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Design and Evaluation of Automatic Agricultural Land Leveling Control System for Scraper

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ABSTRACT

An automatic land leveling control system (ALLCS) consists of different sections such as electronic circuitry, laser and hydraulic devices in order to adjust the height of scraper. A laser beam strikes a photocell array and then the electronic circuit detects the level of the laser beam. If the level of laser beam is not the same as set point, a control signal is transmitted in order to adjust the height of the scraper. In this paper, investigation on design and operation of different parts of the ALLCS are presented. The steady state and transient responses of the system are also discussed. First, the whole system and also the design of its components are described. The block diagram of control system and the mathematical model of its various sections are presented next. Then, based on these equations, the mathematical model of whole system is derived. This model is solved and analyzed by MATLAB's Simulink and the responses of system to different inputs are obtained. The transient response of system to inputs of 10 and -8.5 cm amplitude step functions for embankment and landscape, respectively were investigated. For the embankment, the response was over damped and the time to reach the steady state was 1.15 second. The difference between steady state error simulation and experiment was about 0.04 mm. For the landscape case, the response was over-damped too. However, the steady state response time was faster. This is due to the fact that the height for landscape case was smaller. Based on the experimental and simulation results, the validity of the model is confirmed. The model may be used as a reference to evaluate the functionality of the control system at different operating conditions.

Key Words: Automatic control system; Precision farming; Agricultural land leveling; Computer simulation; Mathematical model; Scraper

INTRODUCTION

Now-a-days, in order to gain maximum efficiency, precision farming is applied and it is tried to use all entries with their optimum values. Moreover, precise land leveling is a prerequisite for achieving high irrigation efficiencies at the field level (Rajput & Patel, 2002). Roberts *et al*. (2000) conducted a research to introduce laser and satellite controllers and to investigation the dynamic behavior of those controllers. They installed each of controllers on height control machines such as distributor asphalt machine, bulldozer, mechanic hoe bucket and grader. Results showed that turbulences in laser systems are less than satellite systems and their responses are over-damped, however by filtering data, it is possible to decrease the turbulences of satellite control systems (Roberts *et al*., 2000). El-Yazal and Wissa (1990) did a research on cane fields to study the value of consuming water in Egypt in 1990. They concluded that in fields leveled with laser leveling machines, with mechanical leveling machines and without any controller (traditional), the quantity of required water are 18404, 23428 and 25488 m³/ha, respectively (Walker, 1989; Haynes, 1996). Also, the quantity of product when they used laser leveling machine, mechanical leveling machines and without any controller were 107.9, 88.7 and 71.9 ton/ha, respectively (El Yazal & Wissa, 1990).

At present, land leveling machines with mechanical controllers are seldom used due to their low accuracy. For high accuracy, low cost and programming ability, in precision farming, electronic control systems are suitable substitution. Generally in land leveling systems with mechanical controller, the accuracy of operation depends on skills, experiences and safety of operator. In order to alleviate these problems, design and manufacture of an automatic electronic control system of height was conducted. If an automatic control system in leveling machines is used then it is not necessary; (i) to perform topography operation using topography cameras in order to determine the height of different points, (ii) to do engineering calculation, which is done in traditional methods and to pay attention to the quantity of landscape and embankment points.

MATERIALS AND METHODS

An automatic control system of leveling machine having laser control comprises of four main parts; laser transmitter, receiver, electronic circuits, hydraulic section, which are described as follows:

Laser transmitter system. This section is separated from three other parts and its task is to create a definite level of laser light in height of land (Hosseinzadeh, 2003). At present, the transmitter is installed on a tripod and setting location is at a point or at a side of field. Height of transmitter should be so adjusted in order to light ray can swirl above of any obstacle in the field even the leveling machine. Since some machines such as bulldozer and scraper move fast, the laser system should have ability to scan the area, about 10 times per seconds. In laser systems, maximum ray that transmitter can cover with high accuracy is 300 m (depends on laser type). Increasing the distance, concentration of laser beam will be reduced and transmittal error may be occurred (Land Leveling, www.land-level.com).

