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Development of Electro-Hydraulic Hitch Control System through Lower Link Draft Sensing of a Tractor

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Three-point linkage plays an important role in controlling tillage implements with the hydraulic system of the tractor which includes draft control too. With increase in the usage of electronics and instrumentation in agriculture, the need was to upgrade the present mechanical hydraulic system of the tractor with electrohydraulic hitch control system (EHH) for better performance. The selection of draft sensing media was at the lower links for better sensitivity. The EHH control system through lower link draft sensing was developed using draft sensors, a control panel for user input and a controller with usage of MATLAB Simulink as an application software. Developed system was tested infield using duck foot cultivator and instrumentation like angle sensor, data acquisition and data logger were used for data capturing. The test results showed that for a change in set draft of 1500N, the system response time and change in depth of operation were 1.3s and 5 cm respectively. Whereas, for change in set draft of 500N the system response time was 0.9 s and change in depth of operation was 4 cm. For the conducted test, the variation in depth of operation was limiting to ±3.1 cm. The results concluded a direct relationship of change in set draft with system response time and change in operating depth. This study provides an overview of developing an EHH system through lower link draft sensing, as well as details of system architecture, control algorithm, MATLAB Simulink code, components used and the methodology and instrumentation technique for testing the same.

Keywords: Draft Control, Lower links, Operating depth, Simulink, Three-point hitch

Introduction

Basic function of tractor is to pull the implement which is accomplished by the three-point linkage. The control of the three-point linkage is achieved via the hydraulic system of the tractors. The user gives command to set the tractor operation in draft control mode or position control mode by the usage of their respective levers in quadrant assembly of the tractor. Draft control levers are used to set the draft of the implement before the start of operation so that wheel slippage is kept within acceptable limit and tractor cannot be overloaded while in operation, this is done to achieve the maximum tractive efficiency.[1,2] For setting the draft, it is important to sense it, hence tractor must have the sensing medium of draft. Three-point linkage have generally three links namely top link and two lower links in the left and right hands side. Presently, this three-point linkage is controlled by mechanical hydraulic system consisting of lift rod connected to lift arm, rocker arm and finally single acting cylinder.[3]In mechanical system the draft can be controlled either by lower links or top link. In top link, springs are used for the sensing of the draft load whereas, in case of lower links there are many options like torsion bar, leaf spring or wishbone shaped spring etc. Mechanical system has some disadvantages like, it does not provide consistent performance on non-homogenous soil also mechanical systems suffer from friction, elasticity, hysteresis more than 15% and the sensitivity is less for mechanical systems leading to response time being much higher.[4] To overcome this, draft sensing method was changed from mechanical to electronic draft sensing. In electronic draft sensing, draft is measured through electronic draft sensor. Some advantages over the mechanical hydraulic systems are high sensitivity, hysteresis less than 5% and less response time.[5] Hence, it was observable that electronic hitch control was advantageous than mechanical hitch control system. Therefore, present study was focused on EHH systems. With the usage of greater width and heavy implements it has become necessary to use high horsepower tractors to pull the same. The dilemma to the manufacturer remains

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whether to sense the draft from lower links or top link. But for the usage of higher horsepower tractors, it is recommended to use lower link sensing due to the shift of line of pull towards the lower link hitch point of the tractor in the three-point linkage.[6] This happens mainly because the line of pull passes from the center of resistance of the implement and virtual hitch point and with an increase in implement size the center of resistance shifts to rearwards, hence making the line of pull also shift towards the lower link point. Though using top link draft sensing there will be the only use of one top link draft sensor. Whereas, using lower link draft sensing, two lower link sensors need to be used. Hence, averaging the output of both is required to eliminate the ambiguity to the controller due to the difference in two output sensed draft force signal of the draft sensor.[7] The difference in these output signals is due to soil non-homogeneity and unsymmetrical implement geometry. It is further to be clarified that the draft force is not the same as the sensed force from the sensor to be used for draft control, as is evident from the free body diagram of three-point linkage force study.[6,8–11] When in operation the draft force is the sum of all the horizontal component of force acting on the three-point linkage of all the three links.[8] But since the force profile of draft and sensed force is the same, hence sensed force is controlled in draft control.[6,12] In mechanical system also the springs are there to sense the draft force attached after the top link point and enclosed in assembly. The advantages of using lower link draft sensing are better sensitivity and less response time with respect to top link draft sensing.[6,12,13] Considering the above facts, the present study was proposed for the development of an EHH system through lower links draft sensing as the draft medium.

Materials and Methods

This section explains the system architecture and hardware parts used for the development of the EHH system through lower link draft sensing, the development of a control algorithm for controlling the EHH system and the instrumentation used to test the developed system.

