

Instrumentation System for a Model Laboratory Soil Bin

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Received: 19-NOV-2022; Reviewed: 06-JAN-2023; Accepted: 05-FEB-2023

<http://doi.org/10.46792/fuoyejet.v8i1.958>

ORIGINAL RESEARCH

Abstract- Tool development and prime mover selection for optimum tillage operation require both the knowledge of soil and tillage tool interaction dynamics which is a function of some system parameters. The actual value of these parameters can only be determined either from field or soil bin experiment via appropriate instrumentation systems. Several published works have been reported on development of soil bin instrumentation system. However, development of a system that can measure and log all the required parameters simultaneously in real time remains an active area of research. The distance moved and the forces acting on the tool were sensed using potentiometer and load cells, respectively. The sensed parameters and the calculated tool linear velocity were processed in parallel using microcontroller with optimised code to ensure real-time and simultaneous logging. The developed system was used for measuring and logging the distance moved by the tool, its velocity as well as the x-, y-, and z- components of force, F_x , F_y , and F_z , acting on the tool. The values of the distance, velocity, and force determined at any time from the start of tillage operation are available on the charts of distance/velocity/force against time obtained from this work. 10 seconds from the start of tillage operation, the distance moved by the tool, tool velocity, F_x , F_y , and F_z are 2.56 m, 0.27 m/s, 147.00 N, 5.00 N, and 15.00 N, respectively.

Keywords- Instrumentation system, Microcontroller, Soil bin, Tillage tool, Transducer

1 INTRODUCTION

The draught and energy requirements for any tillage operation are a function of soil and tool interaction dynamics. Deep knowledge of draught and energy requirements are prerequisite in the tool development and selection of an appropriate prime mover for optimum tillage operations. Therefore, investigating the dynamic interaction between soil and tools is a necessity. This normally involves some machine characterisation parameters which can only be determined via suitable instrumentation systems. The most appropriate data collection method is to carry out field tests. However, to have control over some soil dynamic variables such as; moisture contents and bulk density (Ale, Ademosun, & Ewetumo, 2017) the use of soil bin most especially the indoor type is a popular practice.

This research area has been largely reported in literature (Ale *et al.*, 2017; Ale, Ademosun, & Ewetumo, 2019; Gebregziabher *et al.*, 2016). In their work, a load cell is employed for converting the draught on tillage tool to an equivalent electrical signal for logging but without considering distance moved by the tool and its velocity. A microcontroller-based draught measuring device which utilized load cell as force transducer was developed in (Adewumi & Theophilus, 2019). The device can only display the measured force, but without the facilities for measuring and logging the linear distance moved by the tool and velocity.

An instrumentation assembly developed in (Odey, Manuwa, & Ewetumo, 2018) measures the force on a tool at different depths using a load cell. The device was tested and the generated data were logged using a dedicated logger. Load cell of different ratings were proposed in (Agbetoye *et al.*, 2010) for the monitoring of the force on tool in the x, y, and z directions. Wheatstone bridge version of force transducers was directly used for force measurement while an optical encoder was adopted for distance and speed measurements in a virtual instrumentation system reported in (Boonmung, Eaton, & Jordan, 1999), however the system is fragile because of the nature of the components used.

In the work reported in (Mardani *et al.*, 2010), an inverter unit was used for controlling the speed of the tool carriage drive motor via a chain-driven system that can vary the speed of the motor in a wide range. The pull experience by tool carriage was measured using two S-shaped load cells located between the drive chains and carriage. An optical tachometer was employed for the carriage speed measurement and a dedicated data acquisition system was incorporated. The method used for speed sensing makes wheel slip detection difficult. In the experiment carried out by (Raheman & Snigdharani, 2020) the pull was measured using a S-type load cell attached between the guiding trolley and the drawbar. The angular velocity was measured using a tachometer, while the linear velocity of the wheel was determined using a proximity switch. The acquired data were logged into the HBM Quantum-X data acquisition system. To make use of the logged data, it must be downloaded via a computer which will give rise to additional cost.

