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EFFECT OF FORCE CONTROL SYSTEM ON POWER AND TIME CONSUMPTION OF TREE PRUNING MACHINE

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ABSTRACT - This scientific paper showed the manipulator operation and the end effector of pruning machine with a force control system. The effect of the sensitivity coefficient of force control system, cutting tool rotating speed, wood diameter and the interface effects on cutting time and power consumption were analysed by Duncan's test. Finally, we have analysed and investigated, once with variance analysis results, the system effect of force control on time and power consumption and suitable method of system usage of force control pruning machine. Based on these results, by increasing the sensitivity coefficient of the force control, the work time has increased and the power consumption has decreased. In addition, less rotational speed must be chosen in a sensitivity coefficient level. Therefore, the force control system of a tree pruning machine may be used for energy saving.

Key words: force control system, sensitivity coefficient, tree pruning machine, energy saving, agricultural machinery

REZUMAT – Efectul sistemului de control al forței asupra consumului de energie şi a timpului consumat la maşina de tăiere pentru întreținerea pomilor. În prezenta lucrare, au fost descrise operațiile manipulatorului şi partea terminală a brațului maşinii de tăiere pentru întreținerea pomilor cu sistemul de control al forței. Prin intermediul testului Duncan, au fost analizate efectul coeficientului de sensibilitate al sistemului de control al forței, viteza de rotație a instrumentului de tăiere, diametrul lemnului şi efectele interfețelor asupra timpului de tăiere şi a consumului de energie. Odata cu rezultatele analizei varianței, au fost analizate şi cercetate efectul sistemului de control al forței asupra consumului de energie şi a timpului consumat, precum şi metoda adecvată de folosire a sistemului de control al forței de către maşina de tăiere pentru întreținerea pomilor. Pe baza acestor

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rezultate, s-a observat că, prin creşterea coeficientului de sensibilitate al sistemului de control al forței, s-a mărit timpul de lucru şi a scăzut consumul de energie. De asemenea, s-a folosit o viteză de rotație mai mică la nivelul coeficientului de sensibilitate. In concluzie, sistemul de control al forței la maşina de tăiere pentru întreținerea pomilor poate fi folosit pentru economisirea energiei.

Cuvinte cheie: sistemul de control al forței, coeficientul de sensibilitate, maşina de tăiere pentru întreținerea pomilor, economisirea energiei, maşini agricole

INTRODUCTION

Nowadays, robots are used in industrial, agricultural, medical and more other fields. For instance, they are used in welding, painting, assembling, grinding, finishing, physiotherapy, orthopedic surgery, general surgery, sheep shearing, dairy cow milking, animal slaughtering, picking oranges, vegetable propagation, bedding plants, greenhouse harvesting and so on.

When the force control system is used in robotics, there are force feedback data about motion or force. Force feedback control is used in operations where vision data are not enough and may result in unforeseen manipulator errors.

The use of robots for picking up fruits from fruit trees was first proposed by Schertz and Brown (Schertz and Brown, 1968). Although the word robot was not used in their papers, many concepts for robotic harvesting were concisely established. Parrish and Goksel have made a robotic system for picking up fruits, which consisted of a TV camera, basic robotic arm and a control computer (Parrish and Goksel, 1977). Simonton has developed a robot work cell for geranium cutting, used for propagation (Simonton, 1990). Pool and Harrell have designed a robot end effector for picking oranges. It contained colour camera and an ultrasonic transducer for fruit detection in the fruit tree (Pool and Harrell, 1991). Condo et al. have designed a cherry tomato harvesting machine. Peterson et al. have developed a robot to harvest apples (Peterson et al., 1999). Ryu et al. have carried out research on developing robots for bedding plants (Ryu et al., 2001). The bedding robot contained an end effector, manipulator, conveyer and a monitoring system. The University of Western Australia has developed two robots for sheep shearing. Robots have also been employed in cucumber harvesting (Shigley and Mischke, 1986; Van Kollenburg-Crisan et al., 1998). Greentech Ltd has developed a greenhouse harvester. This machine was a mobile robot, which moved in rows, identifying ripe fruits for picking. Mandow et al. have developed greenhouse-spraying robots (Van Kollenburg-Crisan et al., 1998). Iida et al. have developed watermelon harvesting robotic machine (Mandow et al., 1996).