Architecture of EHH System

As shown in Fig. 1 the inputs to the controller were two lower link draft sensors, angle sensor and input signal set by the user. These signals were conditioned using a moving average algorithm to eliminate the noise in the signal and feed into the draft control function present in the controller. The controller

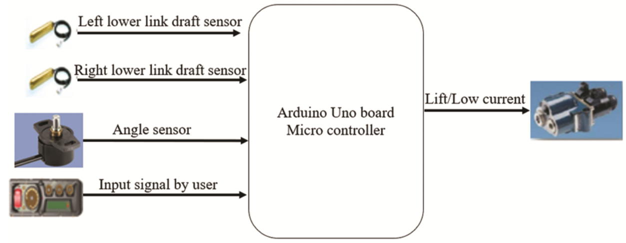


Fig. 1 — EHH systems through lower links draft sensing architecture

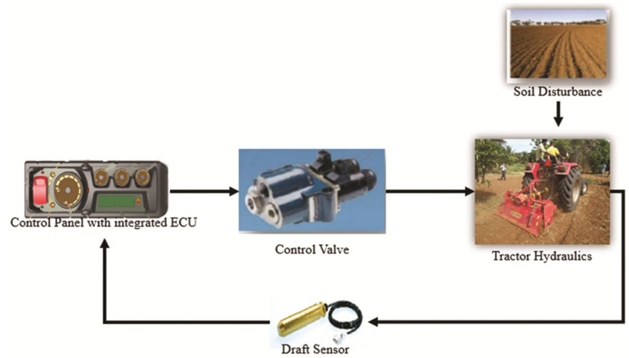


Fig. 2 — EHH system using lower links draft sensing as a closed loop system

based on these signals actuated the lift and low current signals to the control valve. The application software of the tractor was made in MATLAB Simulink platform. This application software was flashed in the controller for controlling the three-point linkage functionality in draft control mode based on the input signal set by the user namely the set draft.

The developed EHH system for draft control was a closed-loop system for on-the-go controlling of the draft, since the draft itself changes with the disturbance created by the soil's heterogeneous nature. In Fig. 2, a closed loop EHH system is shown, where the draft signal is set from control panel and subtracted with feedback draft sensor signal resulting an error draft. According to this error draft signal the ECU actuates corresponding flow through the control valve. Control valve provides flow which is input to the tractor hydraulics to reach desired set draft, set from control panel but there are soil disturbances which do not allow the implement to reach the desired depth and acquire the desired set draft value and this process goes on and ECU provides the signals to attain the desired draft.

Hydraulic Circuit of EHH System

With the usage of EHH systems, the hydraulic valves used in mechanical hydraulic system are replaced with solenoid operated proportional control valves. The hydraulic circuit of the EHH system is shown in the Fig. 3 consisting of pump, lift solenoid valve, low solenoid valve, check valve, ram cylinder, tank, pressure compensating valve and filter. While lifting the implement, lift solenoid valve is actuated by lift current, then flow passes through the check valve and not through the check valve of the low solenoid valve and while lowering, low solenoid valve is actuated then oil flows to the tank through the low solenoid valve and dumps to the tank. The pressure compensator valve was provided to maintain pressure throughout the lift solenoid valve system. Otherwise, there will be fluctuation of flow with respect to current, to be provided through the ECU of the EHH system.[14]

Specification of the Sensor

As mentioned earlier that draft sensor was used for sensing the load on lower link point. The specifications of the same are mentioned in Table 1. Draft pin Load sensor works on the principle of magneto elastic effect. It was designed as a load pin, attached at lower link point. The magneto- elastic effect is measured by means of primary and secondary coils in a central bore of the sensor. In no-load condition, a symmetrical magnetic field is formed between the poles by means of primary coil. If tensile or compressive forces are introduced, then the magnetic properties of the originally isotropic material changes. Subsequently, the magnetic field becomes unsymmetrical. Thus, a magnetic potential occurs between secondary poles. This difference causes a magnetic flux through the secondary circuit so that a voltage is induced in the secondary coils. This voltage is proportional to the influencing force. The position of the sensor was set on the lower link point of the tractor as shown in Fig. 4.

Angle sensor was also used to provide the feedback on the position of the hitch movement of the three-point linkage. The angle sensor working on the principle of rotary potentiometer[15] was fitted on the lift arm as shown in Fig. 5 and calibrated with the operating height of the lower link with the ground. The calibrated value showed that for an angle variation of 0° to 66° the operating height of the lower link hitch point w.r.t ground was varied from 22 cm to 88 cm. The specification of the angle sensor used is mentioned in Table 2 below.

