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Applications of Laser in Agriculture – A critical review

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ABSTRACT

Applications of laser are becoming very important topic in the current research. A large number of applications are already done for the use of laser technology in agriculture. This technology has already proven to be a user-friendly as per the need of the situations. This technology is becoming a well known and acceptable technique to the farmers. Now it has also proven that this technology is no longer as costly and within the reach of a farmer for his specific requirements. Real-time control is becoming an integral part of modern machine systems for high-quality agricultural production. Maintaining consistently high-quality agricultural production, while keeping up with growing labor shortages is a challenge. Labor shortages and environmental constraints coupled with the reality of spatial variability of chemical and physical properties among and within agricultural production areas readily explain the migration toward real-time control of agricultural equipment. The paper aims to describe the major field of applications of laser technology in agriculture in the past time. This paper also presents a review of the most recent advances in the development of sensors and controllers for agricultural applications.

Introduction

Agriculture has evolved along with technology. Most people know about genetically modified seeds, but they don't realize how far the technology that goes into the propagation of food has come. Many technologies have made drastic improvements to how our food is grown, but some have only just started to be explored. Lasers, for instance, have the potential to change the way that farming is done today from the equipment used on the fields to the way that livestock is handled. In other way, several generations ago farmers relied on tools such as almanacs and the phases of the moon to estimate when to begin planting. Today these tools are supplemented with space age technologies that allow the farmer to raise their crop in more precise and efficient ways. Some of these technologies include global positioning systems (GPS), geographic information systems (GIS), yield mapping, variable-rate technology, controllers, laser and remote sensors (http://www.ptroptics.com/lasers-in-agriculture/). Precision farming (the art of using these technologies to increase yields and profits while protecting the environment) is becoming more prevalent in farming operations. There is a need in the farming community for tools that provide the farmer easy access to these technologies while avoiding cumbersome data gathering systems, information overload, or burdensome application equipment.

The results achieved in the application of laser irradiation of plant organisms still continue to attract the scientific interest – in the past realized by He-Ne lasers, and nowadays – by semiconductor lasers. The effect of the spectral influence of the laser radiation, according to Inyushin et al. (1981) in the near past, and nowadays by Inada (1975), Burges (1999), Mori and Takatsuji (1998), Tazawa (1999) and others, provokes a change in the plants functions, activates the faster cell-division, and that results in faster initial rate of growth and development, better resistance to unsuitable conditions and increase of the productivity and the quality of the production. In the year 2005, food crisis arises due to floods and negligence in agriculture. This situation was well managed by implementing new technologies, i.e. laser in increasing the production of bread grain and maize per unit of area. Some types of lasers can be useful both in and out of the fields. Laser marking machines can be used in labs to help seeds develop mutations that can be useful in their lifecycle. Once in the field, the machine can enhance the disease resistance of the crops and shorten the times it takes the crops to reach maturity. It can do all this by ensuring that the plants have the appropriate intake of photon cells and increase the efficiency of photosynthesis. Thus it has been found that laser is an appropriate technology for agriculture purpose so that maximum yield can be achieved. This paper reviewed the application of laser technology in different ways and developments achieved.

Farm Navigation Systems

On-Farm or In-Field Location

Palmer and Matheson (1988) studied the cost and benefits associated with farm navigation systems. They concluded that precise navigation technologies would increase profitability. Environmental concerns were expected to mandate improved chemical application and precise navigation systems were felt to be essential to accomplish this end. The use of the Navstar Global Positioning System for precise implement positioning information was proposed (Larsen et al., 1988). Searcy et al. (1990) evaluated a microwave-frequency triangulation scheme for measuring agricultural field locations. Their system was found to be successful for documenting the path traversed by a combine. A laser scanning method for field machinery guidance was proposed (Shmulevich et al., 1989). Position accuracies to within 150 mm were recorded for a 400 m 400 m field.

