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Design, fabrication and evaluation of a picking mechanism for fruit harvesting

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ABSTRACT

In this paper, a picking mechanism for fruit harvesting was designed and results of field experiments are reported. A prototype model was designed for both efficiency and cost effectiveness. Experimental results showed the proposed mechanism yielded a good accuracy; where a total of 210 fruits are used for evaluating the device, 200 of them were grasped and 9% damaged. The experimental picking system demonstrated potential for using robots in harvesting of fruits with satisfactory quality.

Key words: AVR-Microcontroller, Fruit clamp, Harvesting, Stepper motor

Harvesting is one of the most important agricultural and horticultural operations. The traditional manual harvesting is very labour intensive, and thus expensive. Although Wingate-Hill *et al.* (1981) found that mechanical harvesting was not always cheaper than hand harvesting. Therefore, spending money to improve the harvesting operation leads to the quantitative and qualitative growth in yield and income. Since the cost of harvesting represents 35–45% of total operating cost, there is potential for a significant reduction in total fruit production costs through the improvement in the efficiency of this operation (Sanders 2005).

Robots are machines that are intended to replace human beings in the execution of tasks that involve physical activities or decision-making (Kyriakopoulos and Loizou 2006). Although autonomous harvesting robots have not yet been commercially applied in horticultural practice, but many researches have been conducted towards the design and application of robots for harvesting in both fields and greenhouses (Arima and Kondo 1999; Van Henten *et al.* 2002, Muscato *et al.* 2005, Foglia and Reina 2006, Van Henten *et al.* 2006, Tanigaki *et al.* 2008, Zhao *et al.* 2009, Hayashi *et al.* 2010, De-An *et al.* 2011, Shokripour *et al.* 2012).

The harvesting robots for cucumbers (Van Henten *et al.* 2003), tomatoes (Chiu *et al.* 2012) and strawberries (Qingchun *et al.* 2012) have been researched in all over the world, and some prototypes have been developed. Peterson *et al.* (1999) developed a mechanical bulk robotic harvester for apples grown on narrow, inclined trellises. This type of bulk harvesting requires, in addition to the canopy-like growth habit, uniform fruit ripeness at harvest, firm fruit, resistant to damage, and short/stiff limbs (Peterson 2005). Tree canopy shakers are a promising method of mechanically harvesting citrus fruit, but they lack a reliable method of fruit counting (Ehsani *et al.* 2009). The use of a one by one fruit picking system, although inherently slower, does not suffer from any of the above restrictions. Moreover, only fruits with satisfactory size and maturity are selected for harvesting and can be sorted out immediately (Baeten *et al.* 2007).

The objective of this research is to present a cost–effective picking mechanism for fruit harvesting. We have designed a system for mechanization of the fruits harvesting operation as a research prototype. The device was used on some fruits and evaluated.

MATERIALS AND METHODS

A preliminary prototype was designed and fabricated. It mainly consisted of (a) two fruit clamps, (b) a stepper motor, (c) an ATmega32 AVR Microcontroller, (d) a Transistor Arrays Integrated Circuit (IC), (e) a seven segment display board, (f) potentiometer, (g) push buttons, (h) resistances, capacitors, regulators, an electrical fuse, a diode bridge, an on/off switch, a buzzer, etc. Also a 12 V power supply was used as the electrical power source for all the components.

The stepper motor converts digital pulses into fixed (design-specific) angular steps. These motors are normally used in an open-loop configuration and are the most cost-effective solution in many positioning applications. The

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stepper motor has windings only on the stator, while the rotor usually features permanent magnets.

There are situations in which the equipment cannot be connected directly to the personal computer (PC) or this connection is realized with some restrictions. A low-cost solution means the utilization of a system realized with a microcontroller as an interface between the PC and equipment. Microcontrollers have a fixed amount of Random-Access Memory (RAM), Read-Only Memory (ROM), Input/Output (I/O) ports, timers, analog-to-digital converter (ADC), etc. For this project, the programming of the AVR-Microcontroller was done in Basic language using the BASCOM-AVR software, version 2.0.5.0.

Both crop and fruits are prone to mechanical damage and should be handled with care. To pick the fruit with as little damage as possible, two simple fruit clamps had to be used. The device has two fixed and rotating fruit clamps. Rotating clamp is capable to move in the clockwise and counterclockwise direction.

When the AVR-Microcontroller provides a signal, the transistor in the Transistor Arrays IC - ULN2004A – switches on, thus allowing current to start to flow through to the motor's coil. The rotor turns either clockwise or anti-clockwise depending on the current position of the stepper motor.

Four normally-off push buttons were used to reset the AVR-Microcontroller program and clockwise, anti-clockwise and stop the stepper motor rotation. A normally-off push button switch is a small, sealed mechanism that completes an electric circuit when you press on it. When it is on, a small metal spring inside makes contact with two wires, allowing electricity to flow. When it is off, the spring retracts, contact is interrupted, and current will not flow. The body of the switch is made of non-conducting plastic.

A 10k Ohm rotary potentiometer was used to adjust the angular displacement of the stepper motor. The humble potentiometer (or pot, as it is more commonly known) is a simple electro-mechanical transducer. It converts rotary motion from the operator into a change of resistance, and this change is (or can be) used to control the position of stepper motor and the rotating fruit clamp subsequently.

Here, a 4-digit seven segment was used to display the angular displacement of the rotating fruit clamp. The seven-segment display is a pretty simple device. It is actually eight Light-Emitting Diodes or LEDs (the decimal point is the 8th). It can be arranged so that different combinations can be used to make numerical digits.

Fig 1 Performance evaluation of the device (left: clockwise rotation, middle: anti-clockwise rotation, right: angular displacement).