Receiver section. This part consists of a cell, which is sensitive to the laser light and is installed on a prop; the prop is installed on a frame attached to the cutter side and with a mechanism that is always kept vertically. Moreover, the prop has a telescopic shape in order to have ability to change its length. Receiver sensors are divided into three sections; central cells, upper cells and lower cells. The central cells are related to the neutral situation or no action. Receiver senses the height of apparatus using laser light distributed by transmitter and then conveying it to the electronic part. Moreover, this system can be used in topography and leveling operation. In the first application as surveyor, relation between carrier prop and mechanism of changing blade height is disconnected. In this state, with coming up and down of the machine during its motion on the low and high land, prop comes down and up and thus, laser ray strikes to the different parts of the receiver. Related data concerning the height of field points is transmitted to the monitoring system inside the cabin and after end of operation, data is processed and average height and slope of field is determined. Thus, topography operation of field can be done automatically. In next application, leveling operation, prop including the laser receiver correlates with mechanism of changing blade height. In this state, light ray in definite height of land surface creates a light surface. This surface can be leveled (zero slope) or with attention to spotted slope for leveling land can be angular (desired slope). In onset of operation, the blade is set in such a state that is tangent to the surface. Then, height of prop is adjusted till laser light ray strikes to the bottom or up of the receiver. This information is sent to the control unit and through this, activates hydraulic system and causes the system to move up and down insofar as laser light ray strikes to the receiver centre.

Electronic circuitry. This section is the heart of the control system and constituted of different electronic parts. Processing rate of this section is very important and by increasing the speed, the accuracy of the control system will be increased too. Moreover, this section also receives signal from the receiver and based on that, determines strike location of laser light with receiver and finally with strike location recognition, it will calculate the height and then suitable command will be sent to the hydraulic system.

Hydraulic system. Hydraulic section is a source of generating power for height control system and consists of a hydraulic pump, solenoid valve, double action cylinder and pipes and junctions. The task of this section is to carry up and down the cup and blade using with one or two cylinders, which are located between main frame of scraper and cup.

Generally, before doing leveling operation using the automatic control system, transmitter of laser light should be calibrated and adjusted. After doing these adjustments, the system is ready for operation. By moving the apparatus on a land having height higher than the desired one, then cup, blade and receiver with main frame move up and thus laser light strikes to the part under middle area. This situation is sensed by electronic section and based on the location of laser light a suitable command is sent to hydraulic system to bring down the blade and receiver until laser light strikes again to the middle area. This action is repeated when the system moves in a lower height surface too (Hosseinzadeh, 2003).

Specification of laser transmitter system. Transmitter must have appropriate features such as spreading a rotational laser light at a desired land height so as its slope and its rotation speed can be adjusted. For implementation of this design, the laser light should be rotated, however rotation of laser light source on the land surface is very difficult and for the laser itself is harmful, therefore laser light source should be fixed and the laser beam should be distributed optically in land surface as shown in Fig. 1. As it is seen in Fig. 1, laser source has been set vertically and since the mirror angle is 45 degree towards the land, the laser light is converted to horizontal state. Now, by rotating of the mirror around the axis of laser source, the laser light is distributed horizontally.

Specification of laser receiver. Receiver is a device that determines the height of laser light and transfers it to the electronic circuit. One of the most important specifications that a receiver should have its ability of quick responding. Moreover, the striking time of laser light to the receiver is very short and at this moment, it must transfer its information to the electronic section. The following equation calculates striking time of laser light to the receiver:

$$T = \frac{30 \quad d}{\pi R N}$$

Where

T is striking time of laser light to the receiver (second), d is photocell width (meter), R is distance between transmitter and receiver (meter) and N is the rotational speed of transmitter (rpm). Fig. 2 shows the manufactured receiver.

