltage for operating the robot

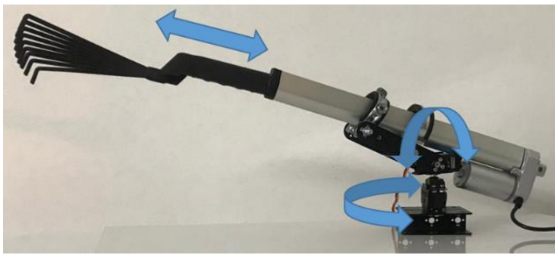

Figure 9. Spherical RRP robot prototype

Figure 10. Preparing the prototype for testing

Figure 11. The prototype harvesting the fruits

3. RESULTS AND DISCUSSION

The robot prototype was successful in performing the harvesting operation. The picking success rate depends on multiple factors including rake design, vision system, and arm trajectory. The prototype workspace is shown in Figure 12. Before testing the prototype in the field, it should be calibrated, where the position accuracy is measured in the X, Y, and Z directions. The resulting errors of the rake positions are shown in Table 4, where the rake error in the X-position, Y-position, and Z-position are shown in Tables 4(a)-4(c), respectively. For most of the cases, it is noticed that the error is acceptable.

In order to eliminate the higher error in some cases, the hardware must be rigged and calibrated. In addition, more precise motors must be installed. For the sake of improvement, some of the error sources have been identified. These are shown in Table 5. Several measures have been taken to reduce the error, such as adjusting the grasping mechanism, re-planning the trajectory, and re-calibrating the sensor. The prototype testing results are shown in Table 6.

The accuracies of the X, Y, and Z rake positions are shown in Figures 13-15, respectively. For benchmarking, Alzoheiry *et al.* [29]; studied the performance of olive harvesting by shaking, focusing on the effects of frequency and amplitude. They obtained values for the fruit removal percentage (FRP) and degree of full-ripe fruit selectivity (DS); The maximum FRP value was 90.6%, and the maximum DS value was 78.58%. While in this work, a maximum picking success rate of 100% was achieved, as shown in Table 6. However, the speed of shakers is higher. Therefore, for future work, increasing the speed of harvesting is one of the issues to be addressed.

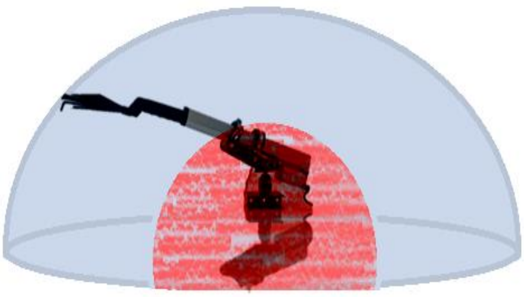

Figure 12. Prototype workspace

Table 4(a). Rake error in the X-position

Desired X position (m)	Actual X position (m)	Error (%)
0	0	0
0.05	0.03	40
0.1	0.08	20
0.15	0.11	26.7
0.2	0.19	5
0.3	0.25	16.7

Table 4(b). Rake error in the Y-position

Desired Y position (m)	Actual Y position (m)	Error (%)
0	0	0
0.05	0.04	20
0.1	0.11	-10
0.15	0.13	13.3
0.2	0.21	-5
0.3	0.28	6.7

Table 4(c). Rake error in the Z-position

Desired Z position (m)	Actual Z position (m)	Error (%)
0	0	0
0.05	0.03	40
0.1	0.07	30
0.15	0.1	33.3
0.2	0.15	25
0.3	0.25	16.7

Table 5. Identified sources of error

Trial number	Picking success	Remarks
1	Yes	Efficient harvesting
2	Yes	Grasping mechanism needs work
3	No	Trajectory issue
4	Yes	Optimal performance
5	No	Sensor calibration needed

Table 6. Prototype performance results

Branch orientation	No. of fruits on the branch	No. of strokes	No. of fruits picked successfully	Time (sec)	Picking success rate (%)
South	11	3	9	10	82%
South East	5	3	5	11	100%
South West	3	1	2	9	67%
South	4	2	4	11	100%
South East	13	4	10	8	77%
North	22	5	16	18	73%
All	58	18	46	67	83%