Despite all these levels of instrumentation for both indoor and outdoor soil bins, the development of a system for the real-time measurements and logging of the distance

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Section B- ELECTRICAL/ COMPUTER ENGINEERING & RELATED SCIENCES
Can be cited as:

Ajiboye A.T., Yusuf A.O., Iyanda M.O. and Popoola O.J. (2023). Instrumentation System for a Model Laboratory Soil Bin, FUOYE Journal of Engineering and Technology (FUOYEJET), 8(1), 5-9. <http://doi.org/10.46792/fuoyejet.v8i1.958>

moved by the tool, velocity and the three components of force on the tool remains an active area of research. Therefore, in this study an instrumentation system for the measurement and logging of the distance moved by tillage tool, tool velocity, and forces on the tool is presented. The results show that the proposed system is capable of measuring and logging these parameters simultaneously in real time. The values of the parameters can also be determined graphically from the graphs of parameter versus time at any given time.

2 METHODOLOGY

2.1 SYSTEM OVERVIEW

The soil bin in this study is 8.00 m long, 1.00 m wide and 0.56 m deep. The tool operational speed is between 0.25 and 1.25 m/s while the tool operating depth is between 20 and 100 mm. Furthermore, the tool width of cut is between 10 mm and 50 mm. The system is expected to: measure the distance moved by the tool, calculate the tool linear velocity, measure the x, y, and z force components on the tool, and log both the measured and calculated parameters data simultaneously in real time. Therefore, the system is made up of a distance transducer, three force transducers, a microcontroller unit, an electric drive system and a speed controller. The block diagram of the system is shown in Fig. 1. The motor for the drive and its speed controller were procured as a unit each.

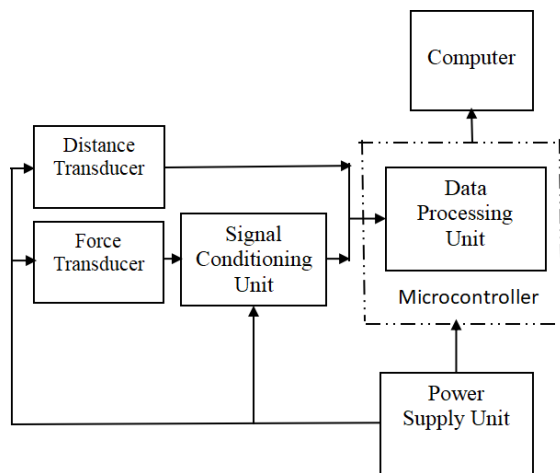


Fig. 1: Block diagram of developed soil bin instrumentation system

2.2 DISTANCE TRANSDUCER

The distance travelled by the tool was measured using potentiometer arrangement. The diagram of the potentiometer is shown in Fig. 2. With this connection the change in distance which results in a change in resistance can easily be converted to DC voltage ranging from 0 to V_c .

If the total length of the potentiometer wire in Fig. 2 is l and the change in length because of movement of slider from point 3 to point 2 is Δl , then

$$R_1 = \frac{\rho}{A} (l - \Delta l) \quad (1)$$

$$R_2 = \frac{\rho}{A} \Delta l \quad (2)$$

where ρ and A are resistivity and cross-sectional area of the wire respectively.

