Development and Evaluation of a Laser Plane Slope Generator System for Application in Land leveling and Construction Process

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Abstract: - Laser measuring and control systems are one of the most important practical technologies and have a wide usage in medical, civil, manufacturing and agricultural fields. A wide variety of industrial products are developed for computerized control of earth moving processes. Machines like grader, loader, scraper, and tractor are able to be equipped with these devices and operate precisely and effectively. The operation is based on producing a reference laser plane in 3 or 4 meters above the ground and then the machine makes a plane with the similar pattern on the ground. Laser plane sometimes has to be completely horizontal and sometimes sloped in one way or sloped in a dual or complex way. Conventional transmitters and generators of laser plane are automatic and have a high price, about 5000$. This research proposes a mechanical-electrical method to replace with the automatic one, and has evaluated its efficiency. As a result, although the precision of this method is lower than automatic one, its price is 1/5 of the automatic method. The possibility of expanding the market of civil and agricultural laser devices increases with this system due to its low price.

Key-Words: - Land Leveling, Construction laser, Agriculture laser, Construction laser

1 Introduction
Broad variety of industrial merchandise are supplied for computerized control of earth moving process by construction and agriculture field vehicle such as Grader, Back hoe, Tractor and Scraper machines. The major assignments of these machines consists of the field topography surveying, soil cutting from spotted elevated area, transferring , filling of low area and surface leveling according to a desired planned . Thickness and height control units of such machines is mainly laser and ultrasonic based transducers. There is a substantial amount of information in the literature on this topic area, mostly associated with element of the intelligent machine control and monitoring [1]. The main components of construction and agriculture laser system and its task is shown in appendix fig.1. The transmitter emits a plane of laser light visible to the human eye. The plane or "blanket" of laser light extends in all directions covering a diameter of 200 to 1000 meter. The plane can be tilted in up to 2 directions hence the term dual slope laser. A receiver mounted on a stand over the equipment blade senses or "receives" the laser signal. Control box ,contained microprocessors then calculate the piece of equipment's elevation relative to the plane of laser light and either makes corrections to the
equipment's cutting edge automatically or if in manual mode, the signal lamp on a monitor tells the operator whether to raise or lower the cutting edge. Investigation on design and operation of different parts of the agricultural laser leveling system are presented by Mohtasebi, s.s, and partners [2]. Laser leveling is a process of smoothening the land surface (± 2 cm) from its average elevation using laser equipped drag buckets to achieve precision in land leveling. Precision land leveling involves altering the fields in such a way as to create a constant slope of 0 to 0.2%. This practice makes use of large horsepower tractors and soil movers that are equipped with global positioning systems (GPS) and/or laser-guided instrumentation so that the soil can be moved either by cutting or filling to the desired slope/level. Higher levels of uniformity of irrigation water application may be achieved by precise land leveling and using appropriate stream sizes based on infiltration rate of the soil. The advanced method to level or grade the laser leveling provides a very accurate, smooth and graded field. This allows for ideal control of water distribution with negligible water losses. Academic study and experience of laser land leveling (LLL) user have indicated that a significant (20-25%) amount of irrigation water is lost during its application at the farm due to poor farm designing and unevenness of the fields, increases the yield and products quality and improves water coverage that improves crop establishment [3]. Through the evolution of the earth moving technologies the use of satellite positioning system with laser techniques has been offered as an accompaniment or substitute in new generations of laser land leveling system operations. Employment of DGPS\(^1\) and RTKPS\(^2\) technologies for precise measurement of height and field coordination has constituted a new facility known as Auto Level. Auto Level automatically controls the height of the scraper blade during leveling operation with high accuracy. It’s not sensitive to fog, dust, temperature change, and covers a large area relative to laser land leveling method. Although this procedure has not been mature enough yet to be presented to the market, but it does have a bright future ahead (www.novanant.com). Reviewing the results of several different researches have shown that the cost of LLL operations have posed many difficulties upon farmers [4, 5, 6, 7]. In Iran, as in many other countries, LLL is a favorable substitute for other mechanical and traditional equipments. But the main limitation, there is still the unaffordable price of it for private sectors. Through some research it's tried to improve technical and economical aspect of LLL potentiality for more utility and propagation in mass consumer market. In an experimental study the elimination of some automatic feature of LLL system and substitution of them with a combination of simple manual method and mechanical devices has been executed. Results shown a reduction in the field capacity of tractor in leveling process, the accuracy is kept, but the total price of the laser equipment used in this method has been decreased by 65% comparing with an automatic laser land leveling system [8].

The aim of this research was a continuation of formerly conducted study to develop semiautomatic mechatronic laser plane orientation devices as a main requirement in conjugation with laser transmitter unit. This simple and low price technique is an alternative for automatic control of laser plane orientation in horizontal and dual slop situation. The assumption behind this study was to supply an affordable, up to 65% cheaper, efficient technology for crop production and sustainable development.

Accuracy, repeatability, and resolution were chosen as the main variable of performance

\(^1\) Differential Global Positioning System
\(^2\) Real Time Kinematic Positioning System
qualification of erected instrument. Accuracy refers to the difference between the actual value and the measured value. Resolutions refer to the smallest change in the measured variable that can be detected by the sensor. Repeatability is, as the term suggests, the ability to repeat the same motion or measurement within certain definable bound.