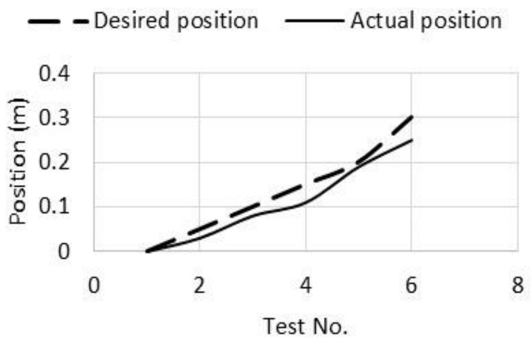

Figure 13. Accuracy of the rake X-position

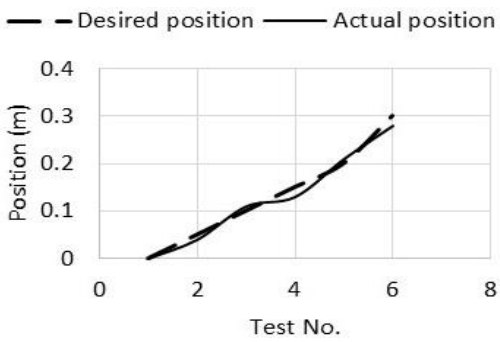

Figure 14. Accuracy of the rake Y-position

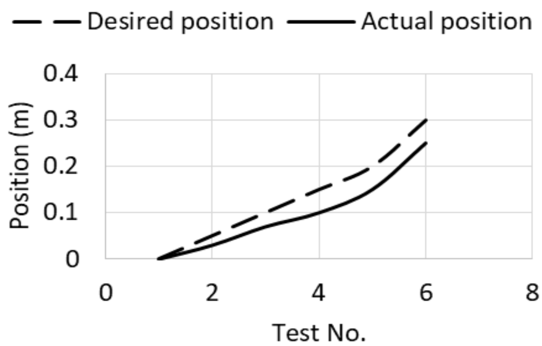

Figure 15. Accuracy of the rake Z-position

4. CONCLUSION

A prototype of a robotic harvester has been designed, simulated, built, and tested on olive trees. The work started by defining the design requirements, which include harvesting irregular olive trees without using mechanical shakers, as they can harm the roots of the tree. Next, the concept design was defined as an RRP spherical manipulator with a static rake tool mounted at the end effector. This tool is simple, yet effective, as it can pick multiple fruits at the same time. It is made of reinforced plastics so that it doesn't cause damage to the fruits. A holographic model based on the concept design was simulated to help in defining the trajectory and verifying the harvesting process. After that, kinematic and dynamic analyses have been performed, yielding essential values such as loads and DH-parameters. Finally, an experimental prototype of the robot was built and tested. Moreover, digital detection was used to identify the fruits. The key factors that were considered in the design of the prototype include the range, accuracy, and payload. Based on the obtained result, the process was very efficient with a small amount of error. The rake positioning was performed with high accuracy, which resulted in a picking success rate of 83%. As a recommendation for future work, it is advised to enlarge the prototype size to be more effective. However, this option requires higher cost of additional equipment and fabrication of gears, pulleys, belts, as well as bigger motors.

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AUTHOR CONTRIBUTIONS STATEMENT

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Salam Ayoub	✓	✓							✓					

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

- The data that support the findings of this study are available from the corresponding author, [O. M. A.], upon reasonable request.

REFERENCES

[1] N. A. Korenevskiy *et al.*, "Method for determining the body's level of protection according to oxidant status in assessing the influence of industrial risk factors on health," *Critical Reviews in Biomedical Engineering*, vol. 51, no. 2, pp. 1–17, 2023, doi: 10.1615/CritRevBiomedEng.2023047224.

[2] R. T. Al-Kasasbeh, N. Korenevskiy, M. S. Alshamasin, O. M. Al-Habahbeh, A. Shaqadan, S. N. Rodionova, and S. Filist, "Fuzzy mathematical models for predicting and diagnosing occupational diseases of workers in the agro-industrial complex in contact with pesticides", *Proceedings- 2022 8th Annual International Conference on Network and Information Systems for Computers, ICNISC 2022*, pp. 290–294, 2022, doi: 10.1109/ICNISC57059.2022.00065.

