CONDITIONS, DEMANDS AND TECHNOLOGY FOR AUTOMATIC HARVESTING OF FRUIT VEGETABLES

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Abstract

The primary step in the process of developing a picking robot is to define its specifications. Then, a decision on whether the robot should move along the plants or the plants to move along the robot has to be made. Other aspects dealing with the economics of the robot (investment and annual costs), working time and required picking speed are decided on. This paper addresses these questions and concludes that a picking robot will be more feasible in a traditional stationary production system than in mobile production systems. For a 2 ha nursery, approximately 8 robots working 12 h a day with a picking speed of one fruit per 3 seconds, are needed to cover the main work load involved in harvesting tomatoes throughout the year. Hence, the room for investment per robot amounts to NLG 89,000.

Based on these findings, this paper presents a technological concept of a picking robot for fruit vegetables.

Keywords: automatic harvesting, feasibility study, fruit vegetables, robotics

1. Introduction

Today, labour is the biggest cost factor of a modern greenhouse holding. More than 30% of the total production costs are spent on wages for the grower and his employees. Obviously, to cope with saturating market demands and increasing competition, the grower is looking for ways to improve the over-all efficiency of the production process. Improving the efficiency of human labour or even reducing the amount of human labour seems to be a key issue. Manual labour in a greenhouse is demanding, especially when under poor climatic conditions. The jobs available are not very prestigious and earnings are low. Therefore, it is becoming more and more difficult to obtain adequate staff. These are reasons why already many years ago, research was focused on the automation of the most tedious and repetitive tasks in horticultural crop production, both inside and outside greenhouses (Tillet, 1993).

For a tomato crop, maintenance (40%), harvesting (27%) and grading (13%) are the most important cultivation tasks. In The Netherlands, tomatoes are produced in large quantities. The total production area is approximately 1100 ha and the size of a typical nursery is larger than 1 ha. The layout of the nursery is rather uniform. Usually, there is a main path along the centre of the nursery with long aisles of about 20 to 60 m perpendicular to the main path. In these aisles, heating pipes can be used as rails for transportation. Tomatoes are harvested from the same plants for 10 months. The same characteristics hold for the production of other fruit vegetables. The production characteristics as well as the fact that grading is largely automated and crop maintenance consists of various tasks which require considerable amount of skill, enable automated harvesting of fruit vegetables to seem to be a good choice as a first step towards automation of horticultural production.

The primary step in the process of developing a picking robot is to define its specifications. Then, decisions on whether the robot should move along the plants or the plants to move along the robot are made. Other aspects dealing with the economics of the robot (investment and annual costs), working time and required picking speed are decided on. Once these decisions have been made, the technical concept of the picking robot can be defined.

This paper consists of two parts. In the first part, with automated harvesting in mind, the tomato production process is analysed and some of the previously mentioned questions are addressed. Based on the results of the analysis, in the second part of this paper, a general technological concept of the picking robot for fruit vegetables is described.

2. Analysis of the tomato production process in view of automated harvesting

2.1 Basic assumptions

The calculations presented in this paper are for a nursery of 2 ha in which tomatoes are grown according to standard horticultural practice. The plants are grown using a high wire training system on rockwool slabs lying in long-shaped containers placed in troughs. The nutrient solution is recirculated and disinfected by a heat treatment system and liquid fertilisers are added by a substrate unit to control EC and pH. Additional characteristics, essential when considering automated harvesting, are the plant density of 2.5 plants/m^2, a yield of 50.1 kg/m^2 and the over-all labour demand of 965 h/1000 m^2, of which 27 % is devoted to harvesting. These data, as well as data relating for instance to the market price of tomatoes, variable costs, labour costs, overhead and the financial impact of capital goods were collected from a statistical data base containing representative data of Dutch tomato production facilities (KwIn, 1994). For more details about this analysis refer to Van Os et al. (1996).

2.2 The required picking speed of a single robot as affected by the operating cycle

From the statistical data base data were collected of The amount of tomatoes harvested throughout the year on a 4-week basis, were recorded in a statistical database (KwIn, 1994). These data were used to determine the consequences of replacing manual labour by a picking robot. The required picking speed of a single picking robot throughout the year was calculated, based on 6, 12 and 24 hours working periods in a single day. The results are presented in table 1. They clearly show that if a single robot is to be used on a 2 ha nursery, the picking speed should be well below 1 fruit per second even if the 24 hours operation is considered.