2 Procedure

An automatic laser transmitter composed of a mainly laser source, a motor which rotate the laser beam in order to convert it to a laser reference plane, a self leveling system and a single or dual laser plane sloping devices. About 60 to 70 percent of the laser transmitter price is devoted to its leveling and sloping system. This accessory is replaced with a Pantilt that used as a stand and swiveling base of camera. The various apparatus undertaken in this project are a rotating single slope transmitter for comparison of its sloping ability with Pantilt sloping capability and a simple cheap transmitter without any extra system. Some additional mechanical piece is also manufactured and used as integrator of major component. The laser transmitter is shown in fig. 1, Pantilt and its control unit is shown in fig. 2.

Fig 1. The laser transmitter and detail of its control panel: 1&2. Laser beam source & module. 3. Handle. 4. Charger. 5. Control panel.
There are perhaps two land leveling philosophies: (1) to provide a slope which fits a water supply; and (2) to level the field to its best condition with minimal earth movement and then vary the water supply for the field condition. The second philosophy is generally the most feasible. Because land leveling is expensive and large earth movements may leave significant areas of the field without fertile topsoil, this second philosophy is also generally the most economic approach. It is a process for ensuring that the depths and discharge variations over the field are relatively uniform and, as a result, that water distributions in the root zone are also uniform. These field operations are required nearly every cropping season, particularly where substantial cultivation following harvest disrupts the field surface (FAO).

The example below illustrates a single grade setting of 0.20% which is defined as a fall of 0.2 meters per 100 meters.

Dual grade Determine the dual (compound) grade of the work area. When using the concept of compound grade, the transmitter can be pointed upgrade at predetermined angle between the two grades with a resultant grade which is greater than either, set into the laser transmitter. By doing this, we essentially tip the plane of the light in one direction to match the primary grade and then again in another direction at a right angle to the first, to match the secondary grade. The work area below is dual. This area has been surveyed for primary and secondary grade.

Primary grade = fall/distance \( \times 100\% = \frac{0.80}{800} \times 100\% = 0.1\% \)

Secondary grade = fall/distance \( \times 100\% = \frac{0.63}{1250} \times 100\% = 0.05\% \)

Use of the trigonometric calculator, the answer is the same, no matter what method is used.

Compound grade = 0.112%, Angle to turn transmitter from primary grade = 26 degrees

Fig 2. Pantilt view of two swiveled axis (A) with its control unit (B) and Pantilt internal view (C)

Fig 3. Laser equipment arrangement in surveying
Basic construction techniques, determining the height of instrument (HI). The height of instrument is the elevation of laser beam. The HI is determined by adding the grade rod reading to a benchmark elevation. Set up and level the laser described (Fig. 3).

1. Attach the receiver to a grade rod and turn on the receiver.
2. Place the grade rod on a job-site benchmark (BM) or known elevation.
3. Slide the receiver up/down the grade rod until the LCD shown an on-grade reading.
4. Add the grade-rod reading to the benchmark to determine the height of instrument.
   Example: Benchmark elevation = 30.55 m (100.23 ft)
   On-grade rod reading = 1.32 m (4.34 ft)
   Height of instruction = 31.87 m (104.57 ft)
5. Use this HI as a reference for all other elevation

3 Field test

The Execution of field test has been conducted through a stepwise process. The instrument assembly is shown in fig. 6, composed of a tripod the Pantilt and all over them is laser transmitter. The establishing horizontal level and compound slope in laser, conducted by this erected device through a special procedure.

3.1 Zero plane or horizontal plane

The laser detector will be placed in front of the transmitter which is sited on a stationary trailer in a distance of, say, 50 meters. The detector should be attached to the grade-rod. The rod will be moved up and down till the detector detects the height of the beam and sends the green signal. Then the transmitter will be rotated mechanically by the Pantilt for 180°. For the laser plane to be leveled it is necessary that the height of the transmitter be equal in both steps. If this does not happen by using the adjustment screw located under the transmitter the plane can be adjusted.

3.2 Single laser plane slopes

If, for example, a 2% slope is required, the rod should be placed in 100 meters distance and the laser plane should be established horizontally as in 1. Then by the vertical axis of Pantilt the laser plane inclined till the laser plane is in 2 meters difference in height with the former state.
For any slope and any rod distance this inclination can be conducted and with a simple calculation the slope converted to slope percent as a common unit in surveying.

3.3 Dual laser plane

The schematic for compound generation of laser plane is created by the horizontal axis of Pantilt as it has been shown in fig 6. The rotation of transmitter was done through horizontal Pantilt axis. The calculation of angle of rotation for compound slope by combination of x and y slope is formerly noted. After execution of some primarily tests, the statistical performance test was programmed. A measuring system requirement, as a rule, mostly interrelated to its accuracy, repeatability and resolutions factors that were considered through that experiment.