[3] R. T. Al-Kasasbeh *et al.*, "Early diagnosis of pesticide-induced diseases through computerized decision support system and assessment of body acupuncture points response," *2023 2nd International Engineering Conference on Electrical, Energy, and Artificial Intelligence (EICEEAI)*, Zarqa, Jordan, pp. 1-8, 2023, doi: 10.1109/EICEEAI60672.2023.10590518.

[4] N. A. Korenevskiy *et al.*, "Computerized decision support system and fuzzy logic rules for early diagnosis of pesticide-induced diseases," *Critical Reviews™ in Biomedical Engineering*, vol. 53, no. 1, pp. 1-22, 2025, doi: 10.1615/CritRevBiomedEng.2024053746.

[5] S. Castro-Garcia *et al.*, "Video evaluation of table olive damage during harvest with a canopy shaker," *HortTechnology*, vol. 19, no. 2, pp. 260-266, 2009, doi: 10.21273/HORTSCI.19.2.260.

[6] R. E. Hidalgo, F. P. Carranza-Cañadas, F. J. García-Salcedo, and P. Triviño-Tarradas, "Parameterisation and optimisation of a hand-rake sweeper: application in olive picking," *Agriculture*, vol. 10, pp. 379, 2020, doi: 10.3390/agriculture10090379.

[7] Sample Costs, *The Olive Oil Source*, 2022. https://www.oliveoilsource.com/page/sample-costs, Accessed on July 14, 2024.

[8] S. G. Vougioukas, "Agricultural robotics," *Annual Review of Control, Robotics, and Autonomous Systems*, vol. 2, no. 1, pp. 365-392, 2019, doi: 10.1146/annurev-control-053018- 023617.

[9] Y. Tang, M. Chen, C. Wang, L. Luo, J. Li, G. Lian, and X. Zou, "Recognition and localization methods for vision-based fruit picking robots: a review," *Frontiers in Plant Science*, vol. 11, pp. 510, 2020, doi: 10.3389/fpls.2020.00510.

[10] C. Wang, S. Liu, L. Zhao, and T. Luo, "Virtual simulation of fruit picking robot based on unity3D," *Journal of Physics: Conference Series*, vol. 1631, no. 1, 2020, doi: 10.1088/1742-6596/1631/1/012033.

[11] H. Luo and Y. Tan, "Research on an under actuated dual separation plate harvestor," *Beijing Linye Daxue Xuebao/Journal of Beijing Forestry University*, vol. 40, no. 12, pp. 110-116, 2018, doi: 10.13332/j.1000-1522.20180374.

[12] K. Zhang, K. Lammers, P. Chu, Z. Li, and R. Lu, "System design and control of an apple harvesting robot," *Mechatronics*, vol. 79, 2021, doi: 10.1016/j.mechatronics.2021.102644.

[13] Y. Onishi, T. Yoshida, H. Kurita, T. Fukao, H. Arihara, and A. Iwai, "An automated fruit harvesting robot by using deep learning," *Robomech*, vol. 6, no. 13, 2019, doi: 10.1186/s40648-019-0141-2.

[14] P. Chimlek and S. Jitanan, "Image basedlime size grading using the comparison ratio of the pixel radius and the actual size of lime fruit," *Indonesian Jo urnal of Electrical Engineering and Computer Science (IJEECS)*, vol. 24, no. 1, pp. 279-286, 2021, doi: 10.11591/ijeecs.v24.i1.

[15] E. Abana, M. Pacion, R. Sordilla, D. Montaner, D. Agpaoa, and R. M. Allam, "Rakebot: a robotic rake for mixing paddy in sun drying," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 14, no. 3, pp. 1165-1170, 2019, doi: 10.11591/ijeecs.v14.i3.

[16] H. M. Saputra, M. Mirdanies, and E. Rijanto, "Accuracy analysis of geometrical and numerical approaches for two degrees of freedom robot manipulator", *Journal Mechatronics, Electrical Power, and Vehicular Technology*, vol. 7, no. 2, 2016, doi: 10.14203/j.mev.2016.v7.105-112.