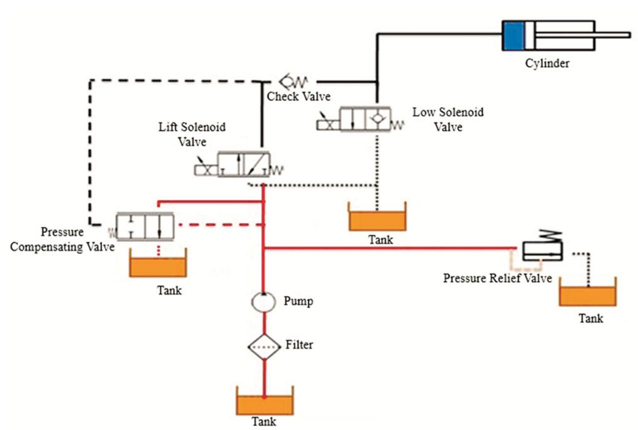


Fig. 3 — EHH hydraulic system

Table 1 — Specification of Draft Sensor

S. No.	Parameters	Numerical/Character Values
1.	Make	Husco
2.	Capacity	± 20 KN
3.	Safe Overload	300 %
4.	Ultimate Overload	500 %
5.	Input Voltage	0.5 V to 4.5 V 2.5 V = 0 KN
6.	Standard Wire Length	200 mm
7.	Connector	Deutsch DTMO4 – 3P, IP67
8.	Current consumption	13 mA
9.	Protection grade	IP 67
10.	Electrical Connection	3 Pin Connector