Surface Topography

Soil profile and bed topography have been the subject of several measurement and control efforts. Harral and Cove

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(Harral & Cove, 1982) presented an optical displacement transducer for the measurement of soil surface profiles. The device collected light from an illuminated spot on a target surface and focused this onto a position sensing photo diode giving an output related to the position of the target. The signal conditioning circuitry discriminated against the effect of ambient light. Adem and Tisdall (1986) reported a laser control bed hillers. Romkens et al. (1988) described a laser-based meter useful for defining surface roughness at a precision of less than one millimeter in vertical and horizontal directions. Huang and Bradford (1990) described a laser scanner for measuring soil surface roughness which was reported to measure to 0.1–0.3-mm precision.

Rice cultivation & levelling system

Rice cultivation is one of the most water-demanding types of cultivation since, in most cases, the fields are permanently flooded while the rice is growing. A reduction in water wastage can be obtained by reducing the water depth while warranting that no part of the field remain un-flooded. This can be obtained by preparing the fields so that they are leveled to within a few millimeters. Specific agricultural tools have been designed to help farmers in this preparation. Most solutions employ a rotating laser to materialize a horizontal plane to be used as the reference in field preparation. A specially designed add-on with a laser receiver, which is mounted on the tractor, reads the laser plane height and drives a blade that is used to move the soil from above-level sites to under-level sites.

Altimetric Field Mapping

If the farmer is planning to level the field and therefore employs the solution described in the previous section, the altimetric value in terms of distance of the ground from the laser plane is already available so that the map could be easily obtained if it was possible to continuously know that the tractor is at a horizontal position in the field. The problem therefore becomes how to determine the tractor position with a cheap and robust solution. Several approaches can be employed to obtain the tractor position; first, the use of global positioning systems (GPSs). Such systems are commercially produced by several companies in the agricultural field and take advantage either of the free wide-area augmentation system (WAAS) technology or of proprietary correction networks to improve localization accuracy. The expected accuracy of these devices is about 3 m (at a confidence level of 1σ; 8 m maximum) for the free WAAS and 1 m (at a confidence of 1σ; 2 m maximum) for the proprietary network. Even though basic GPS receivers have a very low cost, models designed for agricultural applications can be much more expensive, and the subscription to the proprietary correction network, which would be required to reach an acceptable accuracy, can be even more costly [14].

Similar results can be obtained by employing the positioning service provided by the global system for mobile communications (GSM) framework with the additional problem that GSM service is not available everywhere. For these reasons, a different approach, which avoids both using the GPS and the GSM, would be preferable. Among the different approaches, solutions based on laser beams could be favorably considered since they have several advantages like substantial immunity with respect to electromagnetic interferences and potentially reduced cost. The tractor position with respect to a reference point, which is usually located on the field edge, can be conveniently obtained if the tractor distance is measured along with the angle with respect to a reference line, as depicted in Fig. 1 (Corbellini et al., 2006).

The tractor position is therefore easily obtained as follows:

$$X = D.\cos\theta \qquad (1)$$

$$Y = D.\sin\theta$$

The tractor position can be expressed with respect to the field reference system as

$$r = D.(\cos(\theta).i + \sin(\theta).j) \qquad (2)$$

Where i and j are the unit vectors identifying the reference system. In Fig. 2, (Corbellini et al., 2006) D and θ represent the coordinates of the tractor that has to be localized, α represents the tractor heading angle, and θ represents the angle under which the laser receivers are seen from laser head location.

If r is obtained by independent measurements of D and θ, its uncertainty, which is expressed as distance, can be written as

$$u_r = \sqrt{u_D^2 + D^2.u_\theta} \qquad (3)$$

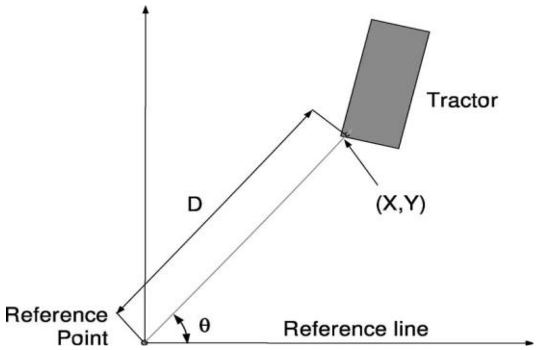

Fig. 1 Polar measurement to obtain the tractor position with respect to a predefined reference point

Classical distance measurements by laser are obtained by means of three basic approaches, namely 1) time of flight (Simone et al., 2006; Palojoarvi et al., 1997); 2) triangulation (Pierce cet al., 1992) and 3) frequency modulation continuous wave (FMCW) (Journet & Bazin, 2000).