The model equation for the potentiometer distance transducer presented in equation (3) was obtained using equations (1), (2) and voltage divider rule.

$$\Delta l = l \frac{V_{out}}{V_c} \quad (3)$$

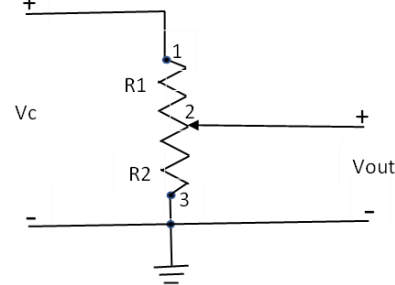


Fig. 2: The potentiometer

Based on the values of l , V_c , and V_{out} , microcontroller was programmed to calculate Δl . Since the length of the bin is 8 m with 1 m reserved for the parking of the carriage at both ends, then l is 6 m. Constantan wire was adopted as potentiometer in this study due to its ready availability, high specific resistance and low resistance-temperature coefficient. The gauge of the selected wire is standard wire gauge (SWG) 26 (0.42 mm diameter) with nominal resistance per meter of 4.9Ω (Wiltronics, 2015). With this per meter wire resistance, when l is 6 m and V_c is 5 V, the current through and power dissipated by the wire were determined to be 0.1701 Amp and 0.8503 Watt respectively. This power dissipation level can be accommodated by constantan wire without affecting its electrical and mechanical properties.

2.3 DETERMINATION OF TOOL VELOCITY

This requires only soft design, that is a programme that will extract the distance and time from the output of the distance transducer unit and the microcontroller clocking time respectively. Equation (4) gives the tool linear velocity, v .

$$v = \frac{l_{tool}}{t_{mc}} \quad (4)$$

where l_{tool} is the distance covered by the tool in metre, and t_{mc} is the time taken to cover the distance in second (in this study $t_{mc} = 1$ second).

2.4 FORCE TRANSDUCER

The value of the maximum average draught (200 N) in this study was estimated based on the method in (ASAE, 1999; Chandon & Kushwaha, 2002). Therefore, RSP1 20kg load cell was selected for sensing the x, y and z force components on the tool because of its high accuracy, ruggedness, good stability, excellent off-centre loading, ability to handle significant side load and easy to mount features (Sensors, 2021). Three load cells were mounted at right angle to each other on the linkage structure to measure the force in the x-direction (tool draught), y-direction (lateral force) and z-direction (vertical force). The arrangement of the three load cells on the linkage structure is shown in Fig. 3.

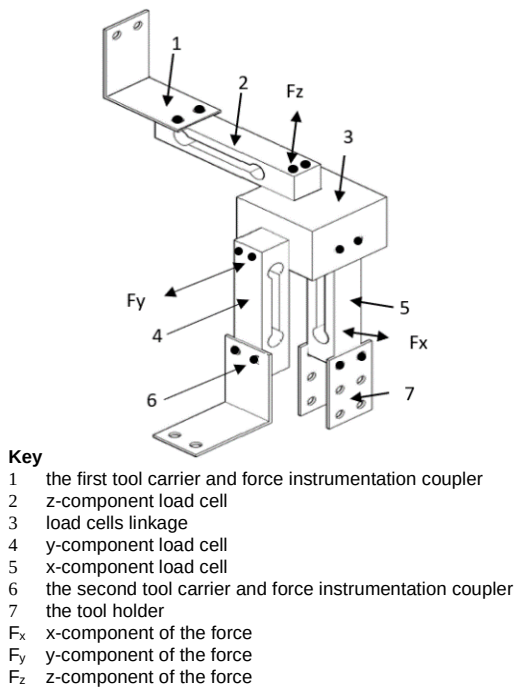


Fig. 3: Schematic diagram of the three load cells arrangement on the linkage structure.

HX711 load cell amplifier was selected to make the voltage from the load cell suitable as input to the Arduino microcontroller (Microcontrollers lab, 2022). The HX711 library was downloaded and added to Arduino Library folder to enable communication between the microcontroller and the load cell. Also, the source code was written in embedded C++ and uploaded into the microcontroller. It should be noted that the calibration factor which can be adjusted as required is embedded in the source code.