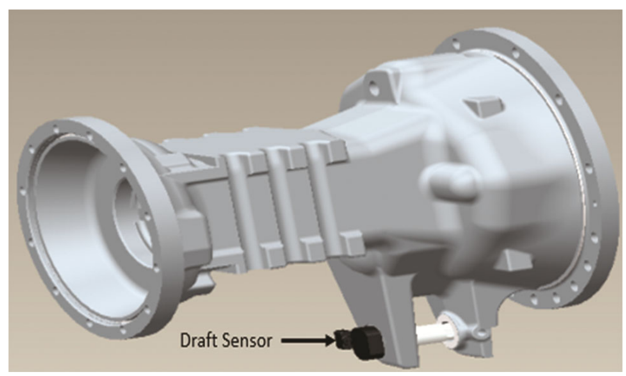


Fig. 4 — Isometric view for position of the draft sensor

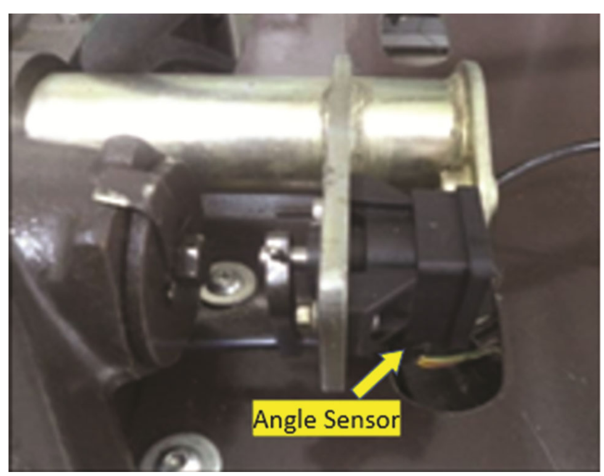


Fig. 5 — Placement of angle sensor

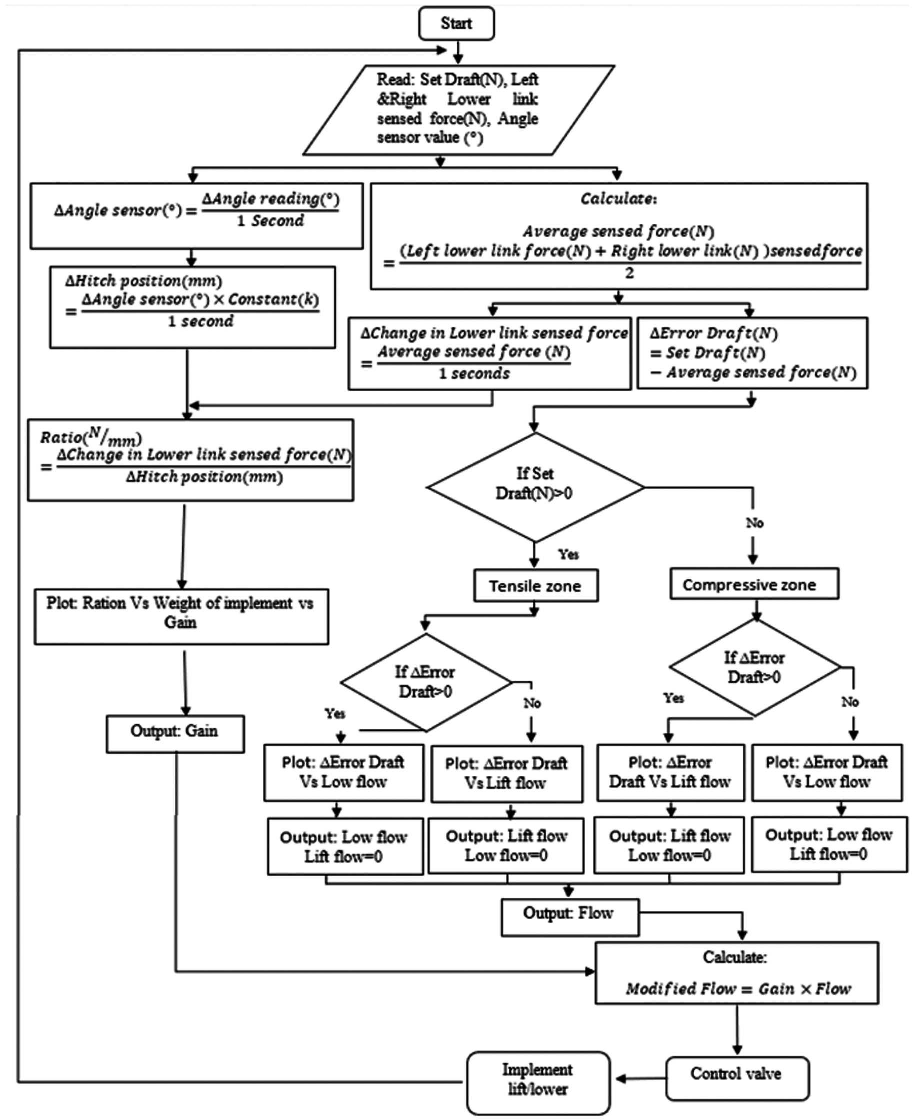


Fig. 6 — Control algorithm of EHH system through lower link draft sensing

Table 2 — Specification of Angle Sensor

S. No.	Parameters	Numerical Values
1.	Make	Bosch
2.	Working	Rotary Potentiometer
3.	Capacity	±44°
4.	Electrical Connection	3 Pin Connector
5.	Input Voltage	0.5 V to 4.5 V 2.5 V = 0°
6.	Protection grade	IP 67
7.	Sensitivity	11°/V

Development of Control Algorithm

Initially the control algorithm was set up and coded in MATLAB Simulink R2013a after that it was flashed into the controller i.e., the Arduino Uno board. The details of Control algorithm are shown in Fig. 6.

As per the flow chart shown, four values were read from the controller, they were the set draft, which is a user interface to be set by the user through control panel, the sensed forces from the two-lower links via the attached draft sensor fitted on the lower link point and the angle sensor input providing the information about the degree of hitch movement. As per the control algorithm, after reading all these inputs, initially the averaging of the sensed forces from both the lower links was done to eliminate the ambiguity values to the controller[7] and subsequently the rate of change of sensed force was calculated based on the average sensed force. On the other hand, rate of change of angle sensor reading was converted to rate of change of hitch position movement using a factor, since for an angle variation of 0° to 66°, the operating height of the lower link hitch point w.r.t ground was varied from 22 cm to 88 cm. The ratio was defined as rate of change of sensed force upon rate of change of hitch movement. The idea behind to define the same was that for a hard soil, hitch travel was less compared to soft and medium soil for same set draft and sensed force. Hence for hard soil it takes less time to attain set draft compared to medium soil which may result in overshooting of flow and soft soil takes large time which may result in delayed response. Hence for hard soil less flow and soft soil large flow was required. The weight of implement also plays a role to some extent on the hitch travel and rate of force change as is evident from the mechanics and free body diagram of the implement working in soil. Hence the mapping was done considering all these and the output gain was taken. The values used in the coding is shown in Table 3.[(16)] These values were derived based on various field testing and hardware in the loop testing.[16] Going back to the average sensed force in the algorithm, there is also computation of error draft which is the difference of set draft with the average sensed force and upon the selection of set draft greater or less than zero the compressive and the tensile zone was defined. Here tensile force is taken as positive for sign convention, where set draft is greater than equal to zero and compressive zone is taken as negative where set draft is less than zero. Once in tension zone, if the error draft was greater than zero than the implement would lower to attain the set draft and vice versa. Similarly, when in compressive zone, if the error draft was greater than zero than the implement would lift to attain the set draft and vice versa. While lifting the implement the lowering valve flow was kept zero and when the implement lowered the lift valve flow was kept zero. All these flows were collected and then multiplied with the gain to arrive at modified flow, which was then feed to the control valve, which controls the lifting and lowering of the implement. The primary objective of any draft control system in hydraulic system of tractor is to make this error draft as zero, but due to soil non homogeneity, this does not happen, and this process is closed loop as indicated in the control algorithm.

The MATLAB Simulink code as per the above control algorithm in MATLAB Simulink R2013a platform is shown in Fig. 7.

Experimentation

After developing the EHH system, it was necessary to set up an instrumentation for capturing the functionality of electro-hydraulic hitch draft control system through lower links. After setting up the instrumentation, field testing was done with duck foot cultivator attached to tractor. The specifications of both duck foot cultivator and the tractor are specified in the Table 4 and Table 5 below.

