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Design Methodology and Optimum Camera Setups for an Experimental Remote-Control Manipulator for Servicing Date Palms

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ABSTRACT

In this article we describe a design process of a manipulator that is designed for complete servicing of a date palm. The feasibility of using this manipulator and determining the optimum position of its cameras as well as the number of cameras to be mounted on the equipment were also investigated. The manipulator was equipped with several cameras for monitoring the operations utilizing a ground-based operator. The operator monitors the manipulator and the end-effector on the display and navigates it using a joystick. In order to build the manipulator, a systematic deign method was utilized. Total length of the manipulator was 100 cm. Four electric motors provide the dynamic force of the manipulator to transport the end effectors to the desired positions for conducting horticultural operations. To investigate the performance of the manipulator, 9 different camera setups and 4 different manipulator distances from the target, were analyzed at 5 replication levels, through a statistical factorial experiment design (4×9). The experiments results showed that the remotely controlled manipulator is efficient in conducting horticultural operations. On the other hand, different camera setups showed significantly different results. The tests also indicated that to obtain the shortest reaching time, three cameras must be installed on the manipulator. The average time for reaching the target from a 100-cm distance was calculated 20.8 seconds.

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INTRODUCTION

Date is an important fruit in many arid regions of the world. As a highly resistant plant, palm trees are the main sources of food for the people of arid regions, where rare plants are able to resist the burning sun with salty soil and water shortage. Egypt, Iran and Saudi Arabia are main producers of date with about %50 of world's date production. These main producers mostly use manual labor for horticultural operations. To do this dangerous task, experienced workers are required to climb the trees to reach the tree crown (Jain et al., 2011).

They prune, pollinate, cover fruits by textiles, harvest and perform other services some of which have to be executed several times a year. The workers are exposed to falling off, bitten by bees and snakes, injured by sharp leaf bases and many other threats. This job needs to be carried out by experienced workers which are courageous enough to climb a 30-meter- long tree, even though, some of the crops cannot be harvested because workers are not willing to risk. A small robot is able to carry out this task and obviate the mentioned problems. Mechanized methods have been limited to the application of mechanical and hydraulic lifters which only raise the worker to the tree crown which the occupational hazard due to elevation still exists. The present research investigates and evaluates the feasibility of using an experimental manipulator instead of manual labor. During the past decades, labor shortage and an increasing interest in the mechanization of horticultural operations concerning dates led to development of mechanical systems for date servicing (Mazloumzadeh et al., 2008).

Jintasuttisak et al (2022) developed and reported a system which was operated by three workers including a truck driver, a boom operator, and a bunch cutter or shaker. Shamsi (1985) proposed the design of a walking machine to carry one worker to the crown of the palm tree. Shamsi (1990) designed a climbing machine based on a sprocket traction system to service date trees. Al-Suhaibani et al. (1988) reported manufacturing and testing a date palm service machine, a "U" shaped platform allows the workers to be able to reach all of the date bunches without any additional movements of the platform.

Al-Suhaibani et al. (1993) reported the field test of the machine in 1990. They showed that it can harvest a date palm tree in 21 minutes which is faster, safer an easier than the manual labor. Sarig et al. (1989) developed an integrated mechanical system that can harvest the fruits by shaking the tree trunk. Shamsi et al. (1998) developed and tested another tree-climbing date service machine. Shamsi (1998) measured the required date palm tree physical properties to check if the tree can resist against the machine stresses. The results show that the tree can tolerate the stresses with a high safety factor. All reviewed machines can only lift the worker to the tree crown. The generic differences in specification between industrial and horticultural manipulators provide an opportunity to adopt a new approach in manipulator design. In order to provide the analytical tools necessary for this new approach further research in the interrelated areas of actuator choice,

geometrical configuration, and control strategy is required (Tillet, 1993). Research has been conducted towards the application of robotics for harvesting e.g. citrus, apples, melons, tomatoes and cucumbers. See Muscato et al. (2005), Tillet (1993) and Edan (1995) for an overview. Kondo et al. (1996), Hayashi and Sakaue (1996), Arima and Kondo (1999) and Van et al. (2002) reported research prototypes of harvesting robots for tomatoes and cucumbers. Applying robotics in fruit harvesting requires the integration of robot capabilities, plant culture, and the work environment which is usually specific for each plant. Autonomous harvesting robots have not yet been commercially applied in many horticultural practices. The robots reported in the literature were not suited for the big bunches of dates. This research was conducted to develop a remotely controlled manipulator. It is equipped with cameras and can be mounted on most of the above-named date harvesting machines. The operator controls the manipulator from the ground which increases the operator's safety.

