DEVELOPMENT OF ONLINE SOIL PROFILE SENSOR FOR VARIABLE DEPTH TILLAGE

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ABSTRACT

Compaction is great concern to farmers and soil scientist since it limits crop growth and yield. There are two types of soil compaction; natural one and the one that is the result of management practice in agricultural production. Sub soiling is a way of minimizing negative effects caused by compaction. Conventional management practice is to use chisel at a certain depth. Field traffic and variation of soil properties through field brings about variation on soil compaction degree and depth. Instead of taking variation into account, sub soiling at a certain depth can cause excessive energy consumption. For sustainable agricultural production, therefore depth variation of chisel is required.

For determination of compaction, soil strength is one of the main indicators which depend on several soil physical and biological properties such as dry bulk density, organic matter content. The objective of this study was to develop an online sensor based on measuring soil strength at multiple depths in order to interpret the depth of compacted soil layer so that the working depth could be adjusted on the go. Mechanical part of the sensor was developed using 3D CAD Design Software Solidworks. Manufacturing and assembling process followed design works. Data acquisition and control system were based on PLC. The acquisition script was developed in Phoenix Contact PC WORX software so that it records the data flowing from load cells and alters the depth of chisel. Laboratory tests were conducted in order to calibrate the load cell and compensate the measurement variation among load cells by modifying script. After all, on the go sensor was developed. Future tests were planned for the assessment of practical usage in situ.

Keywords: Soil compaction, sensor, precision agriculture, penetrometer

INTRODUCTION

Since early 1990s, precision agriculture and its technologies have been considered being the most significant development in agriculture domain aiming management of heterogeneity in agriculture to improve farm profitability, to decrease negative load on environment and to comply agronomic requirements.

Precision agriculture brings on detailed records of whole farm operations. It requires information and communication technologies in order to record automatically generated data. Beside optimization of agricultural production in terms of reducing inputs and increasing profit, this gives farmers the advantage for certification of whole production process to assure costumer requirements without gaps and duplication. The improvement of heterogeneity management of agricultural resources is a primary goal of precision agriculture. Precision agriculture is an approach of “applying the right thing, at the right time, on the right location, with the unfavorable load on the environment”.

The initial studies focused on fertility, and were trying to quantify and understand the variability that reported from previous researches dealing with soil sampling. However, this operation is still conducted by collecting soil samples then required manual analyses in laboratory resulting in decrease in profit of farmer. At a later, this systematic approach has been widened to other agricultural activities such as irrigation, spraying and etc. The concept was map based application, and then it was extended to sensor based application due to recent development on sensor technology domain. Therefore, nowadays, the focus in precision agriculture has been on the go sensing of soil structure.

Soil Compaction

Compaction, a soil physical problem, is one of the great concerns in crop production and environmental pollution. Soil compaction often restricts root development and growth due to increased bulk density and/or strength of the soil, reduces the biological activity of plant roots and organisms in the soil due to reduced aeration, and limits water infiltration.

Conventional soil compaction management method is based on the use of annual/biennial deep tillage; usually at a uniform depth of 20 to 40 cm that require excessive fuel consumption and time consuming. Deep tillage leads to an expensive operation and also deteriorates soil structure over years. There are several handicaps in this operation to eliminate soil compaction. The question is that producers do not generally know; if annual deterioration of soil compaction is needed, required locations in a field and required depth of sub soiling. Moreover, depth and thickness of hardpan layers vary through field. Studies have shown that the depth of compacted layer varies greatly from parcel to parcel and also within the parcel. Uniform depth sub soiling operation may be too shallow or too deep and can be costly (Khalian et all, 2002).

