Development of a Button Mushroom Harvesting Robot using Expert System and Image Processing in Shelf Cultivation Method

Omid Ghahraei[1], Majid Kheshtzarrin[2], Ali Saghafinia[3]
1-Department of Mechanical Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran.
Email:ghahraeiom@yahoo.com,
2- Department of Mechanical Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran.
Email:Irankheshtzarrin@gmail.com
3- Department of Mechanical Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran.
Email: Saghafi_ali@yahoo.com (Corresponding author)

Received: 28 July 2023 Revised: 13 September 2023 Accepted: 15 October 2023

ABSTRACT:
Among the agricultural products, mushroom is one of the best candidates for robotic harvesting methods. One of the main problems of mushroom growers is a critical need for labor within the specified time for harvesting mushrooms, so mushroom growing is labor intensive. In this research, we attempted to develop and apply a harvesting robot for this crop to reduce the problems that growers face in terms of harvesting labor. For ease of end-effector movement between shelves, the robot was developed by Cartesian Mechanism. This robot used image processing and a computer expert system to detect the position of mushrooms on the substrate on the shelf. The end-effector acts by using a suction cup and a non-shear mechanism to harvest mushrooms from the substrate. By testing this robot on the substrate, we could harvest perfect whole mushrooms on average of 81.5% of mushrooms on the prepared substrates. Harvesting time per mushroom was obtained 12.45s, which is the amount of respective time of 8.45s more than harvesting time by labor hands, but in robotic harvesting, robots unlike humans can work 24 hours a day, continuously during growing time. An expert system also could be a valuable asset to change the grower’s strategy in terms of harvested mushrooms size and quality based on customer needs in the market.

KEYWORDS: Mushroom harvesting; Robot; Image Processing; Expert System; Shelf Cultivation Method.

1. INTRODUCTION

Button mushroom is in commercial cultivation and professional growing has been common in Iran for almost half a century [1-3]. The name of button mushroom has been taken from the small shape of mushrooms, though this form is unstable and comes to Basidiomycota in maturity. The last name in 1987 in the United States has been recorded as the name of Agaricus bisporus for white button mushrooms variety. Common button mushroom (Agaricus bisporus) is now grown in 80 countries. Edible mushrooms are rich in protein, essential amino acids, fiber, trace amounts of fat, as well as vitamins and minerals [4].

In mushroom cultivation, harvesting is the most important and cost-intensive stage to achieve high efficiency and productivity [5]. Inability to quickly harvest on time by the harvesting labors can cause damage to mushroom growers; therefore, the need for mechanization in this sector is strongly felt. Mushroom harvesting opportunity at any time from the area under cultivation is not more than one or two days and this causes great stress for the mushroom growers [6]. Labor cost for mushroom growers is considerable and the possibility of employing enough skilled laborers for the latest period of growing does not exist, so this issue can cause to hire temporary and casual labors at harvest time [7], [8]. In button mushroom cultivation, there are different methods for substrate preparation: Field cultivation Method; Shelf cultivation Method; Box cultivation and bag cultivation Method [9-11].

Among the above methods, according to statistics in Iran, 51% of mushroom growers use the shelf cultivation method and 48% of them use the bag cultivation method[12, 13]. This statistic is almost the same as other countries, for example in the UK the amount of shelf cultivation method is 50% and the box cultivation method is about 40%[14]. There are two mushroom harvesting methods: selective method and non-selective

Paper type: Research paper
DOI: 10.30486/mjee.2023.1990853.1171
How to cite this paper: O. Ghahraei, M. Kheshtzarrina and A. Saghafinia, **“Development of a Button Mushroom Harvesting Robot using Expert System and Image Processing in Shelf Cultivation Method”**, *Majlesi Journal of Electrical Engineering*, Vol. 17, No. 4, pp. 53-61, 2023

method. Non-selective methods of mushrooms harvesting are done regardless of size, which is not interesting for growers due to the reduction of harvested mushroom amounts. Machines made by Persson (1972) [15] and MacCana (1985) [16] are good examples of the non-selective method. Mechanical harvesting is used mostly by large mushroom producers in the world. For example, nearly 60% of productions in the Netherlands are mechanically harvested, and the rest are handpicked [17] This amount of harvest is done based on non-selective methods. In the selective method, it is required that the machine extracts information about substrate surface that primarily is image frames to be able to select mushrooms. In recent years, restrictions to obtain sufficient spatial and spectral information for non-destructive evaluation of food and agricultural products such as edible mushrooms have caused imaging to be used as a powerful analytical tool for analyzing biodegradable foods [18].

