DEVELOPING SIMPLE AND CHEAP MEASUREMENT SYSTEM AND LOGGING BOX FOR OBTAINING CULTIVATOR LEGS DRAFT FORCE USING ARDUINO BOARD

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Summary

In this work, an Arduino based system to measure the draft resistance of an individual cultivator leg was developed. Two types of cultivator legs were used: S-type spring leg and rigid leg. An extended octagonal ring was used as the sensor. The strength and strain analyses of the ring were performed by a finite element software. The locations of the strain-gauges were selected so that the load-cell amplifier gives high output voltages.

The measuring system outputs were calibrated with the digital force gauge meter. R-squared value was observed as 0.9999. The Designed and produced measuring system was tested on the tractor in the field successfully. Different tractor speeds, tillage depths and cultivator legs were considered. The measurement values recorded in the SD card with the measurement system were transferred to the computer and analysed. It was observed that when the tillage depth and the tractor speed increase then the draft force values also increase.

As a result of this study, an Arduino-based low-cost draft force measurement system for obtaining draft force of soil tillage machine has been designed, produced, and used successfully.

Key words: *draft force, cultivator’s leg, octagonal ring, Arduino, measurement*

INTRODUCTION

Draft force requirement in soil tillage machines depends on factors such as soil resistance, working width, working depth, geometry of soil tillage tool, forward speed, and machine weight. Draft force measurement is an important indicator in evaluating the tillage performance of the tractor-machine couple. Various transducers and measurement systems are used to measure draft forces between tractor and agricultural

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equipment. Extended octagonal ring (EOR) transducers are popular because they can be installed easily and can be used to measure horizontal-vertical components of forces and moment independently. In today's technology, digital data acquisition and processing systems are used in measurements. The system must be reliable, precise, and usable in tillage conditions. Roca *et al.* (2017) developed a double frame dynamomometer to measure all the forces and moments between a tractor and a connected agricultural machine. One side of the frame is connected to the tractor and the other side is connected to the agricultural machine. They used NI-9237 data acquisition system. The aim of their study was that the system can be easily mounted on any tractor. Yurdem *et al.* (2019) studied the strain values at different locations on the plows with simulation and experiment, and compared the results. They used Campbell Ccientific CR23X datalogger. Wen *et al.* (2021) developed an indoor test bench to evaluate the fatigue life of tractors in short periods. They installed strain-gauges at 24 locations in the system and used statistical methods to study the accuracy, rationality, and effectiveness of the system. Behara *et al.* (2021) designed a rota-cultivator with active and passive combination and measured forces at each link of the three point hitch system by using S type load cells and HBM Quantum data acquisition system. Sadek *et al.* (2021) developed a discrete element model to predict draft forces for high-speed tillage and calibrated the model in the laboratory. Draft forces were measured for an indivually mounted disc. Nejadian *et al.* (2019) used the finite element method to calculate the drawbar force requirement during tillage with moulboard plough. They created model of parts (moulboard, share and soil cross section) to examine with the finite element method and then compared with the test results in the test area. A moulboard plough and 2 tractors were used in the test area, and an S type force measurement dynamometer was attached to a rope between the tractors. Kumar *et al.* (2015) stated that ring-shaped dynamometers can be developed with very low costs and high precision compared to other force measurement systems. They examined whether the dynamometer could make more precise measurements by designing the t/R (thickness-average diameter) ratio of annular dynamometers to be 0.05 instead of the usually designed 0.1-0.5 dimensions. Moinfar *et al.* (2020) carried out soil cultivation experiments with tractors with 3 different traction types (rear wheel drive, front wheel drive, 4 wheel drive), tires with 3 different inflation pressures and 3 different sizes of additional weights. They used 3 octagonal measurement dynamometers positioned on the 3-point hitch arms of the chisel frame in order to measure the draft force requirement. Das *et al.* (2017) used octagonal rings and developed a low-cost measurement system to measure the applied force during friction stir welding where horizontal, vertical and diagonal forces act on the material. They determined the location of the strain-gauges on the rings by the finite element simulation and used National Instruments 6259-USB data acquisition system to measure all the components of the force. Gilandeh and Shishvan (2011) discussed design, construction, and calibration of extended octagonal ring transducers to measure tractor implement forces and used DT800 data logger. They made the finite element analysis to locate strain-gauges on the ring optimally. Kumar *et al.* (2016) developed an Arduino Mega 2560 based system to measure the draft force and skid during tillage.