The agricultural robots have used vision system, which is exposed to error because of the environmental conditions. It is possible to prevent arm collision damage of fruits and branches by using the force control system. Saving energy can be achieved by different methods. In the tree pruning machine, the force control system can be used for saving energy. For this research, we have used the force control system. Power consumption and required time were determined for different sensitivity coefficients.

MATERIALS AND METHODS

The tree pruning machine is a 3 DOF robot, PPR, as shown in *Figures 1 and 2*. It is such designed that it can easily move fruit trees and covers half of the tree. There are two-step motors for linear motions and another one for the rotation of the end effector.

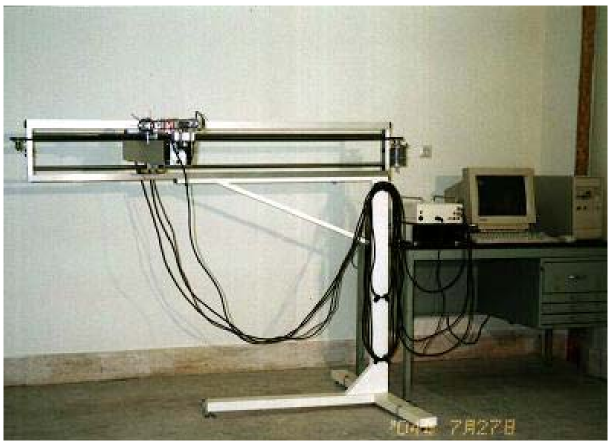


Fig. 1 – Tree pruning machine

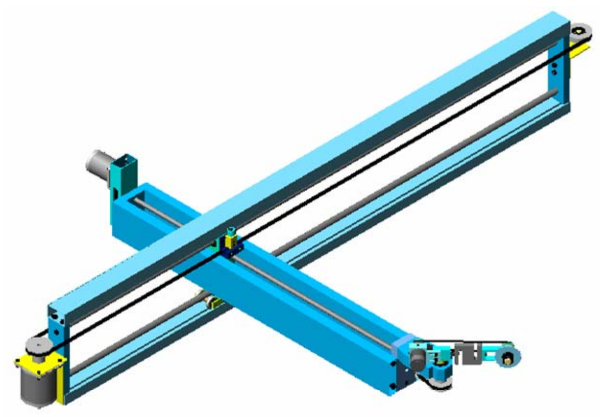


Fig. 2 - Manipulator PPR with 3 DOF

The end effector includes a rotating saw and a load cell (*Figure 3*). The rotating saw is driven by a DC motor. Its speed is controlled by a PWM board. Load cell is S- shaped (20 kgf, model DBBP, Bongshin) and is located between the saw axle and the end effector hinge.

The system block diagram is illustrated in *Figure 4*. A computer is connected to four step-motor drivers through parallel ports and 25 pin connectors. Digital signals are sent to a D/A interface via parallel ports. The output is an analogue signal within the range of 0-5 volts. This signal is sent to a DC motor driver board. The output of the driver is found within the range of 0-30 volts, which is sent to the rotating saw DC motor. The feedback is the output of a load cell, which is a signal within the range of 0-5 volts. This goes to an A/D board, which is transferred to digital codes and sent to computer.