Using Proteus (ISIS 7 Professional) software to set up and simulate hardware circuit diagram.

After designing and construction, the device performance was evaluated on gala apple, peach and plum trees (Fig 1). Gala apple is one of the most widely grown apple varieties in the world. Gala apples are small and have a thinner and smoother skin than most apples. The picking mechanism was tested on seventy numbers of each above-mentioned fruits.

Only fruits with a high maturity level should be picked. For this reason, seventy fruits with a maturity level of more than 70% were used for each above-mentioned fruit types. Human judgment was used for detection location and maturity level of these fruits. Moreover, the fruits were harvested early in the morning, before the temperature of the fruits rises, and they become soft.

RESULTS AND DISCUSSION

Microcontrollers are used to reduce cost and to increase the flexibility and reliability of most new product and system design. The software automatically controls the motion of fruit clamps to the specified point. To achieve this goal, we used stepper motors so that, the exact position of clamps in every motion is known.

Stepper motors, and attendant drivers are the technology of choice for a multitude of industrial position and motion control applications. The low cost of motor and drive combined with the ultimate simplicity of open loop stepper control are the most compelling reasons for the application of stepper motor and drive systems versus competing, more complex servomotors and servo drives. Other stepper motor drive advantages include rugged motor construction, high reliability since no failure prone feedback devices are needed and short commissioning cycles since no servo-loop tuning is required. The performance of conventional stepper motor drive systems is limited, excluding them from applications requiring high speeds, high acceleration rates and smooth motion. They are also prone to excite mechanical resonance, stall easily and emit discernible audible noise. Furthermore, stepper motors can provide accurate positioning without the need for position feedback sensors.

The 200 steps per revolution stepper motor was implemented in half-step mode. Half step simply means that the step motor is rotating at 400 steps per revolution. In this mode, one winding is energized and then two windings are energized alternately, causing the rotor to rotate at half the distance, or 0.9°. Although it provides approximately 30% less torque, half-step mode produces a smoother motion than the full-step mode. Since each pulse causes the motor to rotate a precise angle, typically 0.9°, the motor's position can be controlled without any feedback mechanism. As the digital pulses increase in frequency, the step movement changes into continuous rotation, with the speed of rotation directly proportional to the frequency of the pulses.

Table 1 Evaluation results of fruit picking mechanism

Fruit	Fruit number	Grasped fruit number	Grasped grasping success rate (%)	Damaged fruit number	Fruit damaging rate (%)
Apple	70	67	95.7	4	6
Peach	70	69	98.6	8	11.6
Plum	70	64	91.4	7	10.9

For the purpose of evaluating, the field tests were carried out in the orchards which were located in the Heydareh area of the Hamedan city during June 2012 (Fig 1). The results are shown in Table 1.

The results showed the fruit grasping success rates were 95.7%, 98.6% and 91.4% for apple, peach and plum respectively. Therefore, the average rate was about 95.2%. About 86% of the fruits were picked up successfully without any damages on the surface. About 14% of them were damaged or not grasped. The damaged fruits consisted of the brown scabs scarring on the skin or scratched ones. The experiments demonstrated that the amount of damage (on grasped fruit) caused by fruit clamps was on an average 9.5%. Because of these results, the effectiveness of the prototype device was confirmed by field experiments in an open field.

For more interpretation, the performance of the proposed mechanism was compared with the human harvesting method. It was assumed that the fruits are successfully harvested with minimum no-grasping (Grasped fruit number=69) and minimum damaging (Damaged fruit number=1) were occurring in harvesting by human hands. However, the human harvesting of fruits has been a hard and heavy task in a long time. Analysis of variance in term of fruit grasping is given in Table 2. Results showed that at 1% and 5% probability level, there was no statistical significant difference between the proposed picking mechanism and human harvesting for fruit grasping.

Moreover, the human harvesting was compared with the harvesting by proposed picking mechanism at different fruits in term of fruit damaging (Table 3). Results indicated that there was no significant difference at the 1% probability levels between the two types of harvesting for fruit damage,

Table 2 Analysis of variance for fruit grasping of proposed picking mechanism and human harvesting

Source of variation	Degree of freedom	Mean squares	F value
Harvesting methods	1	8.17	2.58 ^{ns}
Error	4	3.17	
Total	5		

** Significant at 1%; * significant at 5%; ns, non-significant

Table 3 Analysis of variance for fruit damage of proposed picking mechanism and human harvesting

Source of variation	Degree of freedom	Mean squares	F value
Harvesting methods	1	42.66	19.66 *
Error	4	2.17	
Total	5		

** Significant at 1%; * significant at 5%; ns, non-significant

although it was significant at the 5% probability levels.

This mechanism can be used in harvester robots (Agribots) hands, especially ones have moving ability. The purpose of motion control was to guarantee that the fruit-harvesting robot achieved movement with an arbitrary angle to grab the object fruit accurately and rapidly. When the fruits were grasped, the other system can pull and pick.

The experiments conducted over several fruits in orchards showed that the overall performance of the picking mechanism is satisfactory. In this paper, for more convenience, data from previous tests and also the presence of an operator were used to adjust the fruit clamps angle. Obviously, using sensor technology or machine vision this task can be performed online and continuously. Moreover, researches for detection technologies in both location and maturity level are interesting possibilities for further development.

CONCLUSION

The purpose of this project was to design, fabricate and test a picking mechanism for fruit harvesting. The device tests were performed on three types of fruit in the Hamedan orchards. The results demonstrated that the fruit grasping success rates varied between 91% and 98% during the experiments. Furthermore, the fruit-damage rate was less than 12%. Local orchardists accepted this performance level. This study showed that the proposed mechanism as a robotic system could apply in harvesting fruits with the lowest damage, although further development is necessary.

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