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Adaptation of tilt adjustment and tracking force automation system on a laser-controlled land leveling machine

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ABSTRACT

This study is about the mechanization and automation works carried out to improve the operational efficiency of the laser-controlled land leveling machines and to design a more precise, ergonomic, economical and reliable system. At first, the existing laser-controlled leveling shovel has been redesigned through a mechanical design thus being adapted to automation. The mechanical structure was driven by the hydraulic system and the hydraulic system was controlled by the PLC. This new design consists of blade tilt adjustment automation system, track automation system, and maximum load protection system. With its new design, the machine can level out harder lands by less number of repetitions and less fuel consumption with a gradient precision of 0.05°. After the design the time saving of 80% and the fuel saving of 85% has been achieved for the surfaces with the same area and approximately 10 L of fuel savings per acre has been performed. The new shovel system has been enabled to carry 1.3 times more soil for the same slope and also, just this modified machine can be used instead of using 3 separate land leveling machines for 3 different operations. Moreover, the requirement for land leveling in both directions has been avoided in leveling out narrow areas, especially on highway buildings.

1. Introduction

As a general definition, land leveling means shaping the surface by leveling out topographical relief and roughness. Surface roughness is a key element in the hydrological and erosive behavior of soils (Helming et al.,1998). Leveling is applied in many sectors such as airports, construction, maintenance, and repair of roads and railroads, water channel construction, urban planning, and agriculture. It covers a broad range of works, from major landscape modifications to the removal of minor undulations in the field. In this process, the higher parts are cut to fill the void areas or pits. The common feature of these machines is that they have a hard blade that can cut the land and a shovel just over the blade to move the cuttings (Gagnon et al., 2017).

Many new agricultural automation technologies are being developed by university researchers that pose questions about the efficiency and effectiveness (Blackmore, 2009). In recent years, automated systems have been added to agricultural vehicles to increase productivity. However, even with automation technology, human operators are still required to be present inside agricultural vehicles and to interact with these semi-autonomous vehicles (Bashiri and Mann, 2014). Agricultural productivity has increased significantly over the years as a results of intensification, mechanisation and automation (Zhang et al., 2013; Nof et al., 2009). Agricultural automation has resulted in lower production costs, reduced reliance on manual labor, and increased product quality These advances have been achieved with the development of various sensors and actuators. (Edan et al., 2009). An application algorithm, which can be used in computer-aided design/engineering and structural optimisation-based design studies of agricultural machineries was introduced (Celik et al., 2017; Vasovic et al., 2013; Irsel et al., 2015). Chateau et al. (2000) was presented a method of automatic guidance of an agricultural vehicle in a structured environment (windrow harvester) or an iterative structured environment (combine harvester) using a laser sensor. In the mentioned study the sensor parameters were estimated using a correlation based approach. Chiou et al. (2008) was used planar multibody system dynamics to model an intelligent personal mobility narrow-tilting vehicle with four wheels arranged in a diamond configuration. In addition proposed model by Chiou suppoted the measuring of joint reaction forces to assist in advanced controller and mechanical system design. Kidane et al. (2010) was concentrated on development and experimental investigation of a compound control system design for tilt stability of a narrow commuter vehicle. In another study, Kidane et al (2008) was proposed a control system that stabilizes the tilt mode of such a vehicle without

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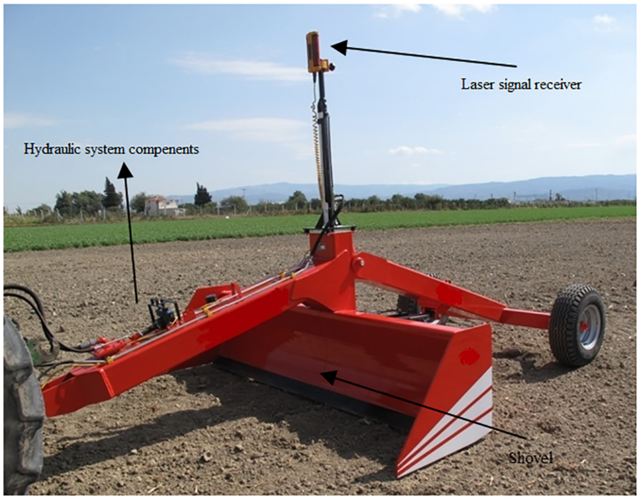

Fig. 1. A Laser controlled land leveling machine.

affecting the handling of the vehicle. Tang et al. (2018) was presented the design of an integrated suspension tilting mechanism for narrow tilting vehicles. Han et al. (2015) performed an auto-guidance tractor system that can be used in tillage operations. A multi-robot tractor system for conducting agriculture field work was developed by Zhang and Noguchi (2017) in order to reduce total work time and to improve work efficiency. Vougioukas (2012) developed a multi-robot system for agriculture work, too. In his study two or more robot tractors used and the system suppoted two modes. Roeber et al. (2016) performed the installation a hydraulic flow and pressure measurement device on the rear of a tractor to provide implement hydraulic power consumption at different hydraulic hose orientations (Karayel et al., 2006). The high-speed camera system observed the seed spacing and velocity of fall of seeds.