2.5 SYSTEM CALIBRATION

2.5.1 CALIBRATION OF THE POSITION SENSOR

To calibrate the potentiometer, a meter rule was used as the standard for graduating the potentiometer wire in metre. When the slider was put at a given position on the wire, the standard distance (l_{sd}) and the corresponding V_{out} were both recorded. These readings were recorded at 0.5 m interval with $V_c = 5V$ and $l = 6$ m. For better system accuracy, five different readings were taken; and the average was determined. The standard distance is the distance between point 2 and point 3 in Fig. 2.

2.5.2 CALIBRATION OF THE LOAD CELL

Load cell calibration is necessary to ensure reliable output. The HX711 library was added to the microcontroller IDE as earlier explained in Subsection 2.4. Then the load cell to be calibrated was loaded with a 10 kg weight and the calibration factor adjusted to make the reading on the display gives 10 kg.

2.6 POWER AND DRIVE UNIT

Considering the estimated draught of 200 N and maximum tool velocity of 1.25 m/s, the motor rating was estimated as 0.25 kW. Due to low cost, ruggedness and availability, a single-phase induction motor was selected. The speed of the tool carriage is controlled by varying the speed of the electric motor which is the prime mover using the speed controller. The frequency inverter selected for the speed control is EDS-A200-2S0004 which can carry 0.4 kW motor being the close approximate to 0.25 kW in the data sheet. The tool carriage can be both forward and reverse drive and stopped using the forward, reverse, and stop function on the speed controller. The electrical connection for the speed controller and the motor is shown in the schematic diagram of Fig. 4. Detailed information on EDS-A200-2S0004 and other series of the speed controller can be found in (ENC, 2016).

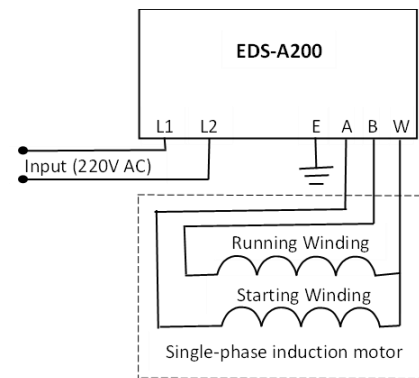


Fig. 4: Schematic diagram of the motor connection to the EDS-A200 series frequency inverter

2.7 SIGNAL AND DATA PROCESSING UNIT

The output voltage from the potentiometer was fed directly to the microcontroller for processing. While that of the three load cells were fed to the microcontroller via the load cell amplifier. Using equations (3) and (4) the distance covered by the tool and the corresponding tool velocity were determined by the microcontroller respectively. Also, the amplifier output voltage was converted to force by the microcontroller.

The distance, velocity, and force data were then formatted and logged to the personal computer via wire using serial communication protocol. However, the user can save the logged data as text, csv or excel file format which can easily be accessed using Notepad, MATLAB, or Microsoft Excel. The flowchart of the programme for executing the tasks by the microcontroller is shown in Fig. 5 for the distance and velocity, while that of the forces is shown in Fig. 6. Also, shown in Fig. 7 is the complete circuit diagram of the developed system.