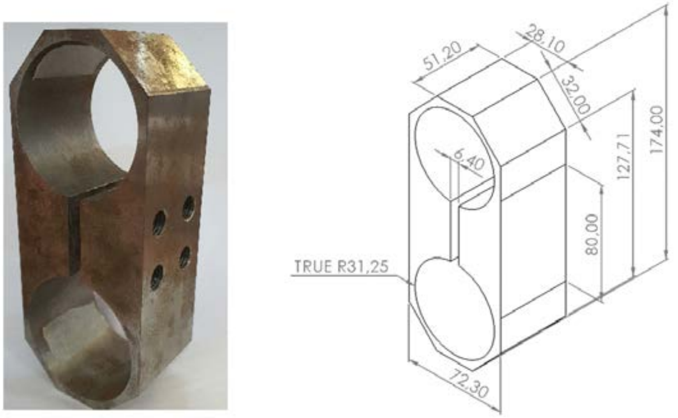
The data received by the system is used to warn the operator for the fuel consumption. They placed strain-gauges to the lower link arms and a ring to the upper link arm of the three-point hitch system of the tractor. Kumar and Tewari (2021) developed an arduino based system to measure dynamic wheel axle torque and draft force of different tractor-agricultural machine combinations. In this study, a measurement system for determination of draft resistance of a cultivator leg using Arduino is introduced. An extended octagonal ring is used. The ring and the location of the strain-gauges are evaluated by the finite element analysis. The ring is mounted to an individual cultivator leg. The system has been tested in the field on a tractor and sample measurement signals has been obtained successfully. There is an increasing trend for developing smart agricultural machines in parallel to developments in sensors and data acquisition systems. Developing a quick, cheap, and portable measurement system is important for the application of smart agricultural machines.

MESUREMENT SYSTEM

An extended octagonal ring with 4 strain-gauges as the sensor, a Wheatstone bridge and a load cell amplifier are used in the measurement system. A data acquisition based on arduino has been developed. The details of the measurement system are given below.

2.1 Extended Octagonal Ring and strain-gauges

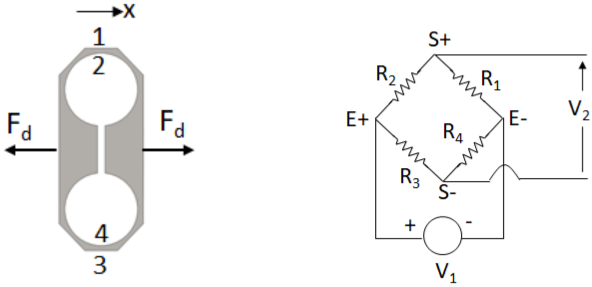
The octagonal ring used in this study is shown in Fig. 1.



(a) (b)

Fig. 1. Picture of a) octagonal ring and b) dimensions (mm)

The locations 1, 2, 3, and 4 for the strain-gauges to measure the draft force (F_d) is shown in Fig. 2 (a). The strain-gauges are installed in the x direction. The Wheatstone bridge used to measure the draft force is shown in Fig. 2 (b) (Gilandeh and Shishvan, 2011).



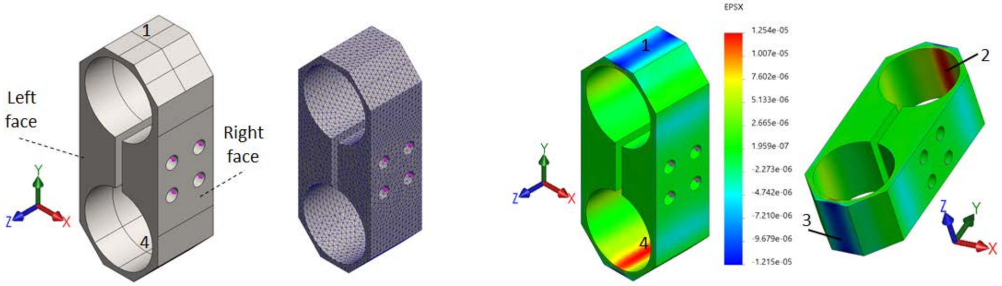
(a) (b)