The first approach is based on the measurement of the required time for a laser beam to reach the object, whose distance has to be measured, and travelling back to the source. A system that implements such a method typically consists of a pulsed laser transmitter, the necessary optics, a receiver channel, and a time-measuring system, which is employed to measure the time between the start and the stop signals generated by the transmitter and the receiver circuitry, respectively. The time of flight has to be measured with high accuracy, and this requires both a narrow optical pulse and a high-resolution time measuring system. Moreover, to allow the receiver to correctly detect the reflected signal, the transmitted optical peak power could be rather high.

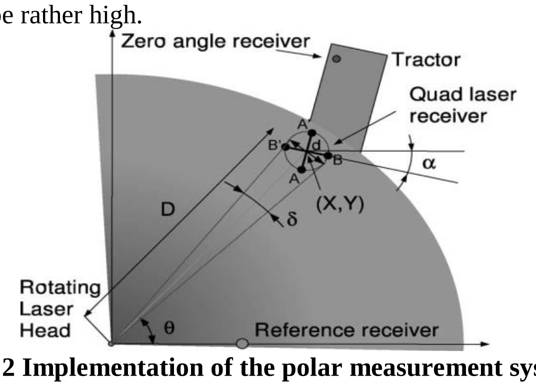

Fig. 2 Implementation of the polar measurement system

The main advantages of this technique are the ability to obtain results with accuracy on the order of centimetres, or even millimetres, in the range of a few meters to several tens of meters. The triangulation method is conceptually similar to the vision system that humans use to perceive object distance and works by observing an object from two spatially separated points of view; the laser beam is projected from the source and reflected from the target object toward collection lenses. The lenses, which are typically located adjacent to the laser emitter, focus the spot images on two camera charge-coupled devices (CCDs). The spot positions are then processed to determine the target distance. This technique is employed for measuring distances in the range of a few centimetres to some meters with high accuracy, but it no longer becomes ideal for more distant objects since the accuracy decreases as the angle under which the target is seen by the system gets smaller. The FMCW approach and its variations are based on the frequency modulation of a laser beam. By means of this technique, the object distance is obtained from phase measurements of both the emitted and the reflected beams. Low-cost systems can be obtained by employing the optical power modulation rather than the classical optical carrier modulation. Such a method is typically capable of dealing with distances of tens of meters and with an uncertainty of a few centimetres. Unfortunately, all the described techniques, although effective in measuring the distance, would require a tracking system to keep the laser beam pointed to the moving tractor, thus increasing the overall cost. For this reason, the authors have decided to explore a different solution that does not require tracking hardware. The proposed solution takes advantage of the already-present rotating beam and does not require any interventions on the laser head so that it can be employed with almost any commercial head. It employs the scheme shown in Fig. 2 and is composed of the following receivers:

1) Four laser receivers, which are fixed at the end of a cross shaped support. This support is mounted on the tractor and is moved by employing the already-present actuator system used for blade movement so that the receivers are kept illuminated by the laser beam;

2) A reference laser receiver, which is fixed to the ground and capable of transmitting a radio signal that is received by a receiver on the tractor (Corbellini et al., 2006).

Laser Controlled Land Leveling System

Laser controlled land leveling system is used in highway, railway, air port, mine, tunnel, bridge, building, water conservancy, agriculture, stock raising and so on. This advanced technology in Agriculture is generally useful for laser controlled land leveling System, farmland spaceflight photo management, remote sensing measure and data analysis, agriculture and stock raising management.Fig3 shows a schematic laser controlled land leveling system while Fig.4 depicts the operating of a similar system in actual field condition.