[17] G. Wang and J. Zhou, "Dynamic robot path planning system using neural network," *Journal of Intelligent and Fuzzy Systems*, vol. 40, no. 2, pp. 3055-3063, 2021, doi: 10.3233/JIFS-189344.

[18] A. Calvo, R. Deboli, C. Preti, and A. de Maria, "Daily exposure to hand arm vibration by different electric olive beaters," *Journal of Agricultural Engineering* vol. 45, no. 3, pp. 103–110, 2014, doi: 10.4081/jae.2014.424.

[19] P. Thamboon, T. Mayoon, N. Tanasanchai, P. Suthisopapan, and W. Anukool, "Vibration isolation scheme based on electromagnetic spring," *Suranaree Journal of Science and Technology*, vol. 30, no. 2, pp. 1-6, 2023, doi: 10.55766/sujst-2023-02-e01602.

[20] O. M. Al-Habahbeh, S. Ayoub, M. A. Yaman, M. Matahen, and M. Sarayra, "A Smart robotic arm for harvesting olive fruits," *RAPDASA-RobMech-PRASA-CoSAAMI Conference*, Cape Town, South Africa, MATEC Web of Conferences, 370, 05004, 2022, 10.1051/matecconf/202237005004.

[21] R. Ahmad, S. Ayoub, "A comparative study of hand-held harvesting machine with traditional methods used for olive harvesting in Jordan," *Proceedings of the 5th Int. Conf. Olivebioteq*, pp. 206-211, 2014, https://www.researchgate.net/publication/315142734_a_comparative_study_of_hand-held_harvesting_machine_with_traditional_methods_used_for_olive_harvesting_in_jordan.

[22] F. J. Castillo-Ruiz, S. Tombesi, and D. Farinelli, "Olive fruit detachment force against pulling and torsional stress," *Spanish Journal of Agricultural Research*, vol. 16, no. 1, 2018, doi: 10.5424/sjar/2018161-12269.

[23] J. Brown, S. Sukkarieh, "Design and evaluation of a modular robotic plum harvesting system utilizing soft components," *Journal of Field Robotics*, vol. 38, no. 2, pp. 289-306, 2021, doi: 10.1002/rob.21987.

[24] P. Patel and B. Bhavsar, "Object detection and identification," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 10, no. 3, pp. 1611-1618, 2021, doi: 10.30534/ijatcse/2021/181032021.

[25] O. M. Al-Habahbeh *et al.*, "Design, building, and testing of an RRP harvesting robot using VR simulations," *2nd Engineering International Conference on Electrical, Energy, and Artificial Intelligence (EICEEAI)*, Zarqa University, Jordan, 2023, doi: 10.1109/EICEEAI60672.2023.10590436.

[26] M. Ibrahim, "Development of an electrical hand-held olive harvester," *Misr Journal of Agricultural Engineering*, vol. 35, no. 3, pp. 827-846, 2018, doi: 10.21608/mjae.2018.95541.

[27] A. Khan and M. M. Gor, "Forward kinematic modeling of a 3-DOF (RRP) polar robotic arm using OOPS," *National Conf. on Emerging Vistas of Tech. in 21st Century (NCEVT-2009)*, PIET, Vadodara, Parul Institute of Engg Tech, Limda, vadodara, 9-2009, https://www.researchgate.net/publication/319632025_Forward_Kinematic_Modeling_of_a_3-DOF_RRP_Polar_Robotic_Arm_Using_OOPS.

[28] E. Mavridou, E. Vrochidou, G. A. Papakostas, T. Pachidis, and V. G. Kaburlasos, "Machine vision systems in precision agriculture for crop farming," *Journal of Imaging*, vol. 5, no. 12, 2019, doi: 10.3390/jimaging5120089.

[29] A. Alzoheiry, M. Ghonimy, E. A. El Rahman, O. Abdelwahab, A. Hassan, "Improving olive mechanical harvesting using appropriate natural frequency," *Journal of Agricultural Engineering*, 2020, doi: 10.4081/jae.2020.1057.

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