The selective method is applicable to the box cultivation method. According to research at the University of Warwick in England using a robot, mushroom boxes were carried and transported by labour to the robot workplace. This process was not cost-effective and in cases with large farms and high-volume production was not applicable in any way. It should be noted that carrying boxes did not end there and the boxes must again return to the cultivation shelf to reuse mushroom substrate in the next flush [19]. Among the accomplished works, the last task of the automatic system was harvesting the button mushrooms in the box. The system was non-transferable to the substrates and could be used as a research robot in the lab. As it is clear, boxes with specified dimensions are placed in the sector in front of the robot and the installed vision system constantly performs the imaging process [20, 21].

Due to the lack of effectiveness of the research so far, the mentioned reasons would not have been feasible in a real substrate. In this study, we tried to develop an automatically selective harvesting system for the shelf cultivation method as the most capable method in Iran and the world that has allocated the largest area under cultivation. This robot has the ability to operate in the real environment and can be transferred to the real growth substrate.

2. MATERIAL AND METHODS

The mushroom harvesting robot was developed according to the identified needs of the shelf cultivation method. Robot systems were provided as an integrated system for use on the growth substrate. Due to shelf cultivation method conditions, the Cartesian robot was considered with three degrees of freedom in three main axes. Speeds, static forces, and singularities were obtained after the extraction of Denavit–Hartenberg parameters. According to the speed and forces, joints and actuator mechanisms were determined.

In order to detect the mushrooms in the substrate and obtain the coordinates of the mushroom centre, a machine vision system using a charge-coupled device (CCD) camera was developed. The installed camera on the robot could move above the shelf cultivation substrate. At the same time, an end-effector was developed and installed to harvest the selected mushrooms from the substrate surface. Harvesting options selection was done by a computerized expert system.

2.1. Features of The Shelf Cultivation Substrate

In the shelf cultivation method, mushroom cultivation salons are classified with multiple shelves. The shelves' frames are usually made of wood or steel and their plates are wood or lace [22]. The vertical clearance between the shelf levels should be at least 50 cm and the lowest level of each shelf must be at least 20 cm from the ground. In the case of using heavy compost, its depth should not be more than 20 cm and in the case of using thin compost, its depth could be considered 25-30 cm. In this method, sowing the seeds and mushrooms growth stages are performed in one salon [23]. In this method, regulations also exist in Iran to equip the mushroom production salon: A standard mushroom production salon has 18 m length, 6 m width and 4 m height. Positioning of the shelves is done considering 200 cm clearance from the entrance, 100 cm clearance from the end of salon and 90 cm clearance from the side walls. The horizontal clearance between two rows is 140 cm. The shelves have 15 m length and 140 cm width. Each row has a maximum of 5 levels with the clearance of 65-67 cm from each other using a compost block and 75 cm using compost bag. The vertical clearance of the lowest level from the ground is 25 cm. The shelves have a depth of 20 cm. So, the cultivated area of each salon with two rows will be 210 m^2. The shelves width should not be more than 140 cm because the laborers who are harvesting mushrooms are able to easily harvest mushrooms without bending over the substrate which leads to damage to the mushrooms [24].

2.2. Three-Axis Cartesian Robot

Although robots are nominally programmable to perform a range of operations and various tasks, for economic and practical reasons, different robots are built for different purposes. In general, not only the size of the robot but also the number of joints and their order, kind of actuators, type of sensors, and control of the robot, greatly depend on what the robot is doing. According to the terms of the shelf cultivation method as mentioned in section 2.1, a Cartesian robot was developed to enable displace the end-effector and the imaging camera between the shelves. In Fig. 1, the schematic of a mushroom harvesting robot and its coordinate system can be observed.

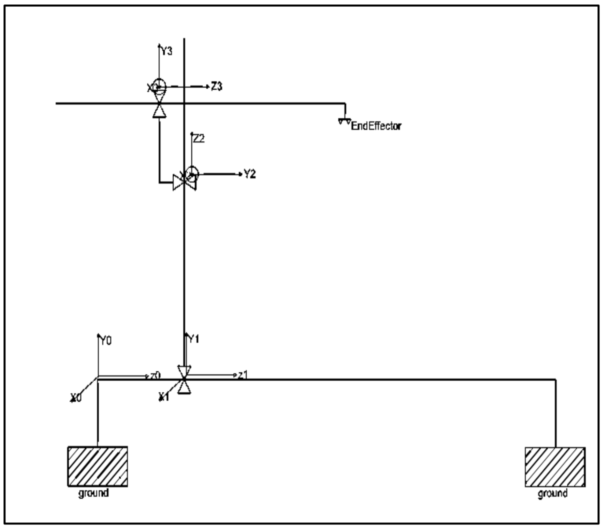

Fig. 1. Schematic of mushroom harvesting robot and its coordinate system.