Specification of electronic circuitry. The task of electronic system is to measure the difference between the actual height of blade and the desired height and then sends the required commands to the hydraulic system. One of the main specifications of the electronic system is its processing rate. By improving the processing rate of electronic system, the delay of control system becomes less and thus the accuracy of the system will be improved. The other specification of electronic system is its flexibility. As it is mentioned before many parameters such as hydraulic system and its components are effective in height control and therefore, the electronic system should have the ability to change the parameters in order to improve the performance and control the system. To do this, the electronic system was designed digitally to reach the desired specifications. Generally, electronic circuit takes information from receiver and also keyboard and based on that activates the solenoid valve of hydraulic system. The brain of electronic system is a microcontroller that processes all the instructions and commands. The microcontroller used here is 8052 with high speed and many abilities and facilities (Mazidi, 2000). The manufactured electronic main board is shown in Fig. 3.

ALLCS block diagram. To present a suitable mathematical model for the system, Newton laws in Mechanics, flow and continuity equations in Fluid Mechanics and also Laser and Electronic laws were used (Hosseinzadeh, 2003; Mohtasebi *et al*., 2005). To solve the non linear differential equations and obtaining the transient response, MATLAB's SIMULINK was used (Anonymous, 1992, 93). Generally, there are different methods for design and analysis of control systems and computer simulation is one of the most powerful methods in this field. In other words, it is a fast, low cost and accurate method for analyzing and optimizing any kind of systems.

Schematic diagrams of system and its block diagram are shown in (Fig. 4 & 5), respectively. In the diagrams, the input is required height and controller calculates the difference between the desired and the actual heights and based on that produces appropriate current signal to activate the solenoid valve. After that the valve spool will be moved and flow delivered to the hydraulic cylinder will be changed and thus the blade position is changed. This process will be continued until the system reaches its desired height.

RESULTS AND DISCUSSION

To validate the mathematical model and to find out the steady state and transient response of the system, some experimental tests were carried out. The experiments were conducted to find the response of system to two height step inputs of 10 and -8.5 cm. These inputs were selected to show two possible states of blades i.e., embankment and landscape. In the experiments, the following components such as a hydraulic pump, a hydraulic cylinder, a directional valve, a laser transmitter and a laser receiver, microprocessor board and other necessary parts were used (Fig. 4). To measure the cylinder displacement, a shaft encoder was used. All required data were sent digitally to the computer serial port and saved for further actions.