Fig.3 Schematic view of Laser controlled land leveling system

Fig.4 Laser controlled land leveling system in actual field

The application and development of laser controlled land leveling System in Agriculture

China has 9 hundred million irrigated area, above 95% use surface irrigation. Most of area farmland land leveling is disqualification, bring about much waste and asymmetry of water, restrict the developing of agriculture. With the developing of economy and level increasing of agriculture, laser controlled land leveling System had applied in agriculture. Recent years, Agriculture department set up a high target which establishes a high standard and efficiency agriculture, laser controlled land leveling technology as a important subject has set up by Agriculture department.

Work theory of laser controlled land leveling System

The system of laser controlled land leveling consist of laser emitter, laser receiver, electro motion extension arm (Hand extension arm), controller, electric appliance hydraulic pressure discreteness and drag bucket. Laser emitter eradiate laser beam which could rotate 360°, forming a datum plane, the laser receiver which install in the grader scraper send the signal to controller uninterrupted, after modifying by controller and send the signal to hydraulic control valve. Hydraulic control system control oil cylinder and adjust the drag bucket spade to make land leveling.

The benefit of laser controlled land leveling system

Major benefits are includes a) Save water-Laser controlled land leveling technology could make the flatness arrive 2cm error, normally could save water 30%, b) Save land-Through laser controlled land leveling technology to control the ridge of field, it could save 3%-5%, c) Save fertilizer-Because of increasing the flatness, it decreases the loose of fertilizer and makes it level off degree which increases the rate of utilization of fertilizer to 20%, insuring the seedling emergence efficiency, d) Increase production-every unit of area increase the production 20%-30% and e) Decrease cost-Using this kind of technology, it could decrease the cost 6.3%-15.4% of production of rice, wheat, soybean, cotton and corn.

Measuring crop biomass density by laser triangulation

Information about site-specific crop parameters such as plant height, coverage, and biomass density is important for optimizing crop management and harvesting processes. Sensors for measuring crop parameters with an acceptable accuracy and high reliability at a reasonable price are essential prerequisite to obtain this information. In agricultural engineering the potential of laser rangefinders for measuring crop parameters is nearby unexploited. Detlef Ehlert et al. (2008) reports the design and the performance of a triangulation laser based system for measuring crop biomass density under field conditions in the vegetation period in 2005. Taking into account that large crop stand areas can be sensed by a laser rangefinder in a short time, a high potential for site specific crop management can be concluded.

The United States Department of Agriculture is already employing lasers for this purpose and others. They call the system they use LiDAR. It shoots a beam of light into the sky and when it hits the receiver it provides all kinds of useful information about livestock operations. It can tell the operators how much moisture is in the air, just like in the irrigation applications. LiDAR is so accurate that it can determine what type of dust particles are in the air and how much air pollution a farm produces. During harvest, new laser technologies are coming into play. The new imaging lasers are being used to measure things like the amount of bruising on fruits and vegetables. This is known to happen during harvesting. More importantly, it can scan for bacterial contamination. The United States has had several cases of bacterial contamination over the last few years. E. coli is generally the guilty bacteria, but it's advantageous for food inspectors to be able to pick up any bacterial contamination.

In a study Lumme et al. (2008) found that, terrestrial laser scanning is a useful tool for growth height and grain yield estimation. Growth height of cereal plants was easy to estimate using laser scanner data and estimated results correlates with tape measures. Besides, ears of wheat were automatically recognized and their size was estimated using laser scanner data. Thus, this study shows that laser scanner could be used as precision farming tool in agriculture. Fig.5 shows the imaged of 3D point cloud data achieved in the study.

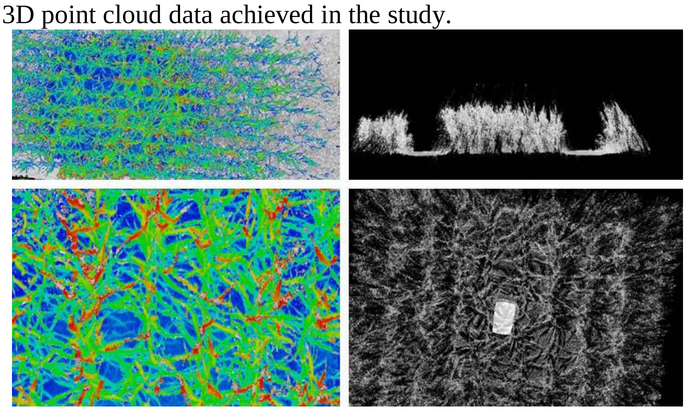

Fig.5 Images of 3D point cloud data (Lumme et al., 2008)