Specifications of the developed mushroom harvesting robot including different fields of mechanics and electronics are listed in Table 1. Information and parameters shown in Table 1 have been obtained through the robot tests. Fig. 2 shows the developed robot for harvesting mushrooms in the shelf cultivation method and Fig. 3 shows the robot while harvesting on the substrate.

Table 1. The main specifications of the developed mushroom harvesting robot.

Index	Amount
Structure	Cartesian
Degrees of freedom	3 axes
Drive system	Stepper motors
Maximum performance range	X-axis: 135 cm
	Y-axis: 135 cm
	Z axis: 70 cm
Maximum speed	X-axis: 20.48 cm/s
	Y-axis: 1.46 cm/s
	Z axis: 14.98 cm/s
Payload capacity	3 kg
Environment temperature	-64°C to +50 °C
Weight	41 kg
Installation method	Free for installation

Fig. 2. Developed mushroom harvesting robot in the current research.

Fig. 3. Mushroom harvesting robot while working on the substrate**.**

2.3. Vision System For Mushrooms Detection

In this study, for imaging the substrate according to the shelf substrate conditions, it is necessary to take images from each level of the shelves. It captured vertically above the substrate to harvest the most appropriate caps of mushrooms. The best spots with minimal overlap in the surface of the substrate using computer software for image cropping should be selected. These set spots were determined in the software system, so with respect to the use of the robot they were adjustable in the robot control software. The images taken by the installed camera on the third axis of the robot from different parts of each level would be sent to the computer. The camera was connected to an image converter in the main computer via an image cable. These images were obtained from the substrate while the robot working, and through the images, the performance of the robot could be monitored.

Since the robot has a selection system for harvesting mushrooms, vision system must have the ability to detect mushrooms and be able to recognize the place of each mushroom according to the obtained images. The software provided on the computer using edge detection algorithm and various image filters clarified the coordinates of mushrooms in the obtained image from any part of the substrate and saved them in its database. Diagnosis operation began by taking each image from the substrate, and then getting information would be done at the same time on the computer.

2.4 Expert System and Mushroom Selection For Harvesting

In initial planning, to control and utilize the robot a personal computer (PC) was used to give possibility of using any parts of the system on time. Program development and choice of programming language were considered as ways of obtaining program which is applicable to PCs. Vb.net was considered as the programming language that is applicable to the Microsoft Windows operating system. Provided software included: control functions of interface circuits, interface control of images taken by a CCD camera installed on the robot and an expert system. An expert system was divided into two subsystems: the inference engine and the knowledge base. All functions of robot displacement to the desired location and operation commands of end-effector were placed in this software. In fact, the software as the main manager of robot hardware carried out various operations including the main functions of image processing of mushrooms locations in the image and functions of converting logical addresses in the image to physical addresses which is also applied to the control of the robot. The software has a graphical user interface to display current operations and a series of functions and procedures for reporting the robot's operation.

2.5. Mechanism of The End-Effector

In most research, an end-effector mechanism is based on a vacuum system and a suction cup. A study was conducted by Hiller on the required mechanical parameters for harvesting mushrooms of substrate by the suction cup. Applied torque to the mushroom to cut from the substrate is an important parameter to develop an end-effector [25].In addition to the required torque parameter, other points were considered in developing end-effector, which can include:

- Mechanism should have the ability to harvest the mushroom caps with a diameter of 35-65 mm.
- Mechanism should be installed on the current three-axis Cartesian robot and able to be displaced among the shelves by the robot.
- Already harvesting three mushrooms by labor takes about 12 seconds, so the current mechanism should have the ability to reach this time.

Based on above-mentioned points and additional information, an end-effector for harvesting mushrooms was developed. In Fig. 4, the mechanism of end-effector is displayed. This mechanism was inspired by the work that was done in previous research [25]. In the end-effector, the suction cup moved towards the mushroom vertically. Then after contacting and pressing down the mushroom with a recursive function that created a vacuum in the suction cup, it would move upwards. At the same time, the suction cup cached the mushroom rotated in a clockwise direction and moved to the top until the mushroom was separated from the substrate. Flow control in different parts could control air inlet and outlet flow on the suction cup. Harvesting operation was independently controlled by the end-effector controller. After separating the mushrooms from the substrate, the third axis of the robot moved and the harvested mushroom was transferred to the container.