Fig. 2. (a) Locations of strain-gauges to measure draft force

R_1, R_2, R_3, and R_4 are the resistance of the strain-gauges located at 1, 2, 3, and 4, respectively. The voltage, V_1, is applied to the circuit nodes at E+ and E-. The sensor output voltage, V_2, is the potential difference between the circuit nodes at S- and S+. The strain-gauges used have the resistance value of 350 ohm, and gage-factor of 2.

2.2 Finite element (FE) analysis

The solid model of the octagonal ring is created in Solidworks as shown in Fig. 3(a). There are 4 holes on the right and left faces. The faces of the holes in the left face are fixed in FE analysis. The draft force in the x direction is defined on the faces of the holes in right face totaling as F_d. The curvature-based mesh with a maximum element size of 4 mm was used. There are 63703 nodes and 40308 elements. The meshed model is shown in Fig. 3 (b). The calculated strains in the x direction, ε_x, are plotted in Fig. 3(c). The results are given for F_d=50 N.



(a) (b) (c)

Fig. 3. (a) Solid model, (b) Meshed FE model, and (c) calculated strains in x-direction

It is observed that strain values, ε_x, are high in the regions of the locations 1, 2, 3, and 4 as compared with the other regions. They are positive (tension) at locations 2 and 4, and they are negative (compression) at the locations 1 and 3. So, the octagonal ring behaves as a load cell to measure the draft force using the Wheatstone bridge shown in Fig. 2 (b).

The experiments using a universal testing machine are conducted to validate the simulation results. The simulation and experimental results are given in Table 1.

Table 1. Simulation and experimental results for strains (ε_x), F_d=50 N

Location*	Simulation (με)	Experiment(με)	Type of strain
1	-10.3	12	Compression
2	+12.5	15	Tension
4	+12.5	14	Tension
3	-10.3	12	Compression

- The locations are given in Figure 3

2.3 Data acquision system hardware

The schema of the data acquisition system is shown in Fig. 4. The system consists of an Arduino uno as the microcontroller, an SD card module, an LCD panel, and LM2596 step down voltage regulator. The Arduino is powered by a 9V battery. LM2596 is used to regulate and adjust the reference voltage for the analog input of the Arduino to increase the accuracy of the measurements. The load cell amplifier (Weighing Transmitters Amplifier Weight Sensor Voltage Current Converter DC 0-5V/0-10V 4-20MA load Cell Amplifier Gain Adjustable) is powered by two 9V batteries connected serially. S-, S+, E-, E+ nodes shown in Fig. 2 (b) are connected to the amplifier. The gain of the amplifier is 150, and it gives an analog output voltage. The analog output voltage signal wire is connected to the analog input (AI) of the microcontroller.