The instrumentation set up for field testing is shown in Fig. 8. As it can be observed that the soil disturbance creates variation in sensed force in the two lower link draft sensors which is controlled by the controller as per the set draft set by the user. The set draft is known through the control panel set by the user, hence the signal input of the same is not taken in the DAQ system. The data acquisition system used was the NI_DAQ by national instruments. The data logging was done through Panasonic tough book. The angle sensor was present in the EHH system developed and the same was used for collecting the information on the hitch movement. To analyze the performance of the system depth variation of the system to attain the set draft and the system response time was analyzed. The system response time was defined as the time required for the height of lower link hitch point with respect to ground to settle at a depth upon the change of set draft. In this paper the change in set draft was considered as the difference between previous set draft and the current set draft set by the user

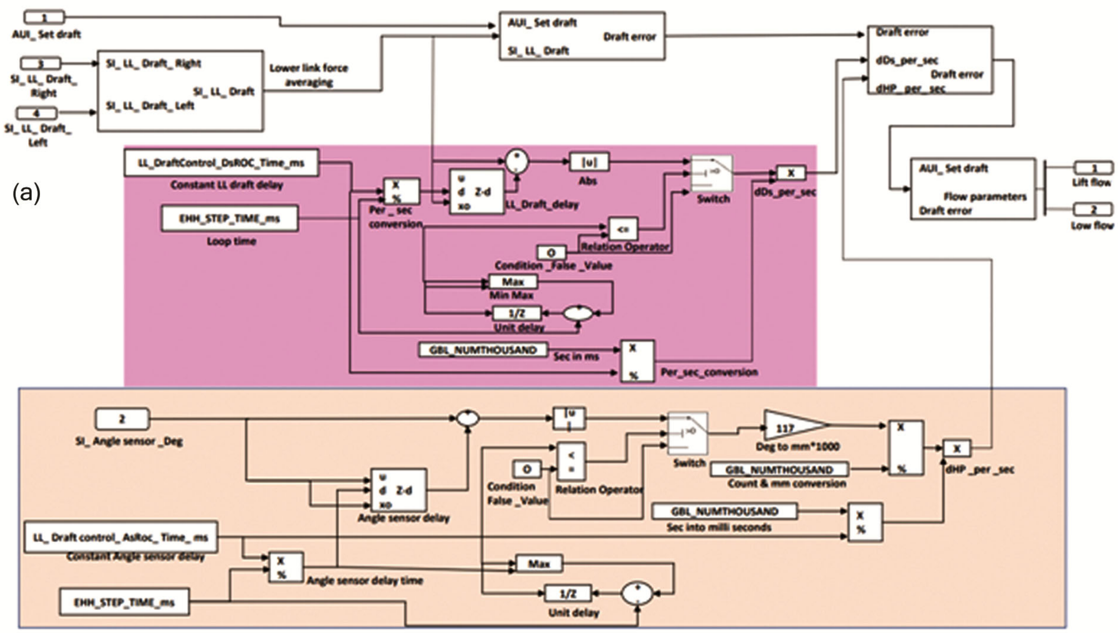
Results and Discussion

This section shows the results obtained of the developed system. The soil hardness was varying

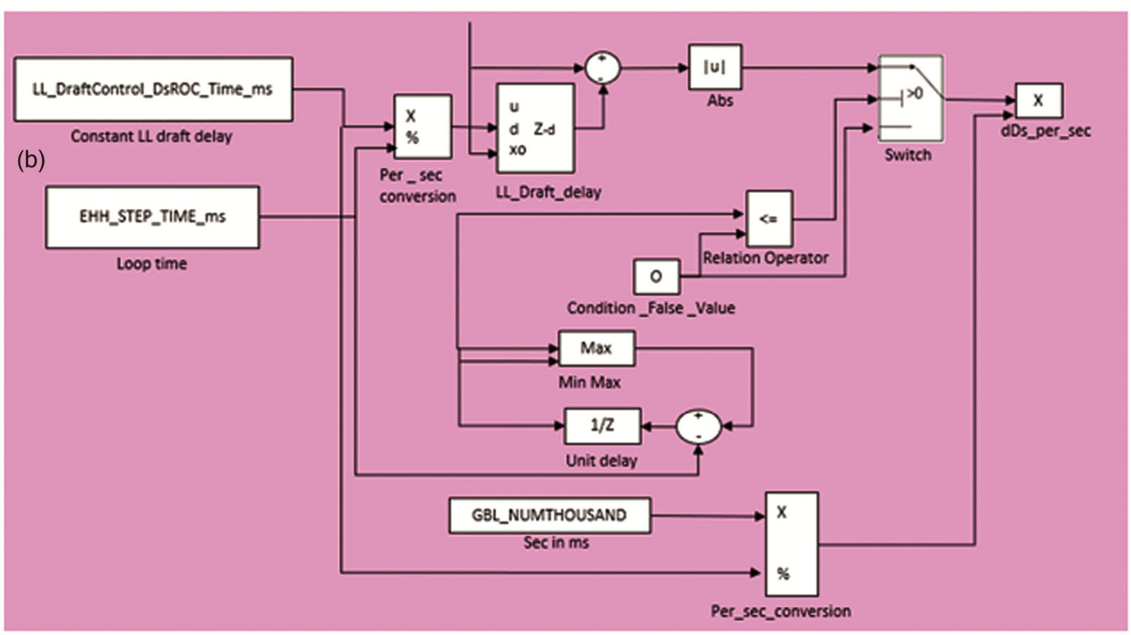
Table 3 — Value of gain and ratio used in MATLAB Simulink code[16]