High-fuel consumption is required in conventional methods to shatter the layer to assist root development. To avoid the drawbacks indicated above, an optimized solution can be variable depth sub soiling. Variable depth operation, which improve the physical properties of soil by varying the tillage depth where and what depth is required for optimal plant growth, could result in considerable energy, fuel consumption savings in sub soiling , and reduce emission caused by tractors. Raper, (1999) reported that the fuel cost of hardpan elimination could be reduced by as much as 34% with variable depth sub soiling as compared to the uniform-depth. Fulton et al., (1996) evaluated that fuel consumption could be reduced to 50% by variable depth tillage compared to fixed depth tillage over the entire field. Variable depth tillage can be implemented either using map or a real-time sensor based technology. Map based variable depth sub soiling approach require two step operation; first one is for mapping the depth following is for deterioration.

However, sensor based sub soiling is single step operation that result in less traffic, fuel consumption, and save time. Moreover, the real-time sensor would provide a unique assembled system for variable depth tillage. The goal of the study was to develop a sensing part of assembled unique system for deterioration of compacted layer that could limit the plant growth. The concept of the assembled system is based on the determination of the depth of compacted layer and alters the chisel operation depth on the go.

Material and Method

The advantage of the sensor design concept is to make the on the go measurement of soil strength at various depths possible. Force-sensing tips mounted in front of the narrow soil-cutting blade side, interfaced with a load cells were located inside the blade. The blade was mounted to frame that specially designed for holding it and the frame was attached to the front of tractor (fig 1). Frame is stabilized on four wheels. The linkage between tractor and sensing blade is a parallelogram mechanism which allows matching soil surface roughness. The issues such as load cell selection, data acquisition system and calibration were considered at designing process.

Fig 1- The sensor with tractor attachment system

Main Blade and Sensing Tips

The figure (2) shows the assembled structure of the soil strength sensing blade as viewed: the frame comprising the blade, the load cells and prismatic tips to sensing of soil strength. Maximum sensing depth and expected maximum soil strength was selected as 50 cm and 10 MPa, respectively, as reported in previous studies (Chung and Sudduth, 2004). Materials and dimensions were selected based on these data. The blade and prismatic tips (fig 3) was made from: stainless steel (AISI No. 17-4PH).