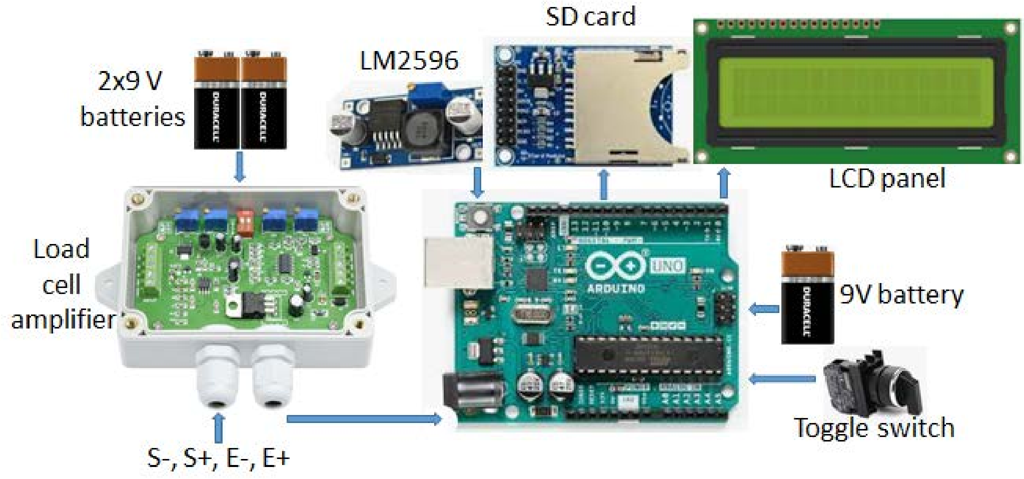


Fig. 4. Schema of acquisition system

Arduino Uno has 10 bit resolution, and its measurement accuracy can be increased by decreasing the reference voltage (Aref) using LM2596 considering the measurement interval. The sampling rate of the measurement system is 15 Hz.

2.4 Data acquisition system software

The flow chart of the Arduino program is shown in Fig. 5. A digital input (DI) signal is sent to the Arduino by using a toggle switch, and the system starts recording the analog sensor signal to a file in the SD card when the toggle switch is turned on. It stops recording when the toggle switch is turned off. The recorded data is transferred to a computer through USB. Then the data is analyzed by MatLAB.

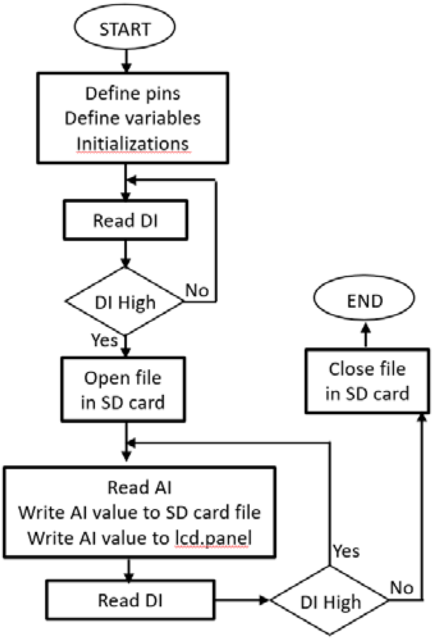


Fig. 5. Flow chart of the Arduino program

RESULTS AND DISCUSSIONS

In this section the calibration results of the measurement system and field measurements are given.

3.1 Calibration

A setup shown in Fig. 6 has been used to calibrate the measurement system. The setup consists of a cultivator leg and the octagonal ring mounted to a frame. There is an adjustable tension wire between a dynamometer (Garatech SH-200) mounted to the frame and the duck foot blade.

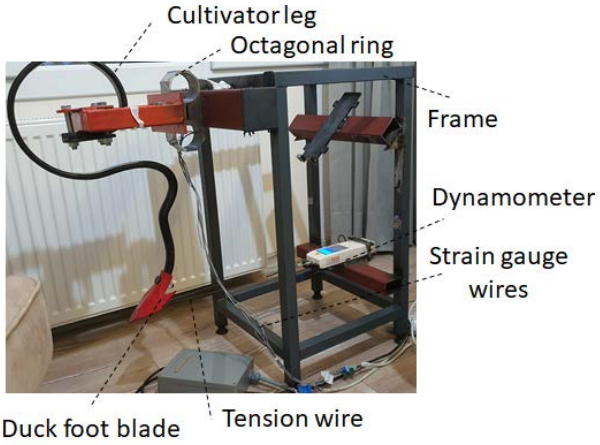


Fig. 6. Calibration setup

The applied tension forces measured by the dynamometer and the measurement system given in Section 2 are compared in Table 2.

Table 2. Tension forces measured by the dynamometer and the measurement system

F_d (Dynamometer, kg)	F_m (Measurement system, kg)
1.05	1.1
2.02	2.1
3.02	3.1
4.03	4.1
5.04	5.1
6.06	6.1
7.04	7.1
8.01	8.0

The linear regression has been applied to the force values in Table 2 and the resultant graph is given in Fig. 7. It is observed that the R-squared value is 0.9999.