S. No.	Type of soil	Cone Index(kPa)	Type of implement	Weight of implement(kg)	Ratio	Gain
1.	Hard	>900	Light	<200	70	1.45
2.			Medium	>200	100	1.25
3.	Medium	500-900	Light	<200	35	1
4.			Medium	>200	55	1
5.	Soft	>500	Light	<200	15	0.9
6.			Medium	>200	19	0.8

from soft to medium soil with cone index variation of 400–900 kPa. The step time of data collected was 200 milli seconds. The data of sensed forces of the two-lower links, average sensed forces of the lower links and the set draft set by the user are shown in Fig. 9. All the forces were tensile force. It is clear from Fig. 9 that the sensed forces and average of sensed lower link forces follow the same profile and there were fluctuating signal around the set draft set by the user. Until 142 s the set draft was set as 3000N, then it was set as 4500 N till 500s and later it was set to 5000 N. As per the control logic the controller is functioning the draft control as per the average sensed lower link forces. This was done to remove the ambiguity to the controller since while in turning and due to non-homogeneous property of the soil there



Overall draft control code



Change in sensed force per second code

(*Contd.*)

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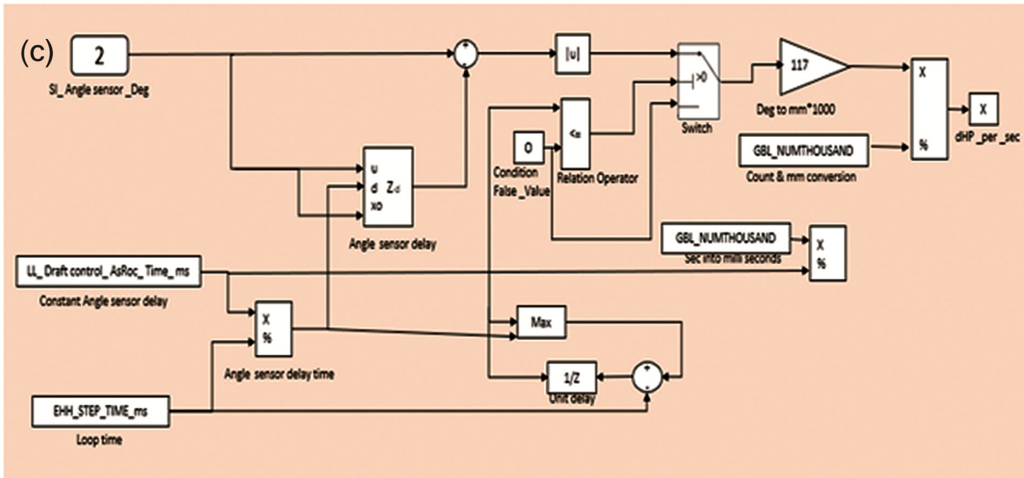
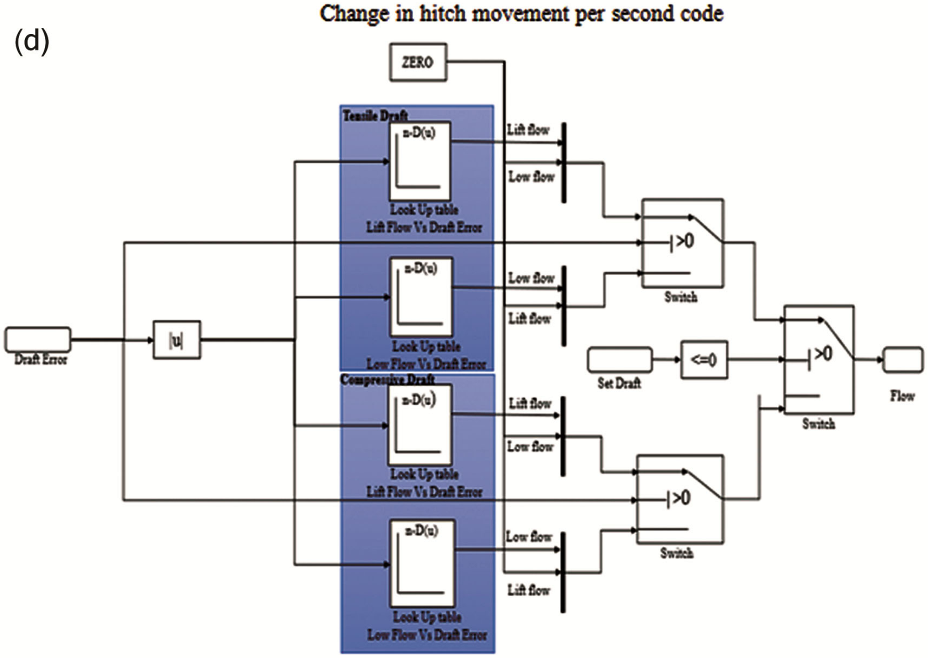