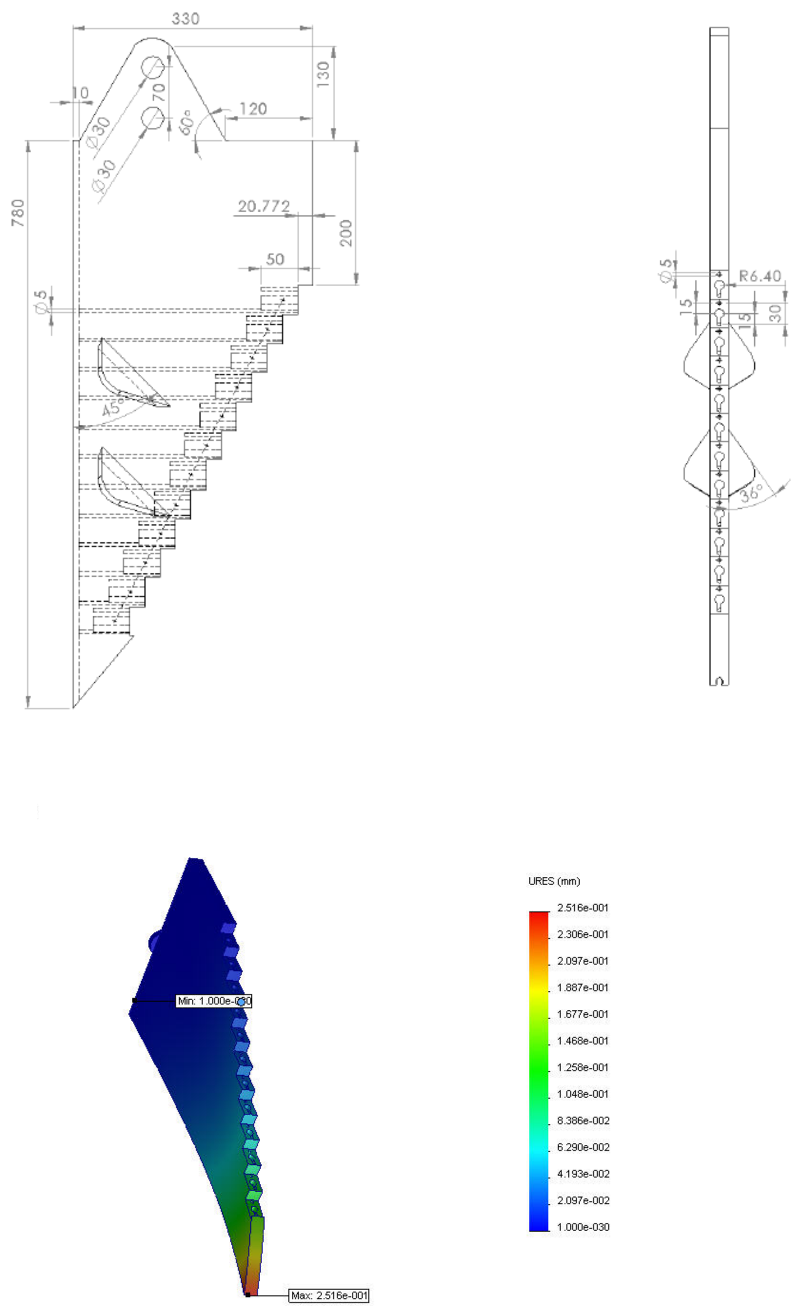

Fig 2- The blade of soil strength sensor

- High data acquisition frequency is required to gather the variability in soil resistance; considering 2 m.s^{-1} operating speed into account, 4 Hz sampling frequency was selected (Chung and Sudduth, 2004)
- A prismatic tip with a 60° cutting or apex angle was selected as the sensing tool (fig 3). Lower edge of the tip has another design parameter in order to eliminate the side effects of soil disturbance creating by lower part of the each tip, which affects force sensing.

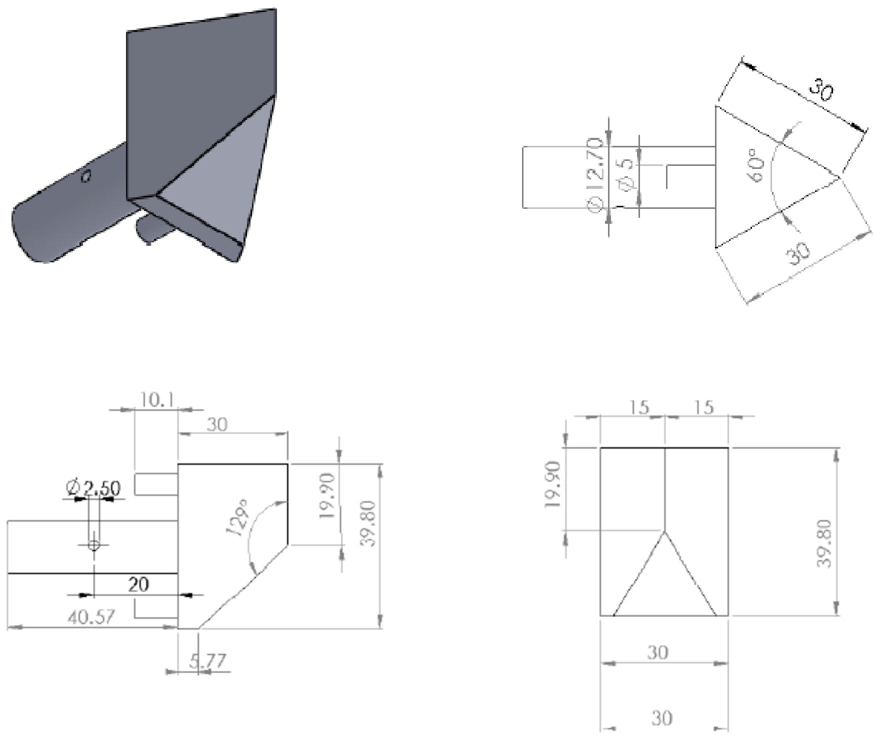

Fig 3- A prismatic tip as the sensing tool

Load Cell Selection

Load cell selection was based on the size and design of the sensing tip and the expected maximum values of soil resistance (fig 4). Prismatic sensing tip has two edges with different shape. While one edge of the tip at prismatic shape, other edge, at circular shape, which interfaces with load cell was selected for prototyping. After a survey of available commercial products, a miniaturized circular load cell with a diameter of 12.7 mm (model LCM307-10KN, Omega. US) were selected.