2.3 The required amount of robots and the room for investment per robot

Given the current technological status of robot harvesting and allowing for future developments, picking one tomato fruit in less than 1 second seems impossible. In other words: one picking robot is not sufficient for a nursery of 2 ha, more robots are needed. Therefore, the number of robots was computed, which are required when the picking speed per tomato varies between 1.5 and 6 s per fruit. These working speeds seem to be more realistic for the near future application. Table 2 shows the required number of robots for a 2 ha nursery operating at 6, 12 or 24 h per day. In the table MIN represents the number of robots needed to cover the basic workload from periods 3 to 12. If the workload exceeds the capacity of the robots used, additional manual labour is required for harvesting. MAX represents the number of robots needed if the robots have to be used during peak loads (periods 5 and 6) and manual labour is not to be used when harvesting. A consequence of this approach is that the robots will not efficiently be used throughout major parts of the year. Hence, between MIN and MAX there is an optimum condition at which all picking is done by robots for most of the year. Additional manual labour is needed for picking in periods 5, 6 and 7 only.

Table 2 also shows the room for investment per robot in relation to the working cycle and working speed. The room for investment per robot depends on the amount of labour saved by automatic harvesting. In today's horticultural practice, approximately 32 minutes are used to pick 100 kg tomatoes (Hendrix, 1993). It means that the picking time per fruit is about 1.2 s. The picking cost is NLG 0.0094 per tomato or NLG 147,000 in total for the 2 ha reference nursery. The life span of the picking robot was estimated at 6 years. Maintenance and interest were set at 1% and 3% per year, respectively. For a working cycle of 24 h, the financial consequence of human supervision at night, which is felt to be necessary in Dutch horticultural practice, were not accounted for. It will certainly reduce the room for investment in each robot.

If a robot is working for a longer period, say 24 h instead of 6 h, or is working faster, say picking one tomato in 1.5 s instead of in 6 s, few robots are needed. As a consequence the room for investment in each picking robot increases. Based on the available technology and the need to have a supervisor during harvesting, a working cycle of 12 h a day with a picking speed of one tomato each 3 s seem to be the most realistic specifications for the picking robot. Hence, the number of picking robots required for a 2 ha nursery is between 6 and 10. Besides, the room for investment is between NLG 77,000 and NLG 98,000 per robot (Table 2). Using a minimum of 6 robots means that additional costs for hand picking - in the tune of NLG 36,000 - have to be accounted for. When 8 robots are used, the additional cost for hand picking is NLG 11,000.

2.4 Driving speed

As earlier stated, with 12 working hours and a picking speed of 3 s per tomato, an average driving speed of 3.4 m/min is necessary. The actual driving speed depends on whether the robot moves continuously alongside the plants or whether it stops before each plant, i.e. with an interval of 50 cm. In the latter case the speed required for a single arm robot increases from 3.4 to 4.25 m/min. Alternative concepts will certainly affect the required driving speed. Since the robot moves from aisle to aisle on the main path, a further increase in required speed is expected.

2.5 Non-stationary growing systems

The main advantage of mobile growing systems over the traditional stationary system during automatic harvesting is that the picking place can be optimised, resulting in high efficiency. However,. the main disadvantage of the mobile growing systems is that they require considerable investments since the total infrastructure of the greenhouse has to be changed. Hence, they become economically infeasible and are not expected to be used for large scale production in the near future. Also, it was found that the room for investment in the picking robot did not change significantly when the use of mobile growing systems were considered instead of the use of the traditional stationary growing system. As a result it seems that the use of the picking robot is more feasible in the traditional stationary production system than the mobile growing system. However, the process of picking will - in essence - be the same for both mobile and stationary growing systems. Modification of the picking robot to suit the different growing systems is not considered to be a major obstacle.

3. The technological concept of a picking robot for fruit vegetables

The above analysis has shed considerable light on the particular specifications for the picking robot for tomatoes. In line with these observations, at IMAG-DLO research has been started with the objective to develop harvesting robots for fruit vegetables. This research is partly funded by the Dutch Ministry of Agriculture. Some important components of the harvesting machines are as follows.

3.1 An autonomous mobile platform

An autonomous mobile platform will be developed for coarse positioning of the picking system. The robot harvester should be able to move through the greenhouse without interference of the grower and should serve as a stable working platform for the operation of the robot arm. The mobile unit will make use of the hot water heating pipes on the floor of the aisles as a means for guidance and support. This kind of heating system is commonly used in Dutch horticultural crop production.