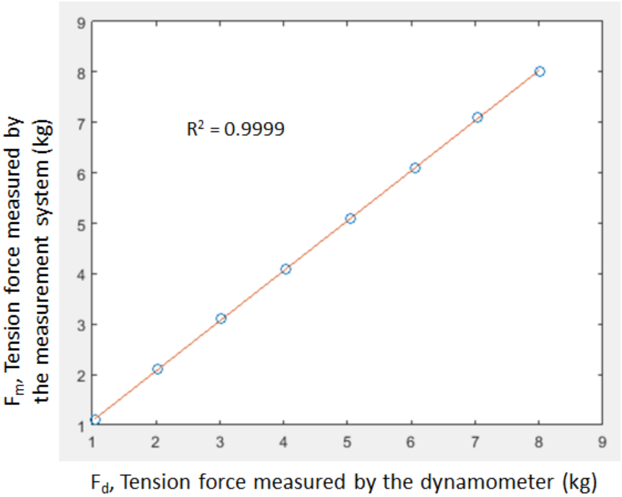
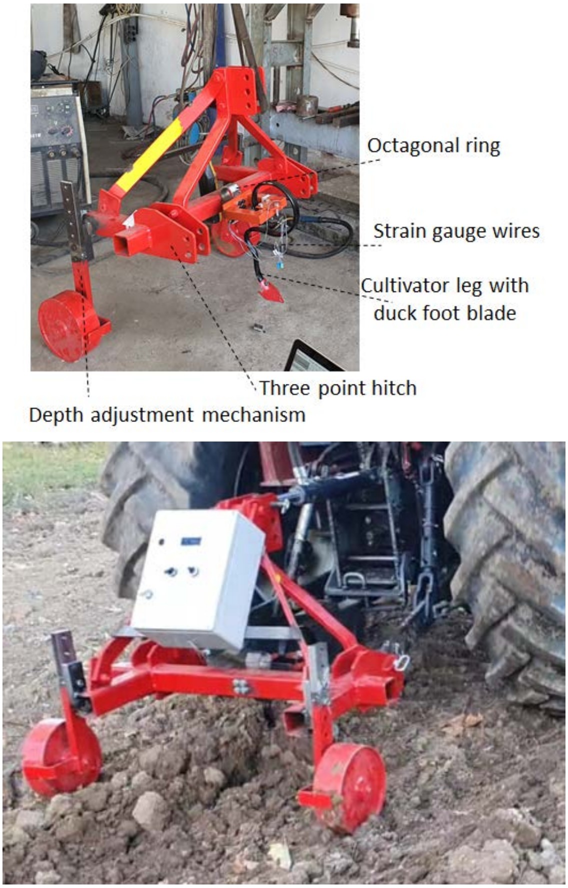


Fig. 7. Linear regression graph for the tension force data given in Table 2

3.2 *Field measurement*

The assembly of the three point hitch, the cultivator leg with the duck foot blade, the octagonal ring is shown in Fig. 8 (a). There are two wheels mounted to the three point hitch with a beam having holes at different distances. The tillage depth can be changed by changing the mounting locations of the holes. The depths which can be selected are 5, 10, and 15 cm. The cultivator leg- octagonal ring-three point hitch assembly mounted to the tractor in the field is shown in Fig. 8 (b). The control panel of the measurement system is also seen in the figure.



(a) (b)

Fig. 8. (a) Cultivator leg-octagonal ring-three point hitch assembly, (b) The assembly mounted to the tractor in the field

In field tests with S type spring leg Fig. 9, the average draft force for 5 cm depth and 1.5 ms^{-1} speed was 126 N and for 5 cm depth and 2.4 ms^{-1} speed was 159 N and for 10 cm depth and 1.5 ms^{-1} speed was 300 N and for 10 cm depth and 2.4 ms^{-1} speed was 337 N.