To detach and fall the mushroom from the suction cup, it again moved down. To avoid a collision of the harvested mushroom with neighbouring mushrooms, the suction cup must be transferred to the highest position. It was tried to use mechanical-electrical actuators in the end-effector. Although there was the ability to install pneumatic equipment, to prevent using extra equipment like air compressors and related components, pneumatic system was not approved.

Fig. 4. End-effector during harvesting.

2.6. Experimental Plan and Testing Methods

After developing the mushroom harvesting robot, it was evaluated in a real environment. These types of experiments were related to their different characteristics and performance of the robot. Limitations and solutions to minimize restrictions for the robot performance testing should be considered. For testing the robot, a plan was prepared including three different evaluations and the results were provided separately: mechanical characteristics evaluations of the robot in terms of accuracy and iteration; robot performance testing in terms of image processing and its operation and simulation of the proposed rules of the expert system; and finally, a robot field test in the mushrooms substrate.

3. RESULTS AND DISCUSSION

3.1. Evaluation of The Mushroom Harvesting Robot on The Substrate

To evaluate the robot's positioning, must be asked the robot to reach and settle in the target position from the substrate with desired speeds. To perform these evaluations, two hypothetical positions were considered. After applying any of the values manually to the system, the positions of the end-effector were measured and calculated. The positioning results of the robot in the direction of x, y, and z axis are shown in Figs. 5, 6, and 7.

According to the Figs. 5 and 7, it could be concluded that displacement at x and z axes with different speeds are the same and without error. Based on Fig. 6, at the y-axis because of the applied weight on the body, displacement with a speed of 51200 pulses per second was associated with error. To have an accurate result, it was better to apply the speed of 10240 pulses per second or less which was accessible without error. In Fig. 5, due to the low rate of x-axis displacement to applied pulse into the circuit, input data to the control system were increased into three pulse levels of 5000, 8000, and 32000 to ensure the results.

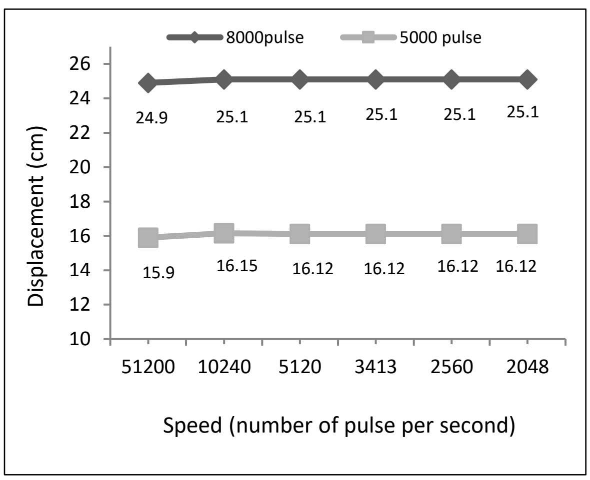

Fig. 5. Positioning results of the robot in the direction of the x-axis.

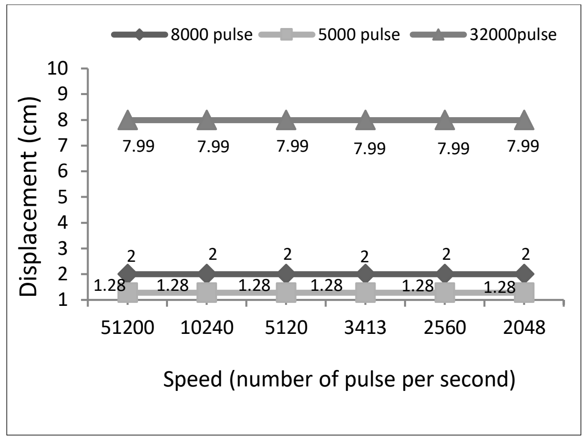

Fig. 6. Positioning results of the robot in the direction of y-axis.

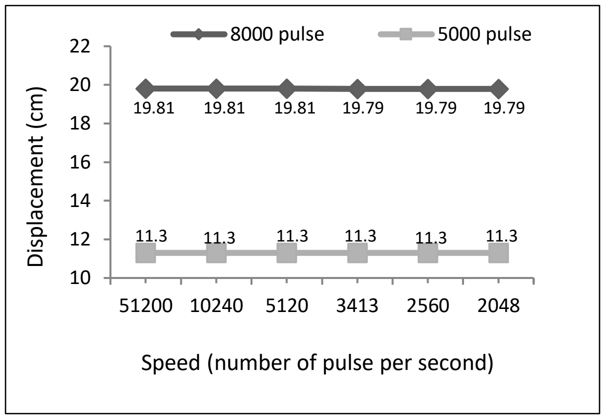

Fig. 7. Positioning results of the robot in the direction of z-axis.

