The concept of a construction solution of a robot for harvesting strawberries

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Abstract. Strawberry fruit products are of high commercial and consumption value, while difficult to harvest due to their very low mechanical strength and difficulties in identifying them within the plants. Therefore, robots harvesting strawberries should connect four subsystems: vision of detection, delivery arm (manipulator), effector (harvesting head), and finally- a platform increasing the working space adapted to the size of the farm. The presented work of the conceptual working section of a combine for harvesting strawberry fruit from crops, carried out in rows or cultivation ridge, from cultivation on field and/ or under covers will meet the requirements for: work productivity, quality of harvested fruit, reduction of the amount of pollution. To requirements have been met, the developed concept of constructions adopted the principle of operation during the first phase of the harvesting (in the natural distribution of fruit within the plants of strawberries) and the working of the work arm head (based on image analysis, initially general, and in the last phase of detailed) maneuvering in surrounded by harvested fruit and machine.

1 Introduction

Automated production is an important current trend and future development in the field of agriculture. Along with gradually evolving technologies, the use of robotics in agricultural production is an important development direction. Research on the design, construction and use of robots for agricultural production is also an important factor enabling the construction of a production environment for high-quality agricultural products. Strawberry fruit are products of high commercial and consumption value, and at the same time difficult to harvest due to their very low mechanical strength and difficulties in identifying them within the plants. According to market research by IndexBox, global strawberry sales revenue was USD 21 billion in 2015 and is still clearly growing. However, strawberry production is heavily dependent on human work, with high work costs, especially at harvest [1]. In Norway, the costs of harvesting occupy more than 40-60% of the total work costs, depending on the method of production, the amount yieldand varieties of strawberry. To reduce production costs and increase product quality, several research groups are trying to

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use robots to reduce dependence on human works in soft fruit production. For example, Chinese scientists have developed a robot performing the operations of planting strawberry plants and fruit harvesting adapting to these operations suitable effector [15-18].

However, efficient and reliable strawberry harvesting has proved extremely difficult for several reasons. First of all, strawberries are easily damaged mechanically, which requires gentle handling when harvesting [2]. Secondly, strawberry harvest requires highly selective procedures [3] because they tend to ripen very unevenly, giving large differences in color and size, and requiring multiple harvesting. Finally, strawberry fruit grows in clusters, which makes it difficult to identify and select individual objects [1]. Overall, the robots harvesting strawberries should combine four subsystems: subsystem fruit detection subsystem ensures effector changing the position, end effector to separate the fruit from the bush and placing them in containers or teams receiving continuous platform and storage bins. The conducted experiments show that the harvesting head is a critical set of this robotic system, because it should enable proper manipulation [4] and select fruit in a delicate and effective way. Appropriate gripper design can significantly improve system stability and efficiency [5]. So far, several types of end effectors have been developed for harvesting strawberries, such as similar to scissors [3], knives with a suction device [8], as well as grippers with adjustable gripping force [2]. Because the position of the strawberry stem (picking point) is difficult to detect [6, 7], especially those in clusters, the scissor end effectors require a relatively difficult vision system solution. It is also easy to cut more than one stem and accidentally destroy the green strawberry fruit. Force-controlled grippers are also difficult to use because it is very easy to injure (mechanically damage) delicate fruits [3].

The development of devices (machines) for harvesting fruit to increase the harvest has been carried out since the 90s in the Netherlands and Japan, and as a result prototypes were developed [8-14]. Many problems associated with soft fruit harvesting are still unsolved, I think that the reason for this is the poorly understood working environment of the collecting heads. The first robot to collect strawberries for cultivation in gutters was developed by Japanese scientists in 2002 [8]. According to research, the robot can make one set of fruit in 11.3 seconds, and the success rate (in the form of correctly harvested fruit) was 41.3%.

2 Concept of a construction

Based on the available results of experimental research, the work presents the concept of the working section of a combine for harvesting strawberry fruit from crops, carried out in rows or cultivation ridge, field and/ or under cover. It should meet the following requirements:

- the working efficiency (harvesting) of the working section will be comparable or greater in relation to efficiency harvesting by human (approx. $7 \text{ kg} \cdot \text{h}^{-1}$),
- the quality of harvested fruit, determined by the reduction of mechanical damage, will be high,
- contamination of the harvested fruit parts with parts of the plant or substrate will be limited, e.g. with broken leaves, unripe fruit, used mulch, soil,
- one working team (head with arm and control mechanisms) will collect (harvest) one fruit working within one strawberry plants.