Application in fertilizer & herbicide use

Farmers frequently fertilize their crops. Lasers can now scan the density of the soil. The idea is that less dense soil is probably more fertile because it is packed with organic matter. This can help a farmer determine what they need to do to prepare the soil for new crops before they ever plant or how much fertilizer he needs to apply once they are already growing. Much like the use of lasers with herbicides, this technology could reduce the amount of chemicals that go onto plants and possibly make the food supply safer. This technology could be especially useful in countries where some herbicides and fertilizer chemicals are not allowed on plants in the food supply. Lasers could very well provide a more effective solution than the farmers currently have.

Herbicides may soon be a thing of the past, but at the moment large-scale agriculture is just now introducing them into their war against weeds. The same leveling lasers used in regulating irrigation are starting to be used in the application of herbicides. These lasers are ensuring that plants in the food chain aren't receiving more chemicals than they absolutely need and they're saving farmer's money. There are studies that prove that lasers can be used to kill weeds without hurting the surrounding plants. Laser technology is currently very expensive, but it can save large farms money in the long run. It can cut back on the amount chemicals used on crops and make cows live more peaceful lives. It can also be used to save the lives of pest animals that would have previously been killed for the preservation of the crop. As with all new technologies, science is constantly finding new ways to use it and better ways to make. One day laser technology will like be used in all farms, large and small, worldwide (LASER-2013).

Model Farming

Pakistan is considered to be the pioneer in South Asia for promoting use of Laser technology in irrigated agriculture. First Laser leveling equipment was tested by OFWM Punjab in 1985. Before devolution, there were 140 Laser land leveling units available with District Governments which have been procured through donor assisted projects, respectively. One hundred units were equipped with tractors whereas 40 units were without tractors. These machines have precisely leveled about 125,000 acres of land. The yearly potential of available Laser equipment was about 25,000 acres/year.

Laser technology and irrigation efficiency

Considerable quantity of water is lost during irrigation due to uneven fields and poor farm designing owing to unleveled fields. It is estimated that about 20-25 per cent water is lost during field application in the form of evaporation and leaching thus affecting the irrigation efficiency. There are numerous factors of depletion of soil fertility and productivity. Among others, unleveled fields cause significant loss of fertilizer nutrients in the process of leaching. Irrigation water and rainwater flows toward low lying areas along with nutrients and subsequently moves downward. Resultantly, fertilizer use efficiency is considerably lower in the cultivated fields. Irrigation water that is crucial input for raising crops is wasted contributing to poor irrigation efficiency as well. Uneven field become less productive compared to leveled fields. Unleveled fields also give rise to salinity and water-logging problems. In this context, leveling of fields is essential to maintain soil fertility and productivity and to save irrigation water. It is an important step towards conservation of water and land resources essential for sustainable agriculture and food security. Leveled fields ensure uniform germination of seed. Cultural practices like hoeing, weeding, spraying and harvesting become easier when crop plants are of equal heights. Pre and post harvest losses are also minimized if crop matures uniformly. Judicious use of inputs viz. fertilizers, irrigation, seed, pesticides etc. is essential to bring down cost of production. And leveling of fields would help optimize use of these inputs and thus would contribute to lowering of cost of production. By leveling of fields, crop harvest could easily be enhanced that is much lesser presently owing to a number of constraints, mainly shortage of irrigation water. It is because unleveled fields causing wastage of land and irrigation water could be efficiently utilized. Increased farm produce would help to alleviate rural poverty that is endemic. Moreover, land leveling would help in minimizing the cost of operation, ensures better degree of precision in much lesser time and save irrigation water.Fig.6 shows laser application in irrigation.