3.2. Evaluation of the mushroom Harvesting Robot Vision

Evaluation of the robot vision depends on the performance of the image processing system. To run this test, eight frames of images taken from different coordinates of the substrate were entered in the image processing function. The output results were compared with the realities of the substrate in each of the frames.

The operation was accomplished by using an edge detection algorithm and another algorithm to identify the mushrooms. The size of stored images was 720 × 576 pixels and the resolution was 96 dpi. Algorithms were implemented by the Vb.net language. Fig. 8 illustrates the image of the software graphical interface that was part of the robot original software for use in the substrate.

The results showed that at eight investigated frames, the average error was 9.45%. Of course, this error is just related to mistake rate in detection and has no relationship to the number of diagnostics. These errors were obtained by applying equal conditions for all eight frames. These values would be changed while unequal conditions and applying different settings to the edge area and allowed size to detect the mushroom cap (minimum and maximum allowed sizes to detect the cap). It was clear that by increasing the image quality, better results would be obtained in detecting the edges that helped to correct diagnosis and reduce the error rate. Most errors occurred when there was adhesion between mushrooms in the picture. It means that the adjacent mushrooms in the image overlap each other. The problem in image processing with harvesting mushrooms decreased in each investigation of the substrate surface. As investigated in eight frames, the problem is visible in Fig. 9. It displays the mushrooms detection by an image processing system in eight investigated frames.

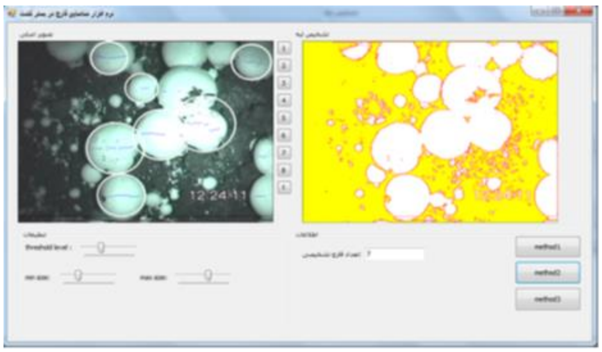

Fig. 8. Image of the graphical interface of machine vision software.

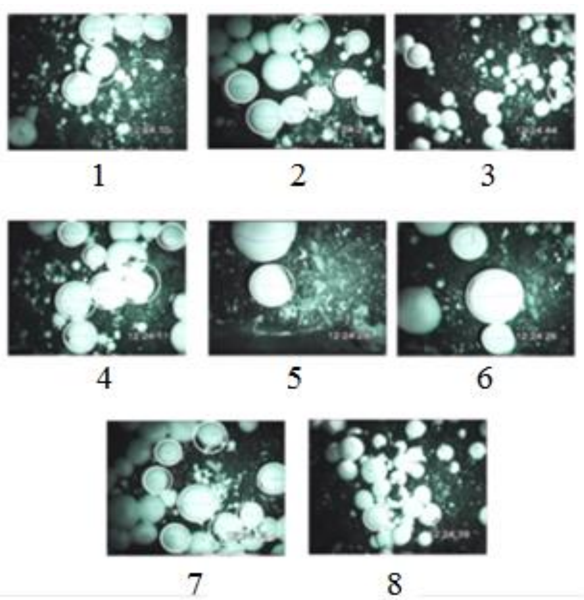

Fig. 9. Diagnosed mushrooms in the eight frames of the substrate.

Coordinates obtained from the center of the circles were transmitted to the expert system. During this action, only a coordinate conversion from logical addresses in the image to physical addresses was performed.

In the harvesting process, according to images taken from the substrate by Tillett & Batchelor (1991), the correct images of diagnosed mushrooms were about 86% and the failure rate in total was around 14%. The average diagnosis duration per mushroom was about 5 seconds. Information processing was taken by a Motorola 68000 processor with a speed of 16.67 MHz [26], [27]. In subsequent work to enhance the quality of the lens and changes in the edge detection algorithm, the correct diagnosis was increased to 90%[28].

In the current study, we succeeded in getting the error rate in the detection of mushrooms by the image to 9.45 % and the success rate in detecting was around 90.55 %. Of course, the processor speed was about 2.99 GHz and 179 times more than the processor used by Tillett & Batchelor (1991). Most of the speed has been spent on the operating system services, but considering the speed of the processor, speeds of information extraction and image processing in our research have been greatly improved compared to other works.