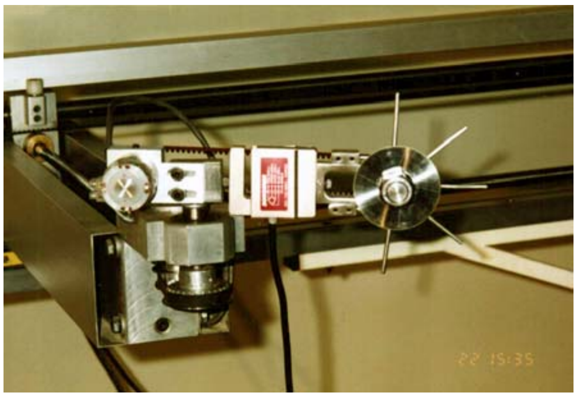


Fig. 3 - End effector

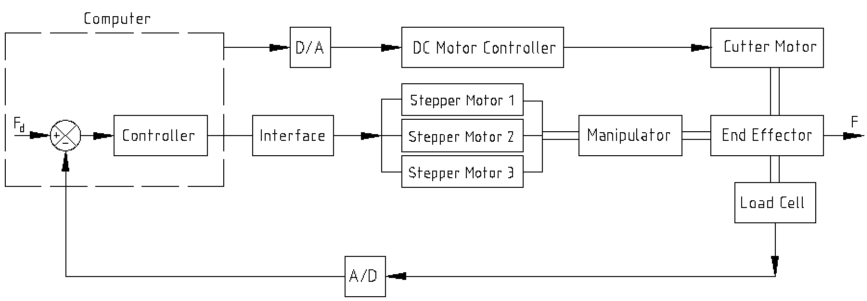


Fig. 4 - Control system block diagram

The arm weight should be designed as smaller and lighter as possible. Then, less powerful actuators can be used. The longitudinal arm is a rectangle frame that may lead to moving the latitudinal arm in its length. As shown in *Figure 5*, the frame of the arm consists of aluminium profile at the top and a rail, which has two aluminium guide rails at the bottom. In addition, two aluminium plates are connected with screws at both ends. Two rails of longitudinal arms consist of a steel bar that plays a role in addition to guiding support to the straight path. The latitudinal arm consists of a rectangle frame and two aluminium profiles (95x25x1.5 mm) with two aluminium plates connected by screws at both ends. This arm consists of an actuator stepper motor that drives it at one side and an end effector motor, which rotates on the other side. Two rails of this arm are made of steel bar. The end effector is connected at the other end, as shown in *Figure 6*.

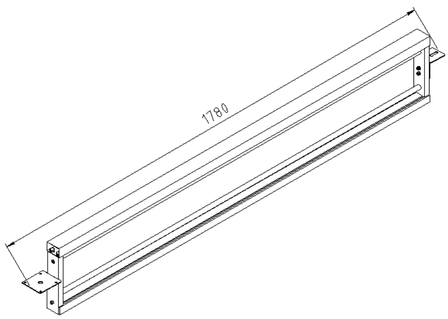


Fig. 5 - Longitudinal arm

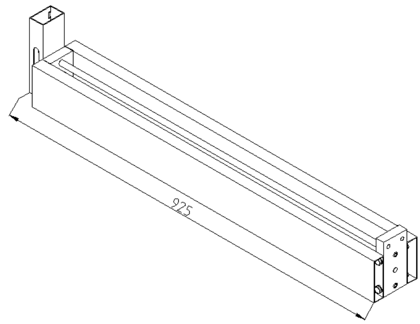


Fig. 6 - Latitudinal arm

The support is an aluminium block with four holes, which axes are perpendicular to each other and a brass nut (M14x2), which is installed in the centre. Four bearings are pressed in the holes (*Figure 7*). The support is mounted on four wheels for running down the rail guides and at the top, two cylindrical wheels, for running on the lip of the top aluminium profile. The support is used for driving the latitudinal arm longitudinally and leading to straight path and for driving the latitudinal arm perpendicularly to the longitudinal one and leading to straight path by power screw.

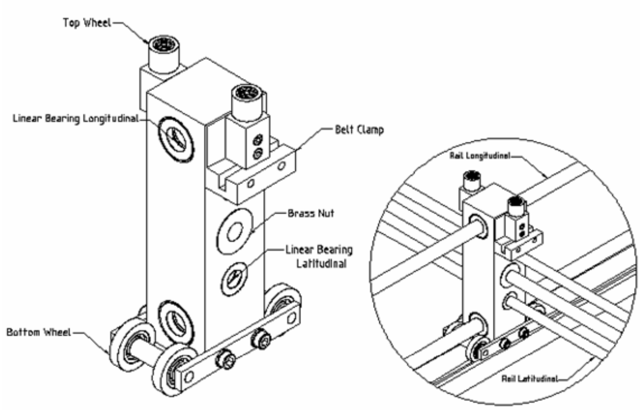


Fig. 7 - Support

For avoiding longitudinal guideways from torsion and bending, due to the latitudinal arm and the end effector weight, we have used four polyethylene wheels at the bottom and two cylindrical wheels at the top.