Fig 4- Load cell for force measurement

Tractor attachment

In order to mount the sensing blade to an agricultural tractor, an attachment system was designed as depicted in the figure (1). The main frame of the soil profile sensor holds the sensing blade. It is attached to the tractor by parallelogram mechanism.

A hydraulic cylinder system is designed to set maximum operating depth. By applying this mechanism in heavy residue or soft soil conditions, continuous measurement of sensing depth can be kept constant.

A shear bolt mechanism is designed to protect the load cells and blade (or main frame) from excessive loads. To design this mechanism, a stress, linearly increasing with soil depth from 0 MPa at the ground surface to 10 MPa at the lower end of the blade, was assumed to force on the blade. These loadings were chosen because 10 MPa was the expected maximum soil strength and 0 MPa was a reasonable boundary condition at the ground surface.

PLC and Control Unit Elements:

In order to automate the mechanical system, electronic components and software were received from Phoenix Contact. Beside some basic elements of automation, the device and tools use in the project are listed below;

- TP 3070T Touch panel with 17.78 cm (7.0") graphics-capable TFT display, 65,535 colors, 800 x 480 pixels,1x Ethernet, 2x USB and integrated runtime of the Visu+ visualization software.
- ILC 130 ETH Inline Controller with Ethernet interface for coupling to other controllers and systems, with programming options according to IEC 61131-3, complete with connector and labeling field.
- IB IL SGI 2/F-PAC Inline analog strain gauge input terminal, complete with accessories (connector and labeling field), 2 fast inputs, 4, 6-conductor connection method.
- EC-E 1A DC24V Electronic circuit breaker, 1 reset input, nominal current: 1 A
- MINI-PS- 12- 24DC/24DC/1 DC-DC converter, primary switched mode, slimline design, input: 12 -24 V DC, output: 24 V DC / 1 A

The software package was PC WORX BASIC LIC. The software for the control system was compiled in this package and upload to PLC unit.

Results

After assembling the sensing tips into sensor blade, data relevance between load and output voltage were analyzed. Since assembling fault would create mismatch in this relation. For calibration, specific software script was written in PC WORX BASIC LIC software package. Calibration data revealed the consistency of sensing tips with higher R^2 value in terms of load - voltage output harmony (fig 5). The R^2 value ranged between 0,9832 to 0,9970 and calibration functions were in linear format. The data revealed the montage success at manufacturing process.