3.3. Robot Performance Evaluation in Harvesting Mushrooms of Substrate

To evaluate the performance of the robot, the equipment was transferred to mushroom cultivation salon. Evaluation and performance testing with real data was carried out in three stages. In the first stage, robot was tested in an empty mushrooms' substrate. In the second stage, before the first flushing, despite of the smaller mushrooms than the allowed size for the harvesting checking was done. And finally, in the third stage close to harvest time in the first flushing, the robot was evaluated. Data collected in three stages was stored in a software database to achieve the best case by analyzing the data after performance testing in the substrate. Evaluation of the substrate and preparation of the frames in the substrate were done only once before the first flushing at the first two stages. Scanning of the substrate in the range of the robot performance took about 10 minutes. This was the time to take images from the surface of the substrate.

In the third stage close to the first flushing, the robot was installed on the substrate. The scanning interval of the substrate surface was determined as 60 minutes. In the third stage, robot performance testing was done by evaluating the scanned frames under the camera and then harvesting the mushrooms by the end-effector. Scanning was performed by the camera for detecting the mushrooms and the end-effector moved to the desired location then the harvesting command was exported to the end-effector. The number of diagnosed mushrooms in the substrate at any checking stage and their differences from the reality of the substrate are shown in Table 2.

After each evaluation of the substrate and harvesting operation, the total diameter of harvested mushroom caps is visible in Fig. 10. Diagnosis duration per mushroom stored through the information in the software database was calculated and diagnosis duration for each mushroom is shown in Table 3. At each stage of checking and harvesting, the number of perfect mushrooms for sale and the number of acaulescent and destroyed (demolished) mushrooms were extracted which can be seen in Table 4.

The average demolition rate by the robot obtained was 18.5% of the total harvested mushrooms, and the average percent of perfectly harvested mushrooms was 81.5%.

Table 2. The number of diagnosed and actual mushrooms in the substrate by the robot.

Harvest number	The number of diagnosed mushroo	The number of actual mushrooms in substrate	differences	Differences percent (%)
1	120	174	54	31.03
2	95	125	30	24
3	50	80	30	37.5
4	35	95	60	63.16
5	10	80	70	87.5
6	15	85	70	82.35

Table 3. Time detection of mushrooms in the substrate.

Harvest number	The number of processed frames	The number of mushrooms	Average time of detection (s)
1	25	120	1.068
2	25	95	1.05
3	25	50	1.065
4	25	35	1.045
5	25	10	1.048
6	25	15	1.046

Table 4. The number of harvested mushrooms from point of view of harvesting quality.

Harvest number	The number of harvested mushrooms	The number of perfect harvested mushrooms	The number of demolished mushrooms	The number of undetected
1	73	62	11	47
2	48	32	16	47
3	32	27	5	18
4	15	13	2	10
5	10	9	1	0
6	13	10	3	2

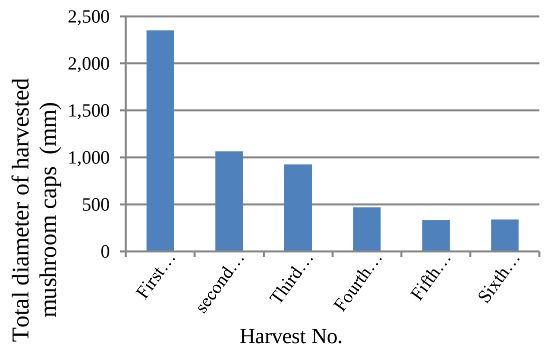

Fig. 10. Total diameter of harvested mushroom caps.

So far, all conducted studies have been developed in laboratory tray substrates. Therefore, there is no available data on shelf cultivation method and about its harvesting success rate in the mushrooms salon real condition.

In this study, we reached to 1.05 seconds that was the average detection time per each mushroom in image. This time has been optimized in amount of 3.94 seconds per mushroom compared to 5 seconds of research done in [26]. According to Rowley (2009), a non-contact laser detection system was used for detecting 3 mushrooms in 5.5 seconds. This time per mushroom is about 1.83 seconds which is longer than the detecting duration of our research.

According to Reed et al. (2001) [28] which was about the amount and quality of harvest, 68% of the mushrooms were harvested correctly which was 57% more than the correct harvesting amount by Tillett & Batchelor (1991). Based on research done by Rowley (2009), the amount of perfect harvesting was 78.2% and the rate of mushroom demolition was 21.8%. In another research, Li & Noble (2005) [29]found that the rate of mushrooms demolition for the human harvesting was about 5-10%.