The end effector consists of the following parts, which are shown in *Figure 8*: DC motor holder, which supports both motor and belt adjustment of the cutting system. Revolute joint supports the motor on one part and is connected to load cell on the other part. The motor rotates the end effector around its axle.

1. The S–beam load cell.
2. Cutting shaft support.

The actuator of the longitudinal arm: a stepper motor (3v-4A-1.8 Deg/Step, model 103-810, Sanyo) 17 *kgf.cm* holding torque is used to drive the support along the longitudinal arm. It is installed at the end of the arm and a pulley on the other end. XL timing belt is driven by the stepper motor and transfers motion to support by clamp, which is installed at the top of support (*Figure 9*).

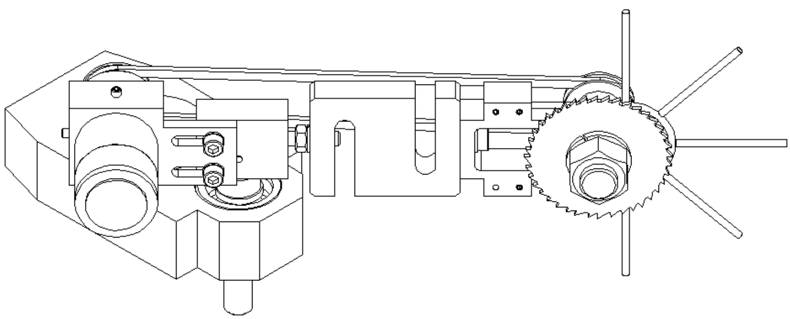


Fig. 8 - End effector

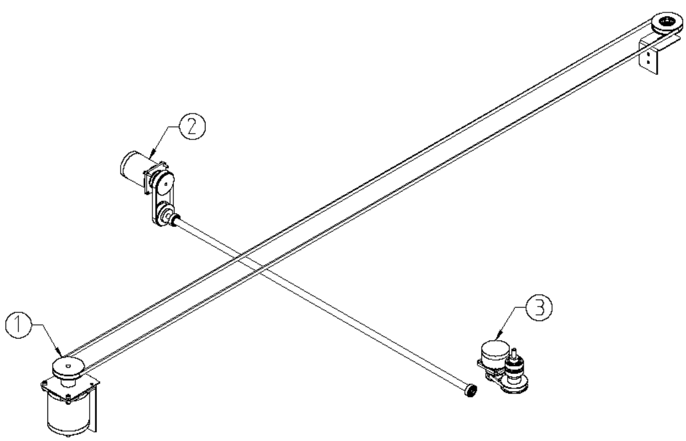


Fig. 9 - Actuators of the manipulator

The actuator of the latitudinal arm: power transfer system in this actuator is a power screw. Stepper motor (5.47-1.5A-1.8 Deg/Step, model 103-710, Sanyo) 8 kgf.cm holding torque is installed at one end of the arm. Its power is transferred by belt and pulley to the longitudinal bolt, which is supported by bearings from both sides.

The actuator of revolute joint: in this actuator, a stepper motor (5.6-0.6A-1.8 Deg/Step, model 103G775-2141, Sanyo) is used to rotary motion 180-degree end effector. The power transfer system from stepper motor to revolute joint is timing pulley.

A control force system has been used to prevent collision damage at the tree pruning machine. This can be carried out by keeping fixed contact force at a definite level. This system decreases the manipulator feed when the contact force increases from the set point. As a result, the machine works at a desired performance.

The effect of sensitivity rate of the force control system was investigated by some experiments. These experiments were carried out on cutting time and power consumption. As a result, the direction of variation of the sensitivity rate can be determined for decreasing the cutting time or power consumption.