MATERIAL AND METHODS

The proposed manipulator has been developed to be mounted on any date palm service machine, especially the climbing machine developed by Shamsi et al. (1985). The basic mechanism of the manipulator and the details of the components such as the pressure that machine gripers insert to the trunk develope are designed based on the physical properties of the date palm tree. Combination of this climbing machine and the manipulator makes a remotely controlled robot.

The manipulator designs

The manipulator was developed by a systematic design method. The first step was to specify the design objectives which proved to be highly useful at all of the designing stages, even though the objectives would change throughout the design process. The initial and interim objectives would change, expand or contract, or be completely altered as the problem became better understood and as solution ideas developed. The developed objectives' tree is shown in figure 1.

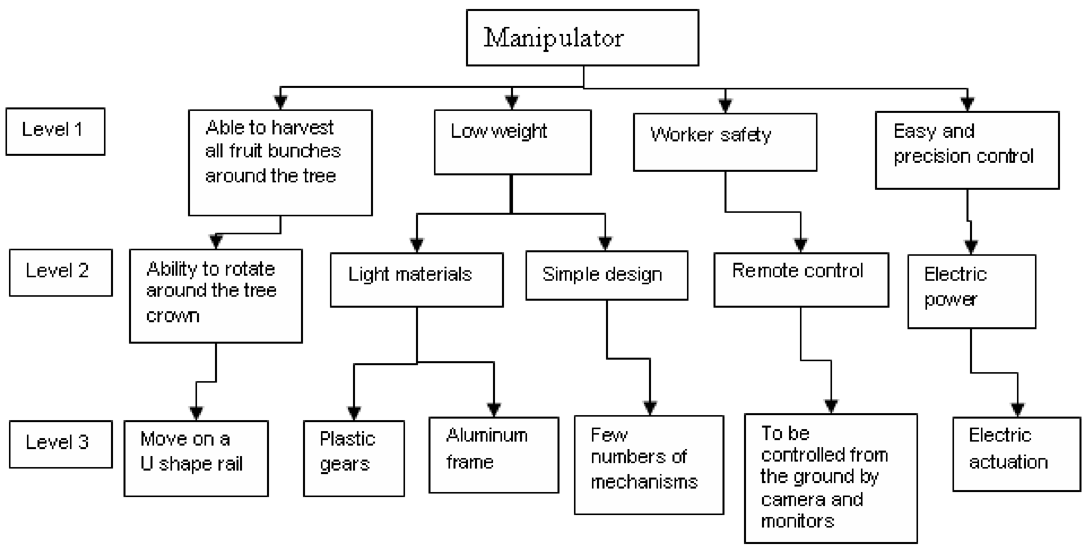

Figure 1. The objectives' tree for the manipulator

The conceptual design phase for each part was developed by the morphological chart, and concept evaluation was conducted using the weighted objectives method (Regenwetter et al., 2022). In order to reach to the fruit bunches on the opposite side of the machine, the manipulator moves on a special U-shaped platform. As for determining the diameter of the U-shaped platform and the length of manipulator links, physical dimensions of date palms were collected and analyzed from date orchards in Bam, Iran (Mazloumzadeh et al., 2010). Based on the foregone data, the average fruit bunch diameter and length were measured respectively as 50 and 77 cm. Figure 2 shows a blue print of the manipulator on a tree climbing machine produced by Shamsi et al. (1985) in two harvesting positions.

Manipulator performance tests

The feasibility of the remotely controlled manipulator for date servicing was assessed by its ability to reach a target. In laboratory experiments an 8 mm-diameter shaft was connected to the end-effector. This small shaft is a pointer, a simulation of a saw or pollinator or bunch shaker acting part. The cameras were mounted around the robot manipulator and operators were able to observe the process through a small monitor and control the robot using a joystick from the ground. As the target, a 100 mm-diameter circle was drawn on a small board connected to a base. The manipulator was moved from a preset position and the pointer was controlled through the camera and monitor system to reach the target. The pointer could reach and touch the circle. Then the target diameter was reduced by 10 mm intervals and the experiment was repeated for each new circle. The smallest accessible target was a 10 mm-diameter circle which could be easily observed and accessed by the pointer. The 10 mm-diameter circle was an acceptable size because it is thicker than any leaf base or date fruit bunch to be cut by the manipulator. This size circle was used during all the manipulator tests.