According to the current research on the shelf cultivation method, the average percent of perfectly harvested mushrooms was obtained at 81.5% of total harvested mushrooms and the rate of demolition was 18.5%. Compared to the average percent of perfectly harvested mushrooms in our study in other conditions, the success in harvesting was increased to 3.3%. It must be considered that current testing was conducted at different harvesting conditions and the robot was developed for working in shelf cultivation method and had the ability to move between the shelves.

The whole speed of the harvesting process for each mushroom was obtained at 6.7 seconds which included time for detection, positioning, harvesting, and putting the cut mushroom in the basket (Rowley, 2009).

In our research, times for the detection process, positioning to end-effector, and harvesting mushroom from the substrate, have been obtained as 1.05, 6.5, and 4.9 seconds, respectively in the average speed. The total time for harvesting one mushroom by the current robot was obtained as about 12.45 seconds.

All three mushrooms harvesting time by humans lasted about 12 seconds [30], [31]. Although the harvesting time obtained by the current robot showed an amount greater than the human factor, the current robot was able to work 24 hours a day during growing time. This ability causes mushroom growers to not harvest small mushrooms untimely in the farms due to the lack of staffing at all times for harvesting mushrooms. The presence of robotics in the mushrooms substrate to harvest improves harvesting quantity and quality as well as harvesting efficiency compared to using human factor.

4. CONCLUSION

Conducting this research proved that a practical solution exists for mechanization in harvesting mushrooms on shelf cultivation methods to improve the harvesting goals. By using an expert system in the current robot, the policy of mushroom growers to harvest may be selective and variable. Small size to large size mushrooms could be used in different applications according to customer needs in the market to make different products such as mushrooms pickles, dried mushrooms, mushrooms conserve, and many more applications as a grocery product. The possibility of the development and application of this new method in Iran by promoting the commercialization of the current mushroom harvesting robot could increase the productivity of mushroom farms based on the shelf cultivation method. Finally, because there is no similar applied sample of the current robot to have the ability to select mushrooms from the shelf substrates in the world using an expert system and image processing facilities, it is predicted that the developed robot could be a practical solution to the mushroom growers' problems in harvesting time and decrease the labour needs, seriously.

REFERENCE

[1] X. Lin and D.-W. Sun, "**Research advances in browning of button mushroom (Agaricus bisporus): Affecting factors and controlling methods**," *Trends in Food Science & Technology,* Vol. 90, pp. 63-75, 2019.

[2] M. Usman, G. Murtaza, and A. Ditta, "**Nutritional, medicinal, and cosmetic value of bioactive compounds in button mushroom (Agaricus bisporus): a review**," *Applied Sciences,* Vol. 11, p. 5943, 2021.

[3] J. Liu, L. Jia, J. Kan, and C.-h. Jin, "**In vitro and in vivo antioxidant activity of ethanolic extract of white button mushroom (Agaricus bisporus),**" *Food and chemical toxicology,* Vol. 51, pp. 310-316, 2013.

[4] H. Ghahremani-Majd and F. Dashti, "**Chemical composition and antioxidant properties of cultivated button mushrooms (Agaricus bisporus),**" *Horticulture, Environment, and Biotechnology,* Vol. 56, pp. 376-382, 2015.

[5] S. Yang, J. Ji, H. Cai, and H. Chen, "**Modeling and Force Analysis of a Harvesting Robot for Button Mushrooms,**" *IEEE Access,* Vol. 10, pp. 78519-78526, 2022.

[6] S. F. Ardabili, A. Mahmoudi, T. M. Gundoshmian, and A. Roshanianfard, "**Modeling and comparison of fuzzy and on/off controller in a mushroom growing hall**," *Measurement,* Vol. 90, pp. 127-134, 2016.

[7] J. K. Raut, "**Current status, challenges and prospects of mushroom industry in Nepal**," *International Journal of Agricultural Economics,* Vol. 4, pp. 154-160, 2019.

[8] J. Dhungana, "**Cost-benefit and resource use efficiency of oyster mushroom production: A case of freed Kamaiya in Kailali Nepal**," *Nepalese Journal of Agricultural Sciences* ,p. 21, 2022.

[9] B. Mehta, S. Jain, G. Sharma, A. Doshi, and H. Jain, "**Cultivation of button mushroom and its processing: an techno-economic feasibility**," *International Journal of Advanced Biotechnology and Research,* Vol. 2, pp. 201-207, 2011.

[10] J. Carrasco, M. L. Tello, M. de Toro, A. Tkacz, P. Poole, M. Pérez-Clavijo, *et al.*, "**Casing microbiome dynamics during button mushroom cultivation: implications for dry and wet bubble diseases,**" *Microbiology,* Vol. 165, pp. 611-624, 2019.