The effects of sensitivity rate of the force control system, rotational speed of cutting blade and wood diameter on cutting time and power consumption were designed and some experiments were carried out. The purpose of these experiments was to measure the system cutting time and the power consumption. Therefore, three experiments with three factors on three levels were carried out. The factors and the level of experiments consisted of the sensitivity coefficient (a) - this coefficient was defined in visual basic programme, which controls the speed of stepper motors. The speed of the longitudinal and the latitudinal arm (sensitivity of end effector) has changed by altering this coefficient. It was determined at levels a_1=1, a_2=2 and a_3=3 and also without force control system a_0=0 (as control).

1. The cutting system rotational speed (n) was defined at three levels: n_1=3000 rpm, n_2=2500 rpm and n_3=2000 rpm. Its speed can be adjusted by software.

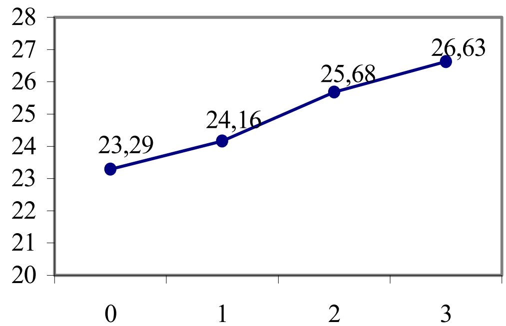
2. Wood piece diameter (d): Circular section wood piece was cut by cutting system. It was chosen at three levels: d_1=12 mm, d_2=14.5 mm and d_3=19 mm.

Data of experiments were analysed for the factorial experiment base on completely randomized design; then, the comparison of means was carried out by Duncan's significant range.

RESULTS AND DISCUSSION

We found no significant interaction coefficient of sensitivity in the speed of rotating cutting system (axn), but we found a significant one at 1% level as concerns the power consumption of cutting system. The interaction of the sensitivity coefficient in wood piece diameter (axd) for cutting time was significant at 1% level, but it was not significant for power cutting system. There was no significant level at the interaction of cutting system rotational speed in wood piece diameter (nxd) and the interaction of sensitivity coefficient in cutting system rotational speed and wood piece diameter (ax n x d) for cutting time and power consumption.

The comparison means by Duncan's test have shown that the sensitivity coefficients a_1 and a_3 resulted in less and more cutting time, respectively. In addition, all the sensitivity coefficients a_1, a_2 and a_3 and a_0 control had a significance difference (*Figure 10*). Once with increasing the sensitivity of force control system, operating process needed a longer time because of speed decrease. It suggests a less sensitivity coefficient to prevent working surface damage. Therefore working time is reduced.



(a)

Fig. 10 - Time consumption versus sensitivity coefficient

Figure 11 showed that the interaction (axd) ratio to the cutting time indicated that all the different three levels (d) with increasing sensitivity coefficient and wood piece diameter have increased working time. As shown in *Figure 12*, the interaction axn ratio to the cutting time indicated that in every sensitivity coefficient increasing cutting system rotational speed did not have an effect on working time. Therefore, for reducing cutting system wear, one should choose less rotational speed in every sensitivity coefficient.