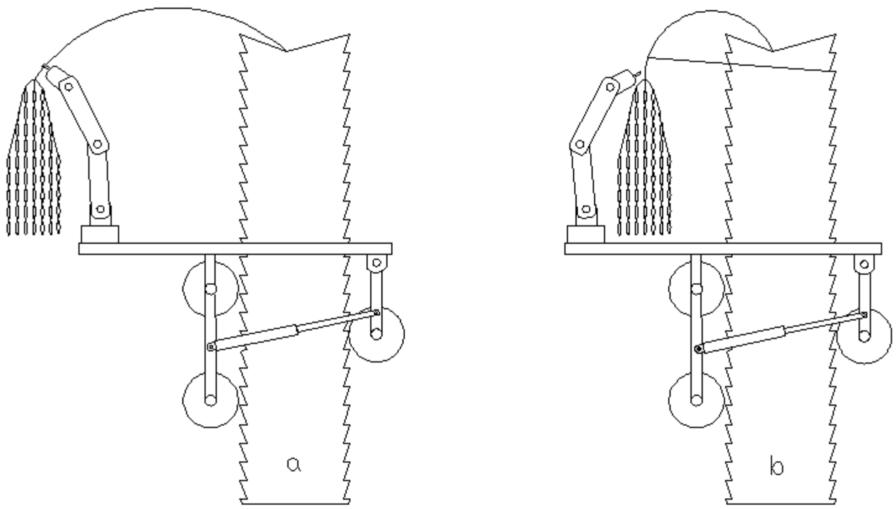

Figure 2. Manipulator mounted on a tree climbing machine at two bunch cutting positions: a) free bunches, b) bunches tied to the tree trunk

Camera setup

Through several experiments, different positions for camera installation were investigated. Five positions were selected for the final consideration. The distances of these positions are defined in Table 1, based on a fixed coordinate system shown in figure 3. Considering the concluded results from primary experiments, controlling the manipulator with one camera was impossible in all conditions, therefore, to control the manipulator a combination of two or three cameras at the selected positions were taken into consideration.

Table 1. Camera positions based on a fixed coordinate system shown in figure 3

Camera position	Coordinate system (cm)		
	x	y	Z
I	0	-150	0
II	0	0	0
III	-60	-100	0
IV	-60	100	0
V (on the arm)	variable	variable	variable

Table 2 shows 8 selected setups plus 1 control which is the direct observation of the target instead of monitoring through the display. The acceptable setups were examined to determine the best option.

Table 2. Different camera setups by the combination of camera positions from Table 1

Camera set up	Installed cameras	Camera set up	Installed Cameras
A	No camera (Direct watching)	F	IV & III & II
B	V& IV	G	IV & V
C	IV & II	H	IV & V & I
D	IV & III & I	I	IV & V & III
E	IV & II &I	-	-

Three cameras (ANT CMOS's ANT-308) connected to a 4.5-inch monitor (NOVA brand) were used for the experiments. To determine the best location and number of cameras, the required time the end-effector (pointer) needed to reach and contact the target (in seconds) was set as the main comparison criterion. To this end a statistical factorial design test with two factors was utilized. Factor A, is the setup of cameras. This factor has 9 levels, 8 levels pertaining to camera setups and 1 level to control. In control level the end-effector was controlled by direct observation instead of observation through the display. Factor B is the distance between the end-effector and target circle including 4 levels of 25, 50, 75 and 100cm. These points were selected according to the accessible region of the manipulator which is a hemisphere of 100 cm radius. The operator will probably gain experience and become faster in carrying out operation overtime. Therefore, the factorial design was used in the shape of randomized complete block design and the experiment was conducted using 5 replications.

RESULTS AND DISCUSSION

The objective tree method offered a clear and useful format for such a statement of objectives. It showed the objectives and the general media of achieving them. The objective tree (Fig. 1) was developed to determine the important characteristics of the manipulator which were necessary during the design process. The manipulator should have been able to harvest all bunches around the tree subsequent to reaching the tree crown. Having low weight and simple and accurate control system are other important criteria. Operator safety is also very important. Developing objectives from level 1 through 2, 3 and more, terminated to find the means of achieving objectives. For example, operator safety at level 3 has been led to a remotely controlled system operated from the safety of the ground. Based on the systematic design method and results of the data analysis of the date palm tree dimensions the diameter of the U-shape platform was selected to be 200 cm. The developed manipulator has an end-effector, a forearm, and an arm base. The total length of the manipulator is 100 cm. Four electric motors move the manipulator to transfer the end-effector to the desired position. The developed manipulator is shown in Figure 3.