In order to meet the above mentioned requirements, the developed construction concept adopted the following principle of performing operations in harvesting technology:

- fruit during the first phase of the harvest remain at rest (in a natural distribution within the strawberry plants),
- the working head arm (based on image analysis, initially general and in the last detailed phase) maneuvers into the surroundings of the harvested fruit,

- the working head equipped with a supporting gripper suction cup extracts (positions) the selected fruit to such a position that it is taken by the head,
- the working head in a 'non-invasive' way (with limited mechanical damage) takes fruit in an alternative way: a – the fruit has stalks (dessert fruit), b – fruit without stalks (fruits for preserves),
- fruit downloaded by the heads is transmitted to the conveyor belt.

Figure 1 shows the systems included in this working section.

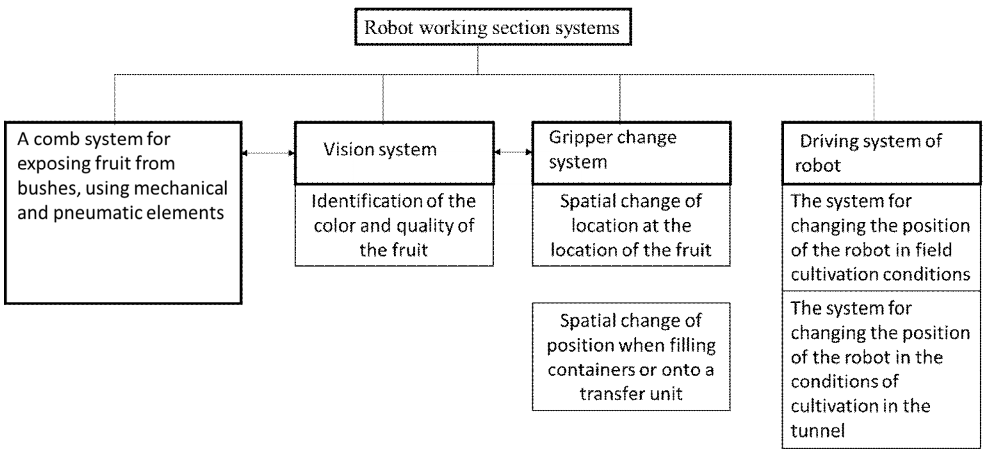

Fig. 1. Diagram of relationships between systems for strawberry fruit harvesting in the field and in a plastic tunnel grown in rows or cultivation ridge

The traction system consists of a tracked chassis and a telescopic shock absorbing suspension system. The traction system provides a four-point support of the combine's working section relative to the ground. The use of track assemblies and a telescopic shock-absorbing suspension system is designed to minimize the transmission of vibrations to the section frame. The telescopic shock-absorbing suspension system will have an adjustment of the position of the section frame relative to the ground, enabling fruit harvesting, alternatively from flat or raised crops.

It was assumed that the working section of the strawberry fruit harvester will have an autonomous frame, to which mechanisms responsible for the harvesting process and traction functions are mounted. The section is connected to the shearer's main frame by means of a suspension system, the construction of which is an articulated parallelogram. The use of this type of suspension ensures parallel arrangement of the frame section to the ground, regardless of its momentary position determined by the shape of the soil surface.

Fig. 2 illustrates the components of this section a working combine.