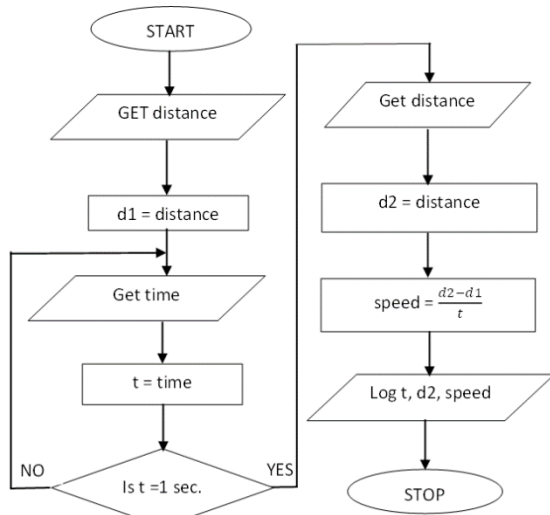


Fig. 5: The flowchart for the distance and velocity data processing programme

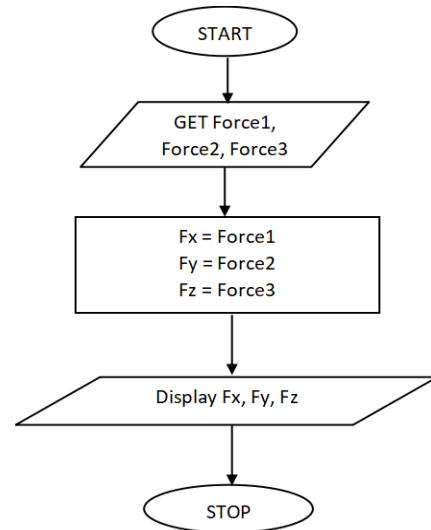


Fig. 6: The flowchart for the force data processing programme

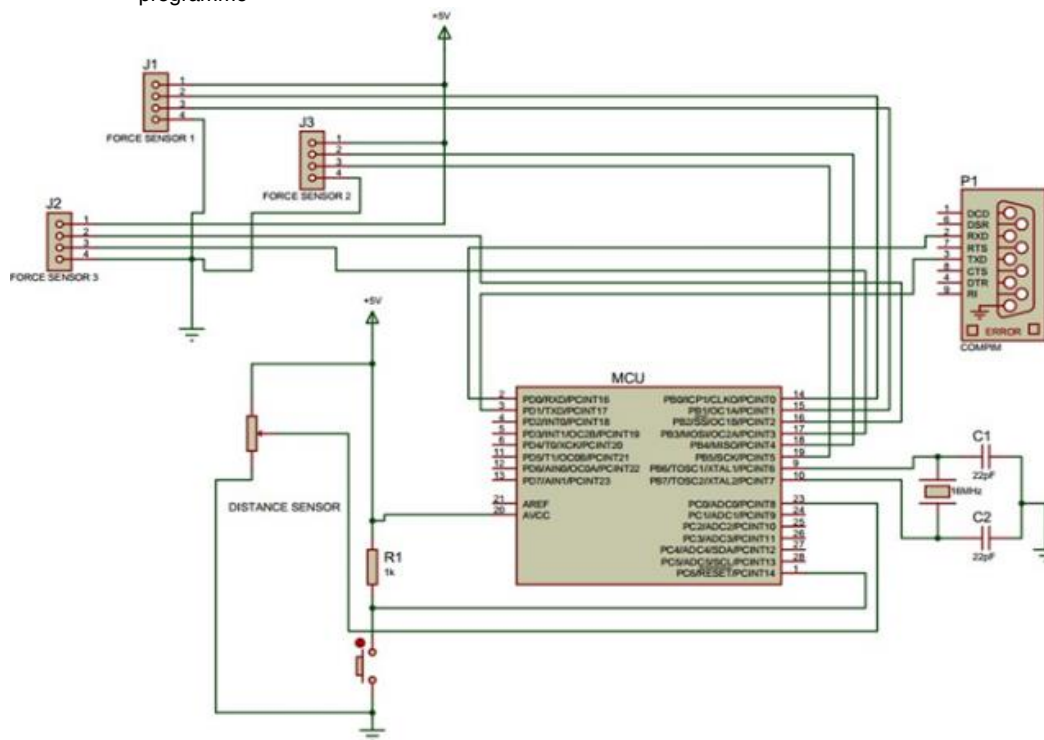


Fig. 7: Circuit diagram for the designed soil bin instrumentation system

2.8 SYSTEM TESTING

The photograph of the developed system is shown in Fig. 8. After dipping the tool into predetermined depth in the already prepared and conditioned soil, the tool was drove from the starting to the stopping end of the bin. Then the distance moved by the tool, the tool linear velocity, and the three force components on the tool were logged at 1 second interval into the laptop PC. For better results, the experiment was repeated 5 times and the average was determined.