Fig. 1. Photo of laser transmitter

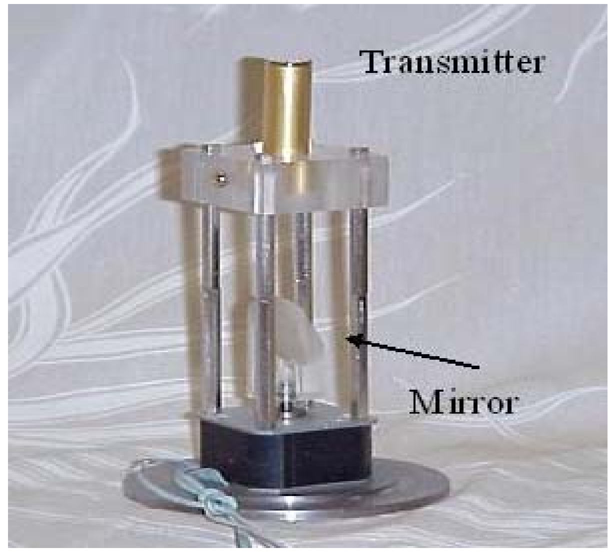


Fig. 2. Photo of receiver

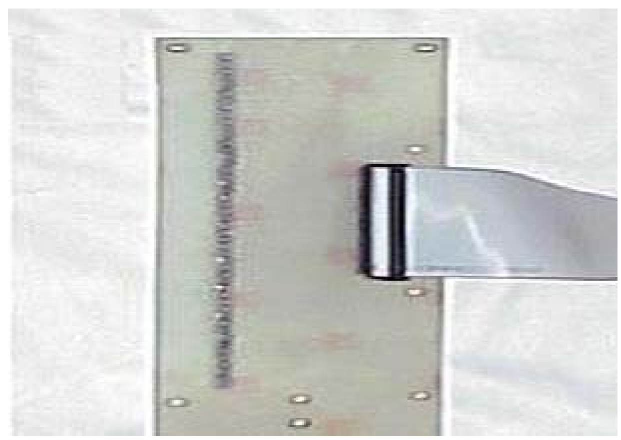


Fig. 3. Photo of electronic main board

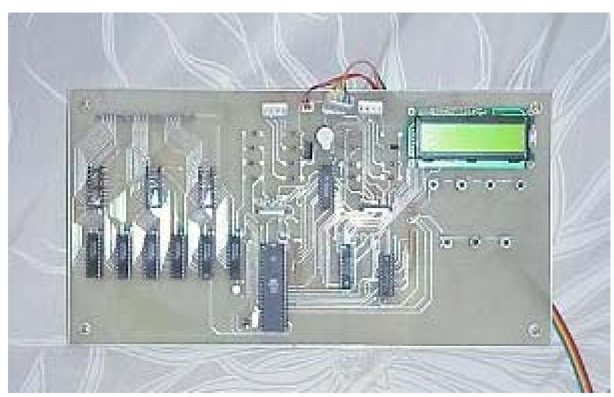


Fig. 6 shows the transient response of system to 10 cm step input experimentally. As it is seen, the steady state error

Fig. 4. Schematic of land leveling system

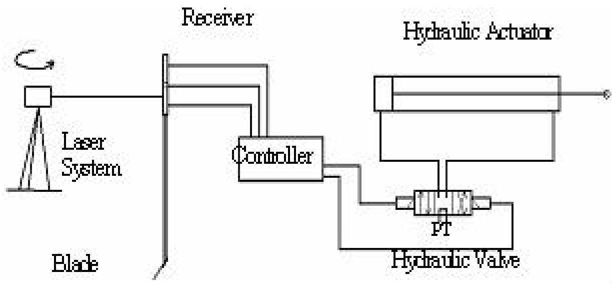


Fig. 5: Block diagram of automatic Land leveling system

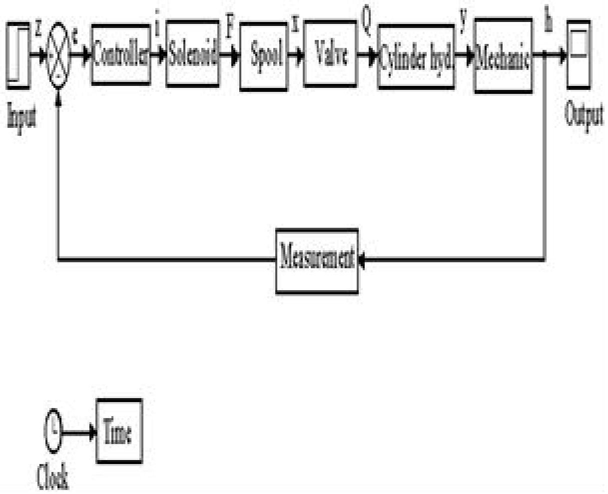
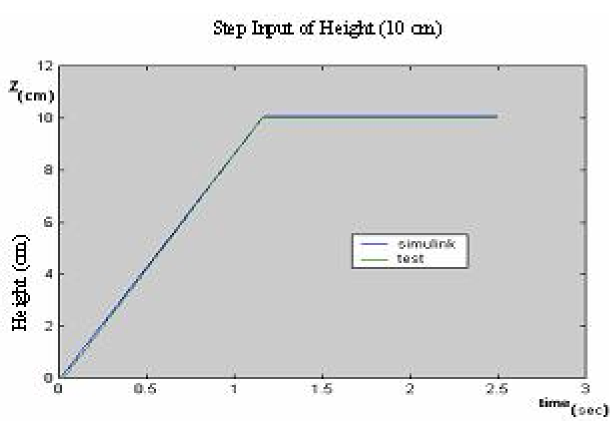


Fig. 6. Comparison of simulation and experimental results



is about 0.004 cm, which is within the range of the system i.e. 0.4 cm. The figure also shows the comparison of computer simulation and experiment results. As it is seen, the response is over-damped and there is a very small difference between them. Transient response of both of them have similar behavior and the coefficient determination standard deviation of these responses are R^2 = 0.95, which is statistically very high showing very small deviation.