[11] A. Hajavi, M. Khoshgam, and M. Hatami, "**A Comparative Study on regarding Rate of the Privacy Principles in legal Issues by WHO Manual at Teaching Hospitals of Iran, Tehran and Shahid Beheshti Medical Sciences Universities 2007**," *Journal of Health Administration,* Vol. 11 ,pp. 7-16, 2008.

[12] S. Nostratabadi and S. Vinogrado, "I**SSN 1648-7974 MUSHROOM FARMING IN IRAN: A CASE STUDY OF TEN IRANIAN MUSHROOM**

COMPANIES," *Journal of Management,* Vol. 2, 2020.

[13] S. Nostratabadi, S. Vinogradov, and B. Almádi, "**MUSHROOM FARMING IN IRAN: A CASE STUDY OF TEN IRANIAN MUSHROOM COMPANIES**," *Management (16487974),* Vol. 36, 2020.

[14] J. Franks and J. Farrar, "**Economics of Mushroom Production: crop year 1997**," *Issue 43 of Special studies in agricultural economics,* 1999.

[15] S. P. Persson, "**Mushroom harvester**," ed: Google Patents, 1972.

[16] C. MacCanna, "**Method and apparatus for harvesting mushrooms and the like,**" ed: Google Patents, 1985.

[17] W. Gao, A. Weijn, J. J. Baars, J. J. Mes, R. G. Visser, and A. S. Sonnenberg, "**Quantitative trait locus mapping for bruising sensitivity and cap color of Agaricus bisporus (button mushrooms)**," *Fungal Genetics and Biology,* Vol. 77, pp. 69-81, 2015.

[18] X. Zou and J. Zhao, *Nondestructive measurement in food and agro-products*: Springer, 2015.

[19] Y. Hua, N. Zhang, X. Yuan, L. Quan, J. Yang, K. Nagasaka, *et al.*, "**Recent advances in intelligent automated fruit harvesting robots**," *The Open Agriculture Journal,* Vol. 13, 2019.

[20] J. H. Rowley, "**Developing flexible automation for mushroom harvesting) Agaricus bisporus)**," *University of Warwick,* 2009.

[21] S. Bachche, "**Deliberation on design strategies of automatic harvesting systems: A survey**," *Robotics,* vol. 4, pp. 194-222, 2015.

[22] A. Philippoussis, P. Diamantopoulou, and G. Zervakis, "Calcium chloride irrigation influence on yield, calcium content, quality and shelf-life of the white mushroom Agaricus bisporus," *Journal of the Science of Food and Agriculture,* Vol. 81, pp. 1447-1454, 2001.

[23] R. Pourbagher, M. H. Abbaspour-Fard, F. Sohbatzadeh, and A. Rohani, "**Inhibition of enzymes and Pseudomonas tolaasii growth on Agaricus bisporus following treatment with surface dielectric barrier discharge plasma**," *Innovative Food Science & Emerging Technologies,* Vol. 74, p. 102833, 2021.

[24] R. Pahlavan, M .Omid, and A. Akram, "**Energy input–output analysis and application of artificial neural networks for predicting greenhouse basil production,**" *Energy,* Vol. 37, pp. 171-176, 2012.

[25] S. Hiller, "**Some properties of mushrooms,**" *International agrophysics,* Vol. 8, 1994.

[26] R. Kumar, V. Chandrasekhar, and A. K. Rao, "**An automatic multi-threshold image processing technique for mushroom disease segmentation**," 2020.

[27] R. Tillett and B. Batchelor, "**An algorithm for locating mushrooms in a growing bed,**" *Computers and electronics in agriculture,* Vol. 6, pp. 191-200, 1991.

[28] J. Reed, S. Miles, J. Butler, M. Baldwin, and R. Noble, "**AE—Automation and emerging technologies: Automatic mushroom harvester development**," *Journal of Agricultural Engineering Research* ,Vol. 78, pp. 15-23, 2001.

[29] L. Rongchun and R. Noble, **"Life-cycle diversity of button mushroom (Agaricus bisporus)**," *Yunnan Nong ye da xue xue bao= Journal of Yunnan Agricultural University,* Vol. 20, pp. 388-391,395, 2005.

[30] D. E. Aldous, G. R. Dixon, R. L. Darnell, and J. E. Pratley, "**Education and training futures in horticulture and horticultural science,**" *Horticulture: Plants for People and Places,* Vol. 3: Social Horticulture, pp. 1087-1115, 2014.

[31] R. Prakash and M. R. Ravindra, "**Robotic Engineering: A Tool for Quality and Safety of Foods,**" *Handbook of Research on Food Processing and Preservation Technologies,* pp. 311-335, 2021.