![Diagram of Dual Laser Plane](image)

Fig 6. Obtaining the compound angle (dual slope) laser plane from single slope grading

Pantilt horizontal axis which is applied for tilting the transmitter and subsequently establishing the sloped laser plane. We decided to its performance evaluation by measuring the least possible change of its rotating angle for each pulse induced to its driver motor. The rotating angle of axis transfer to transmitter and effected the laser plane which detected by the sensitive unit on laser receiver. The average of the deviation in height of laser plane due to one pulse or the least change in slope is listed in table 1. The test undertake repeatedly 10 times for positive sloping and 10 times for negative sloping the tables 1.

### Table 1. Data from evaluation test for precision of Pantilt horizontal axis for single sloping of laser plane

<table>
<thead>
<tr>
<th>Repetition</th>
<th>Deviation of laser beam height, negative slope</th>
<th>Deviation of laser beam height, positive slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>6</td>
<td>51</td>
<td>49</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>8</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>11</td>
<td>51</td>
<td>49</td>
</tr>
<tr>
<td>sum</td>
<td>506</td>
<td>495</td>
</tr>
</tbody>
</table>

Pantilt horizontal precision evaluation conducted similar to formerly test in 10 replication for clockwise direction and 10 times for counterclockwise. This series of test is conducted by adjusting the Pantilt so that a laser plane with a sloped with respect to horizon is created. In each test an electric pulse is induced on the driver motor of vertical axis for least possible angle change. The laser plane slop changes due to the effect of this incremental change in transmitter rotation by Pantilt. The final series of test was related to the ability of designed system for generating of zero slope or horizontal laser plane. This series of test conducted in two set, which each set include 10 replication, for producing the laser plane. The
adjusting method and the gathering data is formerly describe in fig 4.

4 Result

Evaluating experiments’ output data of the designed system for the laser plane needed in agricultural and civil operations have been gathered in data table 2. Then, to analyze them, diagrams of function/parameter have been sketched from these tables.

Table 2. List of experiments, their goals and results quantitatively

<table>
<thead>
<tr>
<th>Test</th>
<th>Component name</th>
<th>Direction</th>
<th>Test purpose</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pantilt inclination(horizontal) axis for sloping laser plane</td>
<td>Positive slope</td>
<td>Precision</td>
<td>0.05 m/20 m 0.14 degree</td>
</tr>
<tr>
<td>2</td>
<td>Negative slope</td>
<td>Precision</td>
<td>0.05 m/20 m 0.14 degree</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pantilt rotation(vertical)axis for compound(dual)sloping</td>
<td>Clockwise rotation</td>
<td>Resolution</td>
<td>0.71 degree</td>
</tr>
<tr>
<td>4</td>
<td>Counter clockwise rotation</td>
<td>Resolution</td>
<td>0.71 degree</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Horizontal leveling</td>
<td>X-axis</td>
<td>Accuracy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y-axis</td>
<td>Accuracy</td>
<td></td>
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</tr>
</tbody>
</table>

To clarify the precision of these experiments, some quantities of the results will be described in detail. The value of 0.05m/20m in the table 2 means that for each time the sloping axis button with Pantilt device is pushed, the produced height difference is 0.05m in a distance of 20m from the laser transmitter. The value 0.14° in is the least change in angle for each time the button is pushed. The 0.14° angle is calculated as the reverse of the tangent of 0.05m height in 20m distance. The value0.71° shows the precision of Pantilt for orbiting the laser plane. This laser plane must orbit to obtain the needed dual angle or complex angle for earth moving process. The diagram of minimum slope change of laser plane for each pushing of the sloping button with Pantilt device for several repetitions is shown in app. Fig 8. The diagram of minimum slope change of laser plane by vertical axis of Pantilt is shown in app. Fig 9. In a series of experiments, consisting of total 20 times repetition on the developed system, the transmitter and its laser plane have been adjusted on a zero angle according to 3.1 section. The precision of the system in ability to generate a horizontally or zero slope laser plane are shown in app. Fig 10.

5 Conclusion

Regarding the results it could be said that the proposed mechanical-electrical method combining with a bubble leveler can be a good replacement of the conventional automatic sloping method. Although the precision of this method is lower than automatic one, its price is 1/5 of the automatic method. The system produced by European companies is about 5000 $, yet this one using Pantilt and a simple orbiting laser device costs only 1000 $. The possibility of expanding the market of civil and agricultural laser devices increases with this system due to its low price. This technology has produced an effective empirical method for precision evaluation comparing other complex calculating methods.

6 Reference


7 Appendix

Fig 7. Application of laser technology in land leveling and construction activity. 1. Transmitter: Produce a reference laser-plane. 2. The precision of the system in ability to generate a horizontally or zero slope laser plane receiver: Sensed the laser beam and measure relative height. 3. Laser control box: Signaling and control panel. 4. Hydraulic: Adjust blade elevation by command signal.
Fig 8. Minimum slope change of laser plane by horizontal axis of Pantilt for each pushing of the sloping button

Fig 9. Minimum slope change of laser plane by vertical axis of Pantilt for each pushing of the sloping button

Fig 10. The precision of the system in ability to generate a horizontally or zero slope laser plane