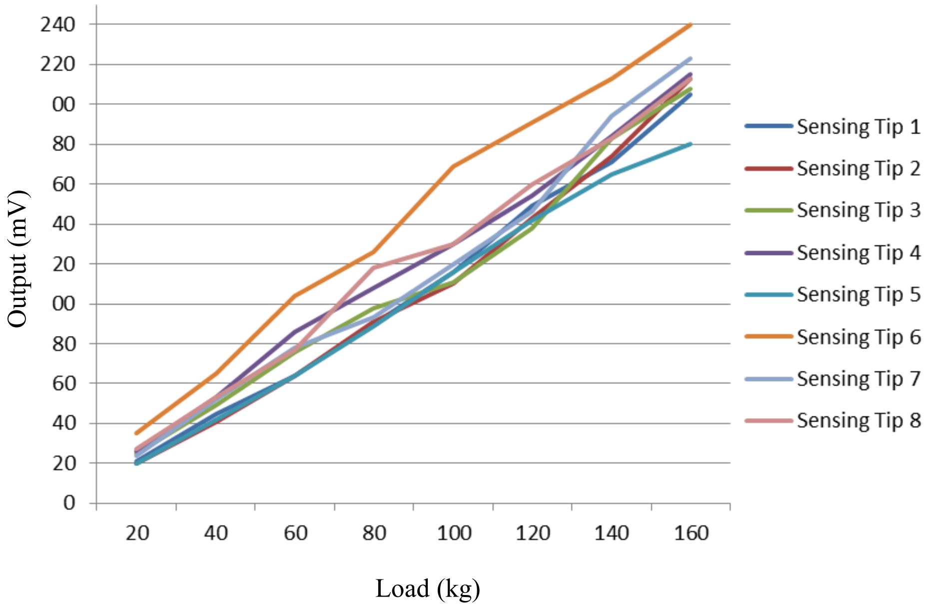

Fig 5- Relationship between load and output

Laboratory tests revealed that the system is ready for field test in order to optimize the sensor in terms of functionality and durability.

Although it was considered at designing stage to use 12 sensing tips for measuring the soil profile resistance at each 40 mm depth steps, four tips were excluded from measurement. Since assuming the crops such as corn, cotton, there is inter-row weeding and soil aeration operation at the depth of 10-15 cm which manage the compaction at that depth range. But, in case of needs the sensing tips could be included.

Development an automatic depth control system:

Automatic depth control system is under construction. The depth control loop will be constructed around the position control loop of the three-point hitch of the tractor, to which the chisel is attached. In this project, the tractor equipped with three-point hitch that is actuated by a single acting cylinder, will be engaged. Since, it is still found on most tractors. Consequently, the downward motion will be realized by the gravitational force. The depth control algorithm will be implemented on a Phoenix PLC. All real-time calculations from the depth control loop are performed by PLC.

The depth will be measured by a linear position transducer (LPT) sensor. The output of the sensor will be used as an input for the position control of the tractor three-point linkage. In order to direct a desired position of the three-point hitch from the depth control loop to the position control loop of the lift, some small adjustments have to be made to the tractor.

Conclusions

The sensing part of the variable depth tillage system was developed. The sensor measures the soil strength through the line of load cell tips then control unit determines the working depth of chisel and position control mechanism is actuated for exact sub soiling depth (fig 6).

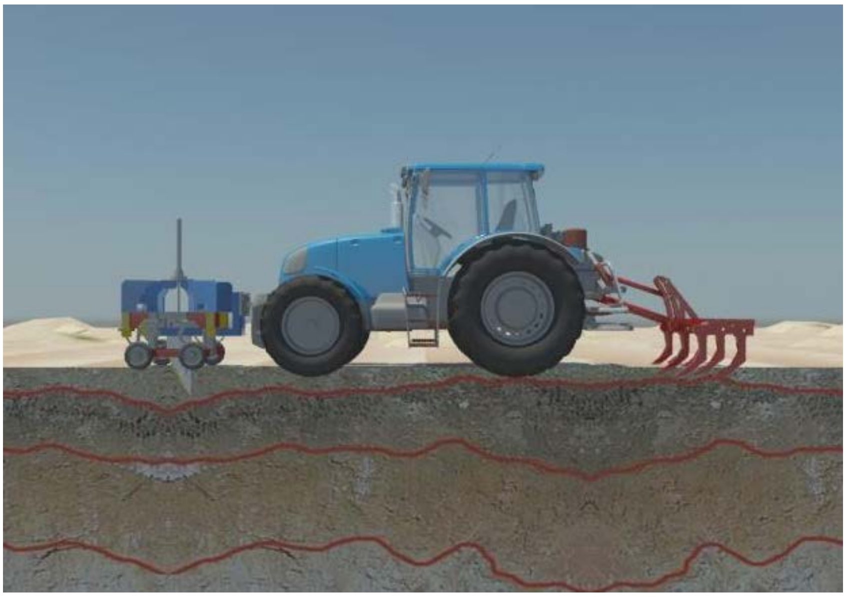

Fig 6- Assembled structure of the Soil Strength Sensor and Chisel on a Tractor

The system will be tested in situ when the soil moisture is adequate for the sub soiling. Some systematic experiments, such as draft force and fuel consumption beside field efficiency measurements, will also be conducted.

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