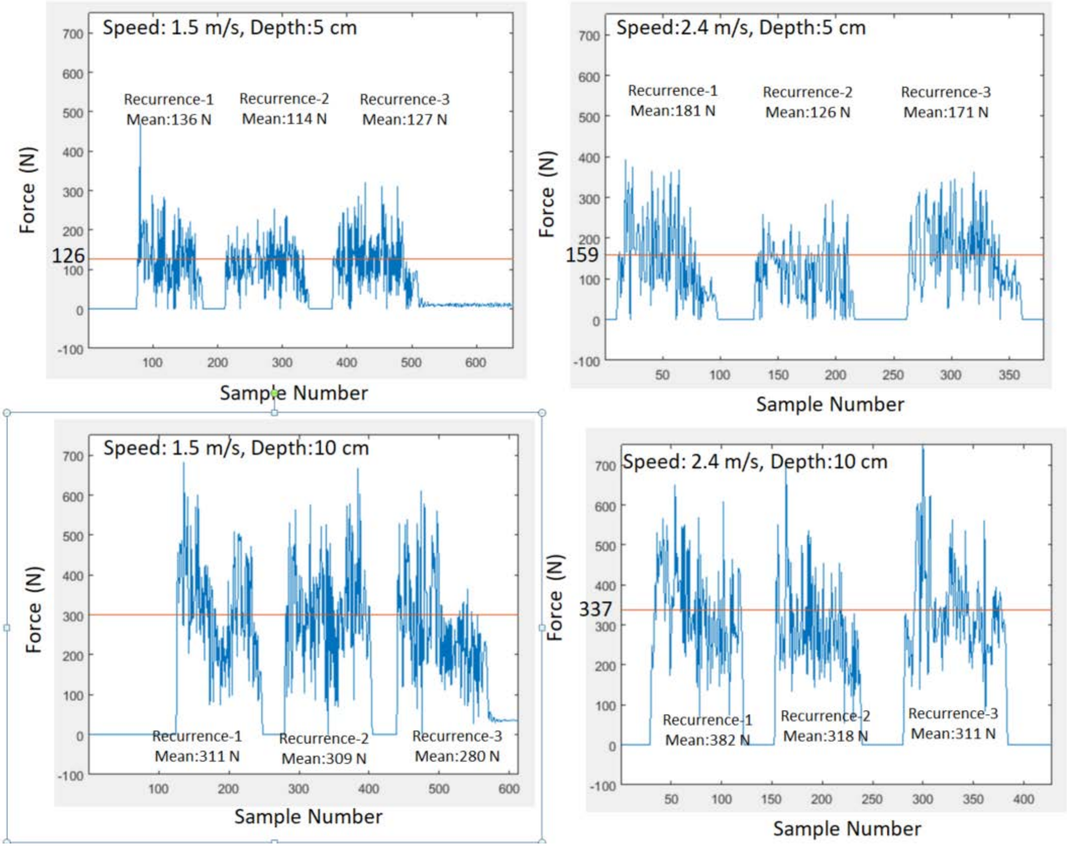


Fig. 9. Experimental results of S-Type Leg

In field tests with rigid leg Fig. 10, the average draft force for 5 cm depth and 1.5 ms^{-1} speed was 177 N and for 5 cm depth and 2.4 ms^{-1} speed was 222 N and for 10 cm depth and 1.5 ms^{-1} speed was 265 N, and for 10 cm depth and 2.4 ms^{-1} speed was 308 N. As a consequence, can be seen from the test results, that while tillage depth and the tractor speed increase then the draft force values also increase.