Change in hitch movement per second code



Simulink code to generate flow based on error draft

Fig. 7 — MATLAB simulink code: (a) Overall draft control code, (b) Change in sensed force per second code, (C) Change in hitch movement per second code, (d) Simulink code to generate flow based on error draft

Table 4 — Specification of the tractor used in field testing

Parameter	Specification
Model	MF 9500 (2WD)
Make	TAFE
Engine	Simpson
Maximum speed at no load	2300 to 2420
Low idle speed	700 to 800
Speed at maximum torque	1000 to 1200
Rated Speed (rpm)	
PTO Use	2200
Drawbar Use	2200
Maximum drawbar power (hp)	46
BHP	59

Table 5 — Specification of the Duck foot cultivator for field testing

Parameter	Specification
Description	Duck Foot Cultivator
Number of Tines	5
Mounting category	CAT II
Working Width (mm)	2000
Weight (kg)	250
Minimum HP range	35

will be variation in the sensed forces of the two-lower links.[7] The variation of sensed draft from the set draft was observed between −1500N to 1200 N as shown in

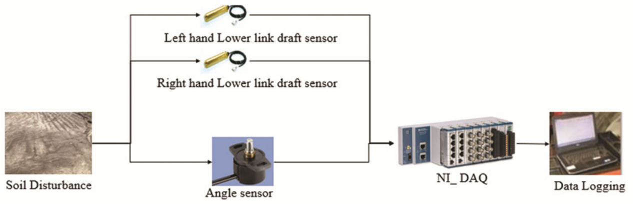


Fig. 8 — Instrumentation set up

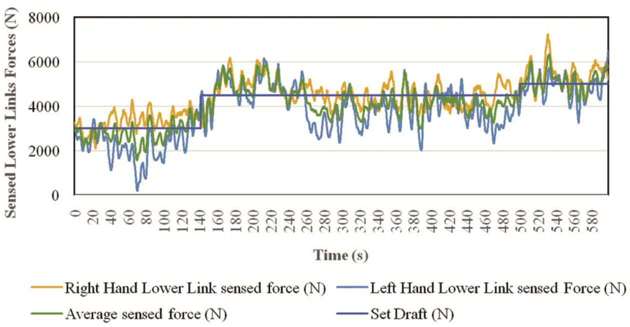


Fig. 9 — Variation of sensed lower link force with time

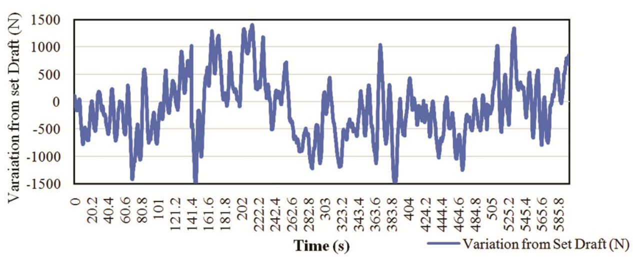


Fig. 10 — Variation of sensed force from set draft with time

Fig. 10. This variation was obvious to happen due to variability in cone index which is 400 kPa to 900 kPa of the soil. It is clearly visible from the graph that the average sensed force maintains the set draft value due to controller action on actuating the valves.

Depth Variation of the System to Attain Set Draft

The variation of average sensed lower link force with time and the variation of height of the lower link hitch point with respect to ground over the time is shown in Fig. 11. From Fig. 11 it is observable that for the set draft of 3000N during time 0 to 142 s, the height of lower link hitch point with respect to ground was 35 ± 3.1 cm, similarly for the set draft 4500 N during time 142 to 500 s the height of lower link hitch point with respect to ground was 30 ± 2.8 cm and for the set draft 5000N, during time 500 s onwards the height of lower link hitch point with respect to ground was 26 ± 2.5 cm. Thus, upon increase in set draft the height of lower link hitch point with respect to ground decreased to attain the set draft. It was known that the height from lower link hitch point to the bottom most