3.2 The robot arm

The main task of the robot arm is to achieve fine positioning of the end-effector so that it is able to perform well its task. Design parameters for the robot arm are as follows. The robot arm should be sufficiently fast during picking. The robotic arm should have the minimal required degrees of freedom to be able to locate and harvest the fruits at all possible locations in the crop. Limitations are put on the geometrical and physical properties of the arm because it has to deal with dense and rather fragile canopies and the amount of space between the rows of the crop is limited.

3.3 Fruit detection

In most fruit vegetable crops, the harvestable fruits are sometimes partly covered by the canopy. Measurement technology is needed which locates the fruits in the canopy. This may include vision techniques. The required sensors should be carried by the platform or the robot arm.

3.4 Detection of ripeness and quality

Once a fruit has been located, its ripeness should be established so that it can be decided whether the fruit is ready for picking or not. Quality parameters have to be determined and stored. Ripeness can be defined in terms of colour, hardness, size and possibly shape. The required sensors will be carried by the robot arm or the end-effector.

3.5 The end-effector

Once the ripeness and quality have been established the next operation will be to harvest the fruit. The picking process consists of two steps. First, the end-effector grasps the fruit. Then, secondly, it separates the fruit from the plant. The end-effector should have sufficient grip on the fruit such that the fruit will not be lost. However, mechanical stress that may reduce the quality of the fruits should be prevented. Depending on the kind of fruit which is harvested, a suitable mechanism has to be designed to separate the fruit from the plant without causing damage to other fruits, the stem or leaves.

3.6 Fruit handling and logistics after picking (grading, packing and transport)

Since most of the handling time in robotics is spent on detecting the fruit and moving a gripper towards it, it is very important that the fruit is only handled once to maximise the capacity of the harvest process from picking to packing. Therefore, the logistic chain of activities (e.g. picking, grading, transport out of the row, packing, etc.) should be combined into one operation.

4. Conclusions

If only one robot should pick all tomatoes on a 2-ha nursery, it should pick a tomato within 0.15, 0.3 and 0.6 seconds, while working for 6, 12 or 24 hours a day respectively, in the busiest period. Given the current status of automatic harvesting technology and even allowing for developments in the near future, these picking speeds do not seem to be realistic.

It is more realistic to have several picking robots working in a single nursery. Assuming a working cycle of 12 hours and a picking speed of 3.0 s per tomato, 8 robots are required to pick tomatoes in a nursery of 2 ha. These minimum driving speed should be 3.4 m/min and the maximum room for investment per robot is NLG 89,000. Under these circumstances, it is only during peak periods in labour demand (in summer), when manual labour will be required for picking tomatoes.

5. References

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Table 1. The available picking time per tomato throughout the year for a single picking robot on a 2 ha nursery

Period	Yield (kg/m^2)	Picking freq.	Average fruit weight (kg)	Number of tomatoes harvested per plant	Total number of fruits picked	Available picking time (s/fruit)		
						6h	12h	24h
	A	B	AFW	C=(A/ AFW*B*p l/m²)	D=C* area* pl/m²)		E=WH* 3600/D	
1	0	0	--	--	--	--	--	--
2	0	0	--	--	--	--	--	--
3	1.5	4	0.050	3.00	149000	0.15	0.29	0.58
4	3.9	10	0.053	2.94	146000	0.15	0.30	0.59
5	6.2	12	0.059	3.50	174000	0.12	0.25	0.50
6	7.8	12	0.067	3.88	192000	0.11	0.22	0.45
7	7.9	12	0.077	3.42	170000	0.13	0.25	0.51
8	7.3	12	0.077	3.16	157000	0.14	0.28	0.55
9	5.4	12	0.067	2.69	133000	0.16	0.32	0.65
10	4.8	12	0.059	2.71	135000	0.16	0.32	0.64
11	3.9	10	0.056	2.79	138000	0.16	0.31	0.63
12	1.4	6	0.050	1.87	93000	0.23	0.47	0.93
13	0	0	--	--	--	--	--	--
Total	50.1	102						

Table 2. The required number of robots for a 2 ha nursery and the room for investment per robot as influenced by the working time and the picking speed

Working hours	Picking speed (s/fruit)	Number of robots			Room for investment (1000 NLG)		
		Min.	Mean	Max.	Min.	Mean	Max.
6	1.5	6	8	10	98	89	77
	3.0	12	16	20	49	45	38
	6.0	24	32	40	25	23	20
12	1.5	3	4	5	202	179	154
	3.0	6	8	10	98	89	77
	6.0	12	16	20	49	45	38
24	1.5	2	2	3	358	485	257
	3.0	3	4	5	202	179	154
	6.0	6	8	10	98	79	77