According to literature there is no work on the shovel tilting system on a laser controlled land leveling machine. The main purpose of this study is to transform an existing land leveling machine into a more efficient and reliable system. Land leveling machine is not only used in agricultural fields but also used in to highways and urban planning. For this purpose, it is aimed to enable the blade, which is fixed at the original machine, to rotate depending on the slope of the ground. Moreover, it is aimed to automatically uphols the blade in case of a predetermined maximum load value in order to ensure self-protection of the blade and the efficient use of the tracking force. In line with these purposes, the blade has been thoroughly redesigned according to methodical construction principles and it has been sized by using assembly stress analysis (Altinbalik and Irsel, 2014; Nor et al., 2012; Zaheriea, 2011). System automation has been designed within the framework of the goals of development work. The designed and improved system has been manufactured and ground tests have been carried out. In this study, a laser-controlled leveling shovel which can only be used in the agricultural sector has been transformed into being available to be also used in the other sectors. Thus, instead of purchasing different machines for different sectors, it will be possible to provide service for many sectors by using the redesigned machine.

2. Material and methods

2.1. Current laser controlled land leveling machine

A general laser-controlled leveling machine consists of hydraulic equipment, tubes, and pressure gauge as shown in Fig. 1. The hydraulic pump of the tractor facilitates the receiver tower's up and down motion. This motion is carried out manually by the operator by using control valves at the tractor. The second pump driven by the tractor drives the cylinder that performs the up/down motion of the blade of the laser-controlled leveling machine. The up and down motion of the blade is controlled manually or it is moved automatically by a laser-controlled automation system.

Leveling machine's laser control system is composed of three main components as seen in Fig. 2. It consists of three parts, a laser signal emitter, a laser signal receiver, and a laser signal control system. The laser signal emitter generates a rotating beam with 900 nm wavelength at 640 rpm. The laser signal receiver, which is basically composed of BWP34 photodiodes and basic electronic components such as transistors, is placed on 4 columns through 200 mm from top to bottom. The signal receiver detects BWP34 diode on which the beam falls.

The laser control system operates by continuously transmitting signal, which is emitted from a fixed elevation, onto the strip in the middle of the receiver shown in Fig. 2b. If the laser beam falls higher or lower than the center of the signal receiver, the signal receiver must be moved in this direction. This movement is carried out by the laser control system by providing output to the related solenoid valve. Thus, the laser signal falls into the center of the receiver. The elevation (Lk) is determined by the distance between the center of the signal receiver and the contact surface of the blade as seen in Fig. 3. Over which elevation the blade will perform the cutting operation is determined according to the beam emitted at a fixed elevation. Therefore, the center of the laser signal receiver follows up the signal and the blade follows up the green[1] line in the Fig. 3, accordingly. The aim of the laser control system is to allow the blade to move at the elevation determined by the operator. Adjustment of the receiver tower and selection of the elevation is performed by the operator. Signal receiver gets the signal for the first time by the assistance of the operator. If the incoming signal is above the center of the signal receiver, the blade is automatically moved downwards, and if it is below the center, the blade is automatically moved upwards. This is the basis of the laser-controlled automation system.

2.2. Problems of a laser controlled machine

The most important problem of the existing laser-controlled leveling machine is that the receiver cannot display accurate reference value due to the slope when working on a sloping land. Laser-controlled leveling machine receives the signal at a single point and that is the center of the entire blade width as seen in Fig. 4. As the selected blade width increases, the received signal's ability to represent the whole blade decreases. If there is a slope perpendicular to the blade direction, the elevation of blade's signal receiver, the L_k distance, deviates. The signal detection error is defined in Eq. (1) based on the slope angle. When the blade is tilted according to the slope of the land, it moves over the reference elevation for a distance (Ls_h) based on the tilt angle (α).

$$Lsh = Lk\,(1-cos\alpha) \quad (1)$$

Moreover, the existing laser-controlled leveling machine makes a plunge error to the ground at turns during leveling operation independent from the automation system and slope. This error occurs because the blade inclines left while turning left and it incilines right while turning right during the operation. This error value will increase gradually when it is required to pass from the same location for several times during the operation.

In areas where the length to width ratio is too high, using existing leveling machines is economically and physically inefficient. For the areas with equal length and width, leveling must be carried out in both directions with an angle of 90°. This causes an increase in time and fuel consumption required for leveling. The fuel consumption of the tractors

[1] For interpretation of color in Figs. 3,18,19, the reader is referred to the web version of this article.