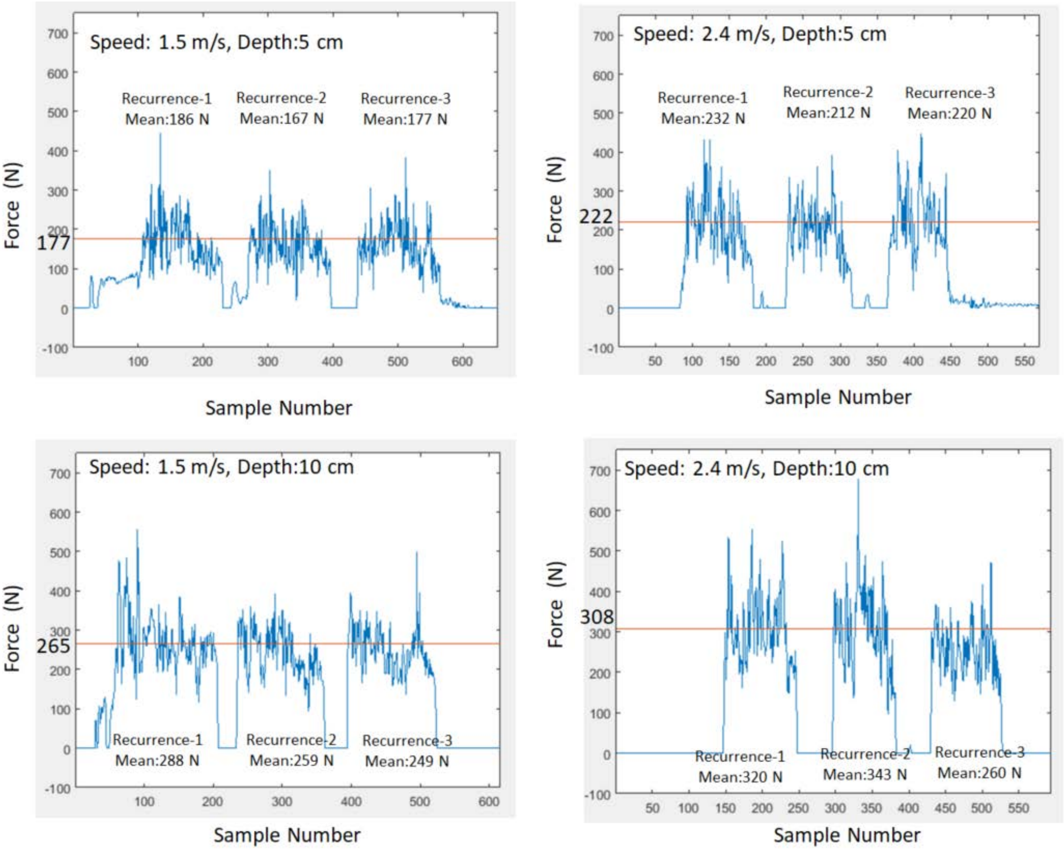


Fig. 10. Experimental results of Rigid Leg

In this thesis, a double ring octagonal element is used. The full-bridge Wheatstone bridge sensor signal was amplified by an amplifier and recorded on an SD card in the Arduino-based measurement system, and then the results were analyzed on the computer.
The Arduino software used in the thesis can be developed and the results can be analyzed and evaluated by disabling the computer.

Financial values of the main elements used in the system: Arduino Uno, 9,54 USD; LCD serial screen is 3,29 USD; SD card module, 0,53 USD; SD card, 0,56 USD; LM2596, 3,29 USD; 3 battery slots, 3,28 USD; 3 x 9V batteries, 1,43 USD; control panel box, 7,73 USD; 2 buttons, 1,11 USD; other consumable, $2.68; load cell amplifier is 9,72 USD, totaling 43,16 USD. The production cost of the octagonal element varies according to the number of productions. Estimated cost is 100 USD. The cost of 4 strain gauges is 24USD.

It is quite low compared to the cost of measurement system elements such as S-type force sensor and HBM Quantum data acquisition systems used in similar studies (Behara *et al.*, 2021).

CONCLUSIONS

Measurement of draft force in agricultural machines is important for design and improving tillage performance. There is an increasing trend developing smart agricultural machines.

Smart agricultural machines demand new sensor and measurement systems. Measuring draft forces for individual parts in tillage equipment can be used to improve tillage performance. Developing inexpensive measurement systems is important for implementing such approaches. In this study, an Arduino based measurement system for the draft force of an individual cultivator leg was developed. The Arduino-based force measurement system is a viable solution with open code software architecture during soil processing. No delay/read error was observed in data transfer. Determination of various and instantaneous resistances in soil cultivation was also possible with the help of this system. The total cost of the measuring system for obtaining leg's draft force was approximately 180 USD. This is very low value when compared to professional measuring system prices. The system consisted of an extended octagonal ring as the sensor. The octagonal rings have the capability of measuring the components of the draft force independently. It is possible to design octagonal rings with different geometric properties to increase the measurement sensitivity of the draft force. It was observed that the R-squared value of the proposed system is 0.9999. Example measurements were obtained successfully on a tractor in the field.

ACKNOWLEDGMENTS

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