Fig. 7 shows the comparison of computer simulation and experimental results to -8.5 cm step input. The experimental response is over damped and after 0.815 second it reaches its steady state value of -8.507 cm. In simulated response, the response time is 0.818 second and the steady state value is -8.505 cm showing the very closeness of simulation and experimental results and thus validation of proposed mathematical model. Now, by validation of mathematical model it is possible to find the response of other parameters.

Fig. 8 shows the spool response to the step input of 10 cm height. It takes 25 ms for spool to move from middle (neutral) position to the left or right positions and thus maintains the required flow rate for the system. Moreover, the maximum stroke of spool is 5 mm and the response is over damped. Also, Fig. 8 shows that the return time to the middle position is 20 ms.

CONCLUSIONS

In this research an automatic control system for land leveling machines was designed, manufactured and evaluated. This system can be installed on most of leveling

Fig. 7. Comparison of simulation and experimental results

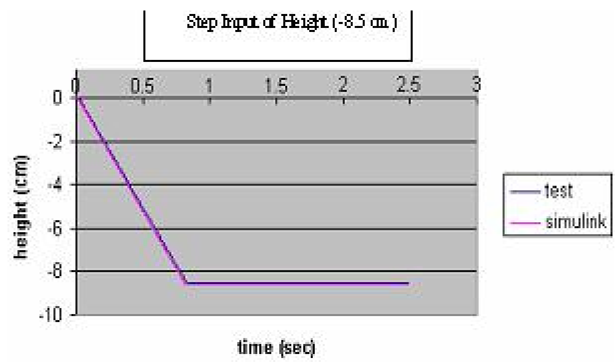
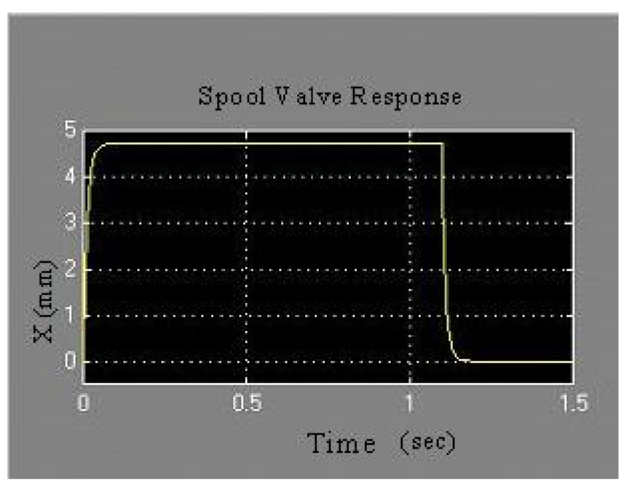


Fig. 8. The Transient response of spool to step input of 10 cm



machines such as loader, grader and scraper. Moreover, the dynamic response of system and its components were fully analyzed and simulated. Using the proposed model it is possible to evaluate the response of system having different pumps, hydraulic valves, different cylinder speed, etc.

The dynamic response of system to different inputs of 10 cm for embankment and -8.5 cm for landscape were investigated. For the embankment the response was over-damped and the steady state response time was 1.15 second. Moreover, there is a delay about 20 ms due to delay of spool movement of hydraulic valve. The difference between steady state error simulation and test was about 0.04 mm, which is negligible.

In the second state i.e. landscape, input is -8.5 cm and the response like the previous case, was over damped. However, the steady state response time was faster. This is due to the fact that the requested heights for embankment and landscape were different i.e., -10 and 8 cm. Moreover, for the embankment, the hydraulic pump should fill the front of piston, which has more space in comparison to the back of piston. This means that the effective area of cylinder head is more than that of the other side of the cylinder. Therefore the response time during the landscape is shorter.

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