3 RESULTS AND DISCUSSIONS

The potentiometer readings (the readings of l_{sd} and corresponding V_{out}) obtained in Subsection 2.5.1 were used for plotting the tool distance calibration graph shown in Fig. 9. The tool distance calibration equation

(Equation (5)) was obtained from Fig. 9 via curve fitting which gives coefficient of determination (R^2) of 0.9985 and then coded into the microcontroller for actual distance measurement.

$$l_{sd} = 0.012V_{out} - 0.00052 \quad (5)$$

Since the calibration procedure for the load cell was adequate as explained in Subsection 2.5.2, the generated data for F_x , F_y , and F_z would be reliable.

The plots of distance, velocity, F_x , F_y , and F_z versus time are shown in Fig. 10. It can be seen from this Fig. that at any given time, the distance moved by the tool, tool velocity and the tool force components can be determined.

**Key**

- 1 Motor speed controller cable
- 2 drive motor
- 3 instrumentation and tool holder
- 4 load cell linkage
- 5 x-direction load cell
- 6 tool
- 7 instrumentation and tool holder carrier
- 8 computer USB cable
- 9 soil bin.

Fig. 8: Photograph of the instrumented model laboratory soil bin

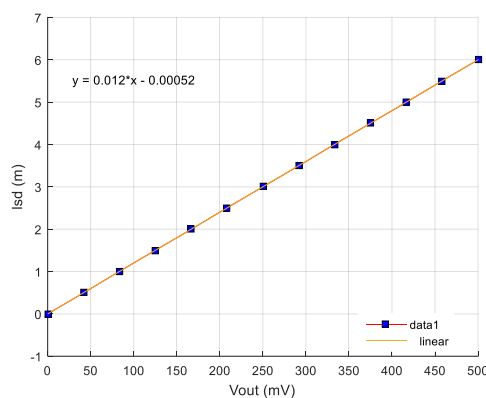


Fig. 9: Plot of standard distance vs. potentiometer output voltage

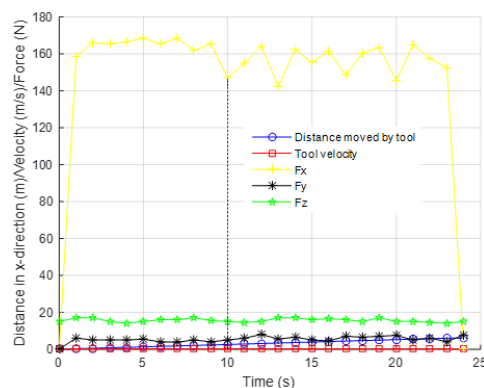


Fig. 10: Graph of tool dynamic parameters versus time

Using Fig. 10, it is possible to locate the point on the soil in the bin for a particular scenario of dynamic parameters for further examination. Since, the instantaneous values of all tool parameters can easily be determined from Fig. 10, then the characterisation of the soil and tool behaviour at any location along the tool path can be carried out with ease. For example, when time is 10 seconds, the distance moved by the tool, tool velocity, F_x , F_y , and F_z are 2.56 m, 0.27 m/s, 147.00 N, 5.00 N, and 15.00 N, respectively. The results clearly showed that the system will enable easy

characterisation of soil tool interaction dynamics in time and space along the tool path since all the required parameters will be available.

4 CONCLUSIONS

A system for measuring and logging the three tool parameters simultaneously in real time was developed: distance moved, linear velocity, and force. The developed system was appropriately calibrated via transducer calibration and then tested. The system can log the parameters' simultaneously in real time. The values of the system parameters can be determined at any time instance from the charts of distance/velocity/force against time. It can be concluded that the system will enable easy characterisation of soil tool interaction dynamics at any time and location along the tool path.

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