Automatic sprinkler

Automatic sprinklers have enabled farmers to decide when they irrigate their crops and how much water goes onto those plants, but there has not been a good way for farmers to know exactly how long those sprinklers should run each day. This flaw has led to plants getting too much or too little water through the extreme seasons that have become the new normal in the United States. The more moisture there is in the air the more the laser will twinkle when it reaches the receiving end of the device on the other end of the field. This moisture level will then determine how much water should go on to the field.

Fig.6 Laser application in irrigation

PDPA Laser-Based Characterisation of Agricultural Spray Nozzles

The spray quality generated by agricultural nozzles is important considering the efficiency of the pesticide application process because it affects spray deposits and drift-ability (Taylor et al., 2004). Further, spray quality influences biological efficacy of the applied pesticide as well as environmental hazard (Permin et al., 1992; Klein et al., 2002; Wolf, 2002). The ideal nozzle-pressure combination should maximize spray efficiency by increasing deposition and transfer of a lethal dose to the target, while minimizing off-target losses such as spray drift and user exposure. The spray characteristics that will influence the efficiency of the pesticide application process are the droplet size and velocity distribution, the volume distribution pattern, the entrained air characteristics and the spray sheet structure (Miller and Ellis, 2000; Pochi and Vannucci, 2002). Over recent years, several techniques using laser instrumentation have been developed to determine droplet characteristics. For example laser diffraction, (e.g. Malvern laser) (Barnett et al., 1992; Butler et al., 2002) the optical area probe technique, (e.g. Particle Measuring System) (Combellack et al., 2002) and the Phase Doppler Particle Analyzer (e.g. Aerometrics) (Farooq et al., 2001). Each instrument type has different measuring characteristics. The Malvern uses a spatial measuring technique, is not capable of measuring velocities and determines a spatially averaged size distribution. The Phase Doppler Particle Analyzer (PDPA) relies like the optical area probe technique on single droplet measurement. As for the PDPA, a droplet passes through a small sampling volume, scattering light by refraction. The frequency of this light being proportional to droplet velocity and the spatial frequency of the same light inversely proportional to the droplet diameter (Bachalo and Houser, 1984). Arnold (1987) showed that droplet velocity influenced droplet measurement due to the resident time of in-flight droplets in the laser measuring volume.

The optical area probe technique allows size and velocity to be determined of individual droplets passing through a small measuring volume. Generally, the Particle Measuring System instrument measured a significantly greater volume median diameter compared to the Malvern, except for very low flow rates (Arnold, 1987). The PDPA gave consistently lower values for the volume median diameter and lower percentages of spray volume in droplets less than 100 μm in diameter than the PMS (Tuck et al., 1997). Besides different measuring techniques, there are important differences between different researches in measuring set-up and protocol (e.g. nozzle height, scan pattern, sampling strategy, data processing, etc.) which have an effect on the measuring results (Chapple and Hall, 1993; Bulter et al., 1997). Because of differences in measuring technique, set-up and protocol, different researches have shown a wide variation in mean droplet sizes for the same nozzle specifications (Western et al., 1989; Miller et al., 1995; Hewitt et al., 1998; Porskamp et al., 1999; Womac et al., 1999; Nilars et al., 2002). Young and Bachalo (1987) investigated differences in measurements of droplet size between all three laser techniques and found that comparative data can be obtained when measuring reference sprays.

Conclusions

From the above discussions and findings it has been observed that, laser is playing an important role the field of control of agriculture. It has been successfully tested in the control of agricultural vehicle like autonomous tractor, in the field if measuring crop biomass density. Laser is being used in the land leveling system for the agricultural fields. Over recent years, several techniques using laser instrumentation have been developed to determine droplet characteristics like a PADA laser. In the case of rice cultivation, the fields are permanently flooded during rice growing. A reduction in water wastage can be obtained by reducing the water depth while warranting that no part of the field remain un-flooded. This can be obtained by preparing the fields so that they are leveled to within a few millimeters by laser based specific agricultural tools. Judicious use of inputs viz. fertilizers, irrigation, seed, pesticides etc. is essential to bring down cost of production. And leveling of fields would help optimize use of these inputs and thus would contribute to lowering of cost of production.

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