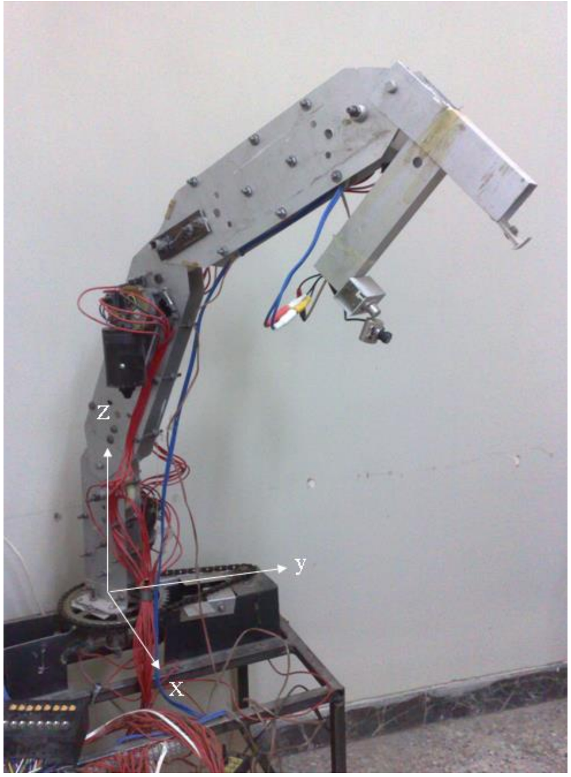

Figure 3. The developed experimental remote-control manipulator

After feasibility experiments, the reaching speed tests were conducted to find out the optimum camera setup. The average time the remotely-controlled pointer consumes to reach the target was employed as the main performance criteria. Reaching times are tabulated in figure 4. These times were analyzed by a statistical factorial design test as explained in material and method section. The objective was to find out if there is any significant difference among the 9 camera settings. Finding the suitable camera position to control the pointer with the minimum number of cameras and the minimum time consumed to reach the target is the objective of the experiments.

The results of the analysis of variance (Table 3) show that there are significant differences between different camera setups, however the operator's experience and interaction effect of factors A and B, are not significant at the level of %5.

Table 3. Results of the analysis of variance for different camera setups

S. V	df	SS	MS	Fs
Treatment	35	2381.53	68.04	1<
Block	4	202.78	50.7	0.40^{ns}
A (cameras)	8	6777.78	847.22	6.7**
B (distance)	3	1254.86	418.29	3.31*
A×B	24	3998.89	166.52	1.32^{ns}
Error	140	17690	126.36	
Total	214	20071.53	-	-

To determine the optimum setup of cameras, considering the time that end effector riches the circular target, levels of factor A (camera setup) were compared with the control level (direct watching, without camera) using LSD test. Results are shown in Figure 4.

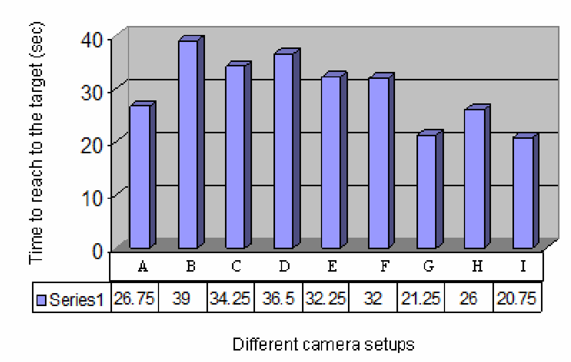

Figure 4. Time of reaching to the target in 9 different camera setups (s)

Results of the LSD test showed that the pointer reaches the target faster at G and I settings (Table 4). The difference of the applied settings with that of the control setting is significant in the level of 5%. It also showed that there is not a significant difference between G and I. As Table 4 shows, time records of level G are nearly monotonous for reaching the target in all distances but level 'I' requires more time in shorter distances (25 and 50 cm) and less time in farther distances (75 and 100 cm).

Table 4. Time of reaching the target at G and I setups

Distance (cm)	Setup (s)	
	I	G
25	27	23
50	25	22
75	17	21
100	14	19

The reason for taking longer time at setup 'I' is due to the wasted time for switching between cameras (there are three cameras and one monitor). The best setting is 'I' and for optimum results, it is advisory to switch on 2 cameras for short distances and 3 cameras for farther distances. At this setup the pointer reaches the target at an average time of 20.8 s. From an economical point of view, using G setup is recommended as the system works with 2 cameras. It should be mentioned that, at both setups, one camera is mounted on top of the end-effector and moves with it. Second and third cameras are mounted on the machine frame far from the manipulator base in a fixed and symmetric position relative to the manipulator (Table 4: G and I setups).

CONCLUSIONS

The feasibility of using a remotely controlled manipulator to service date trees was investigated in the present study. The results showed that this method proves applicable in servicing palm trees. The operator is able to control the manipulator through a monitor safely from the ground. The smallest accessible target was a 10 mm-diameter circle and the best camera setup is three cameras, one mounted on top of the end-effector and the other two on fixed positions at the sides of the manipulator base. When the end-effector is 100 cm away from the target and moves towards it, the pointer can reach a 10 mm diameter target in 20.8 seconds.

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