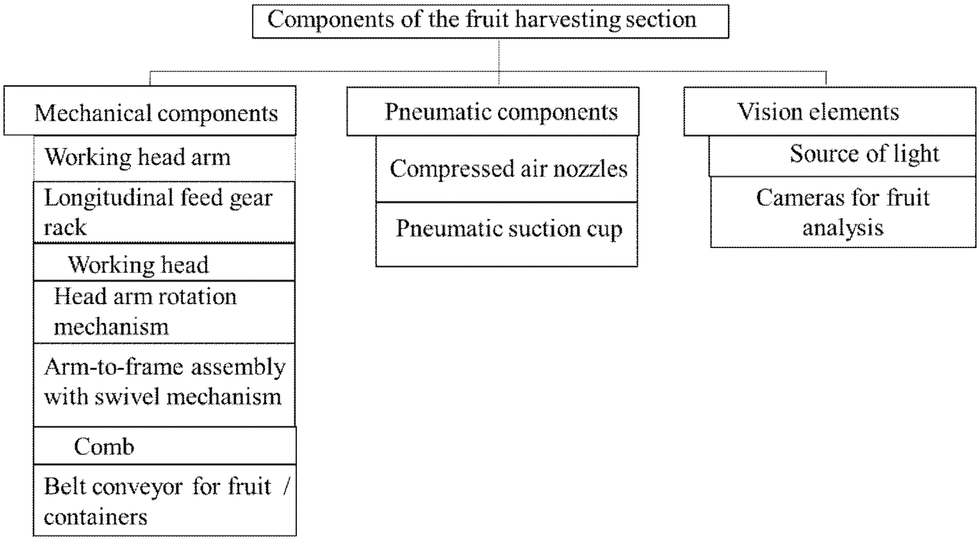

Fig. 2. Components of the working section of the strawberry harvester

The working section will be equipped with six or more working sets (heads with arms and control mechanisms) collecting (harvesting) fruit. The number of working teams depends on the maximum number of fruit picked from one strawberry plant in one harvest cycle. The assembly directly carrying fruit will be the working head attached to the arm of the head. The head's arm is divided into two sections, the longer covering about 0.8 length of the whole arm, on which the rack of the longitudinal feed mechanism of the arm is used, and the shorter to which the working head is attached. The connection of both parts of the arm will be carried out by a head rotation mechanism in a vertical plane. The second vertical arm rotation mechanism occurs as a subassembly of the arm integrating unit with the section frame. The rotation of the head arm in the horizontal plane will be carried out by the head arm rotation mechanism. Additional mechanisms involved in the fruit harvesting process are combs (finger construction) attached to the arms. The chafer interacts with the work of the working team (head with the arm and control mechanisms) and, like the working team, will be controlled by a microprocessor controller, and the control range will be determined by the analysis of the object image and the location of the collecting unit. The task of the comb is to tilt part of the strawberry plant to reveal ripe fruit that is the subject of the harvesting process. The combs will be equipment supporting fruit harvesting in working groups from the third to the last. Control of the comb will be carried out longitudinally with the aid of the longitudinal feed mechanism of the comb, and in the vertical plane using the rotation mechanism. Longitudinal control of the head arms and combs will be carried out using gear mechanisms, and the rotation of the arms using gears. The source of the drive for these mechanisms will be electric motors. The working head will be made of tilting jaws, and its capacity will be shaped so that it fully accommodates the harvested fruit in a non-invasive way. In the central part of the bottom of the head a pneumatic suction cup will be used, whose task will be to pick a ripe fruit, its initial displacement (positioning, extracting from the plants mass) to such a position in which the head acquiring ripe fruit does not take away the impurities (broken leaves, unripe fruit, parts of litter or soil fragments). The suction cup will adjust its position depending on the conditions (fruit location), sliding out of the head along the axis of the head's arm. After the fruit is picked up by the suction cup, the suction cup and the head will move in such a way (the attachment is withdrawn and the head moves towards the fruit) to place the fruit non-invasively inside the head. Depending on the direction of the harvest (for consumption or processing), the head will be equipped with a set cutting off the harvested fruit from the stalk. Consumer fruit should contain stalks, and intended for processing should not. In order to refine the image used to control the working mechanisms of the working (harvesting) unit and the comb, a camera identifying the harvested object is provided at the bottom of the working head. The fruit harvested by the working team will be transferred to a fruit conveyor belt.

3 Summary

The presented concept of construction should contribute to the improvement of the effector's work through the use of working teams in the form of combs, the effect of which will be to display the fruit. The use of the suction cup in the effector (working head) will allow the fruit to be extracted from the plants habit to such a position that it can be taken non-invasively (broken) by the head jaws. The positioning of the vision system in the effector can improve the more efficient handling of the head during fruit picking operations, and thus reduce the time of surgery. The modular (sectional) construction of the robot will allow adjusting its construction parameters to the area of cultivation.

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