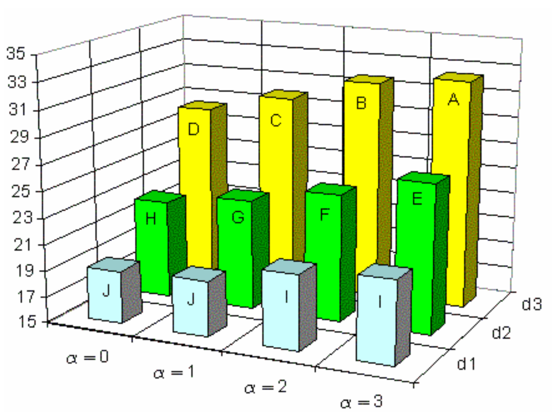


Fig. 11 - Interaction axd ratio to the cutting time

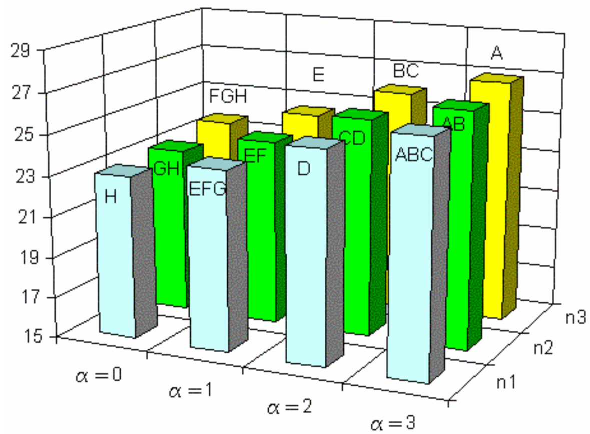
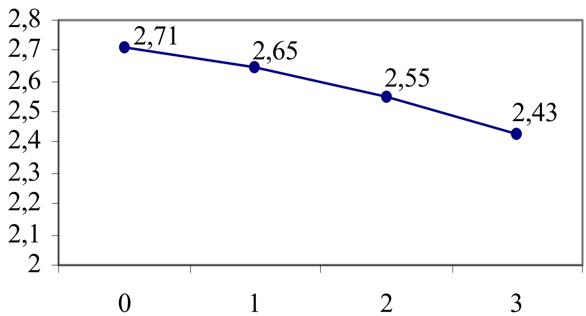


Fig. 12 - Interaction axn ratio to the cutting time

Comparing the sensitivity coefficient to power consumption, we found that the sensitivity coefficient a_1 was the highest and the sensitivity coefficient a_3 had the least power consumption. In addition to the sensitivity coefficients (a_1, a_2, a_3), the control (a_0) had a significant level (*Figure 13*).



(a)

Fig. 13 - Power consumption versus sensitivity coefficient

Figure 14 showed that once with increasing the sensitivity coefficient, the power consumption was reduced, because once with increasing the sensitivity coefficient, the arm speed diminished and the result was the reduction of loading rate to cutting system. Interaction (axn) ratio to power consumption indicated that at every level of the rotational speed of cutting system with increasing the sensitivity coefficient decreased power consumption (*Figure 15*). This was because of decreasing speed. The force control system in the pruning machine can be used for saving energy.

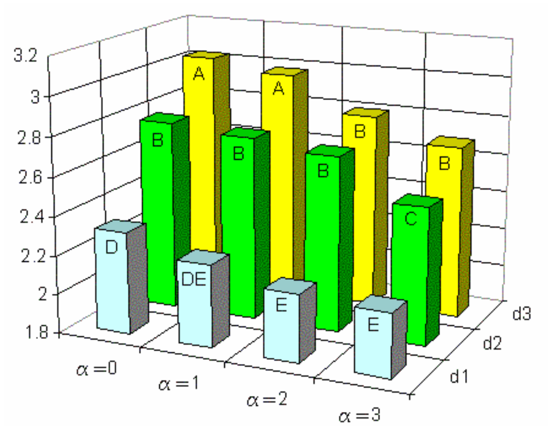


Fig. 14 - Interaction axd ratio to the power consumption

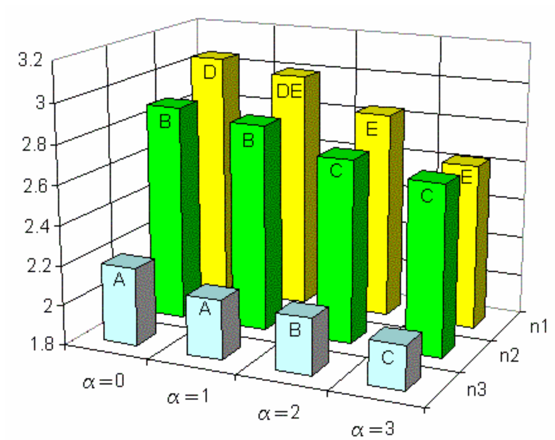


Fig. 15 - Interaction axn ratio to the power consumption

CONCLUSIONS

By increasing the sensitivity coefficient of the force control, working time increases.

By increasing the sensitivity coefficient of the force control, the power consumption decreases.

At every level of the sensitivity coefficient, a less rotational speed must be chosen.

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