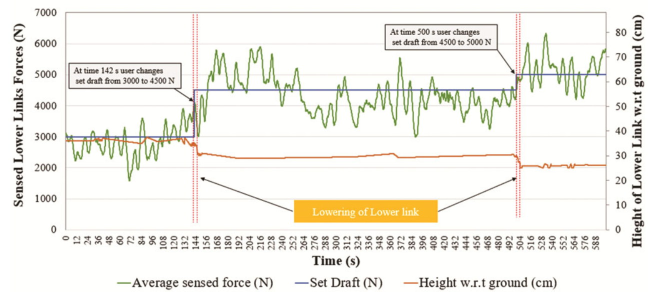


Fig. 11 — Performance and response time of the developed system

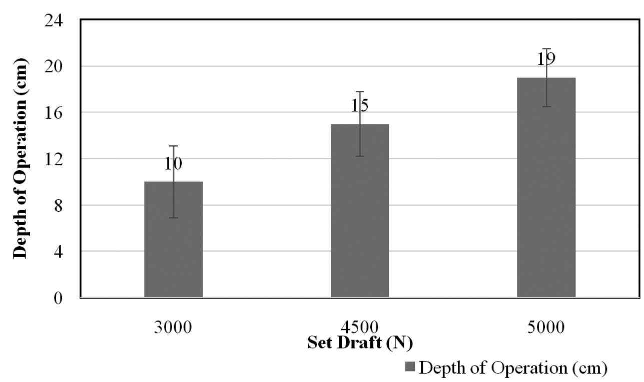


Fig. 12 — Depth of operation with set draft variation

point of the implement was 45 cm. Hence the depth of operation was calculated as the difference between height from lower link hitch point to the bottom most point of the implement and the height of the lower link hitch point with respect to ground while in operation. As shown in Fig. 12, the calculated depth of operation was 10± 3.1 cm for set draft of 3000N, 15 ± 2.8 cm for set draft 4500N and 19 ± 2.5 cm for set draft 5000N. It is evitable from the above data set that the depth of operation increases with increase in set draft which is quite opposite to the trend followed by the height of lower link hitch point with respect to ground.

System Response Time

As shown in Fig. 11 that upon increase in set draft the height of lower link hitch point with respect to ground decreased to attain the set draft. It was also observed that upon change in set draft from3000 N to 4500 N at the time of 142s the height of lower link hitch point with respect to ground gradually decreased from 35 ± 3.1 cm to 30 ± 2.8 cm and the corresponding depth of operation increased from 10± 3.1 cm to 15± 2.8 cm within 1.3s. Similarly, upon change in set draft from 4500 N to 5000 N at the time of 500s the height of lower link hitch point with respect to ground gradually decreased from 30 ± 2.8

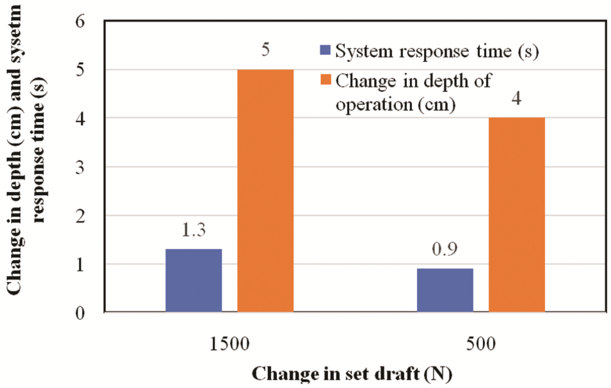


Fig. 13 — System response time with change in draft

to 26 ± 2.5 cm. The corresponding depth of operation increased from 15± 2.8 cm to 19± 2.5 cm within 0.9s. In Fig. 13 the system response time with respect to the change in set draft is shown. It was observed that the system response time for change in set draft of1500 N was 1.3s and for change in set draft of 500N the system response time was 0.9s. The 1500 N change in set draft resembles the condition of set draft change from 3000N to 4500N, similarly 500N change in set draft resembles the condition of set draft change from 4500N to 5000N. The trend observed was that with decrease in change in set draft the system response time also decreases. This is because for less change in set draft the travelled distance to attain the set draft or the change in depth of operation is less. As shown in Fig. 13 that for change in set draft of 1500N the change in depth of operation was 5 cm and for change in set draft of 500 N the change in depth of operation was 4 cm. Hence to cover lower change in depth of operation, the time required will be less. Hence, for change in set draft of 500 N the time required was less as compared to the change in set draft of 1500 N.

Conclusions

This paper claims to have developed an EHH system through lower link draft sensing mechanism using MATLAB Simulink as an application software and lower links draft sensors, control panel, controller, and electro-hydraulic hydraulic system as hardware's. The observed system response time was within 1.3 s for change in set draft of 1500 N and 0.9s for change in set draft of 500 N. The variation in depth of operation of the developed system was limiting to ± 3.1 cm. These observations have been made by using a MF 9500 two-wheel drive tractor attached to 5 tine duct foot cultivator in a field whosesoil hardness was varying with cone index variation of 400–900 kPa. Though lower link draft sensing through electro-hydraulic hitch control system is used for better response time, but the system also adds up one more sensor attachment compared to top link sensing and hence the cost also adds up which is a limitation of the system. For further study combination of integrated draft and slip control system can also be developed to achieve the optimal tractive efficiency.

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