Development of Load Cell and Real-Time Force Measurement System

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***Abstract*—Todays force measurement systems have become very important for industry and agriculture. Load cells are widely used for measuring forces and also weighing to increase efficiency and effectiveness in many applications. With the help of advanced technology, more user friendly and robust force measurement systems need swiftly increasing to compensate production requirements.**

In this work we aimed to develop a robust system for real-time monitoring of force variations on the junction points of vehicles. Here, a three-dimensional (3D) force transducer and a real-time force measurement system have been developed to measure force variations on three-point linkage of tractors. The developed system provides real-time data transfer to computer via wireless communication (RF-Radio Frequency) for providing real-time monitoring of the processed field data.

Test results shows that the designed 3D force transducer has rated capacity (RC) 75 kN. and rated output (RO) for this transducer is 1/2100. This system has ability to acquire field data remotely and works around 5 km range. The developed system is also tested for sensitivity, accuracy and nonlinearity.

Keywords— Force Transducer; Dynamic Calibration; Load Cell; Wireless Communication

I. INTRODUCTION

There are many application areas in which load cells are used for determining forces applied to an object. One such environment is a weighing scale wherein the strain of a load cell is measured to determine the weight of an object that is placed on a load support [1].

A load cell includes a counterforce and at least one force transducer such as a strain gage. The counter is configured and inclined to support a load and to deflect in response [2]. It is a type of transducer that converts force into electrical signal. Load cells usually consist of four strain gauges in a Wheatstone bridge configuration as full bridge. Those strain gauge load cells are commonly used in industrial applications for sensing loads [3].

Load cells are sensors widely employed in industry to measure force or weight. In particular, they are employed in automatic weighing instruments such as checkweighers, catchweighers, weigh-price labellers, multi-head weighers. Since the performances of these machines are ever increasing (their rate of operation can overwhelm a hundred weighings per minute) and their size with costs are continuously decreasing [4].

Nowadays, force measurement systems have become very important for industrial and agricultural applications. Load cells are widely used to measure force and also for weighing in industry and agricultural applications.

In this work, a 3D force transducer and a real-time force measurement system has been developed to measure force variations on three-point linkage of tractors. Fig. 1 shows developed 3D force transducers and electronic units of the measurement system.

Figure 1: The Developed Force Measurement System

The aim of this study is to develop a robust system that provides us real-time monitoring force variances on the junction points of vehicles used in agricultural lands. Thus, load cells which sense force differences on three-point linkage are designed to sense 3D force variations. A measurement system was built in order to transfer field data to the computer via wireless communication.

The following factors are considered as design parameters:

- Real-time monitoring of field data,
- Graphical monitoring of field data,
- Robustness,
- Linear output,
- Dynamic calibration,
- Accuracy.

II. Material

A. Mechanics

Load cells are widely used in industrial instrumentation due to their low cost and high accuracy. Strain gauge load cells are commonly used for sensing force or load. This type of load cells is accurate within 0.03% to 1% [2].

Here the strain gauge load cells are used as a force transducer. Mechanic part of these transducers shown at Fig. 2 which are custom designed 3D force transducers used or sensing force variations in three dimensions.

Figure 2: Custom Designed 3D Force Transducers

B. Electronics

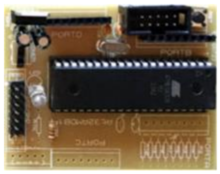
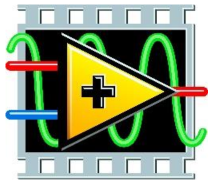
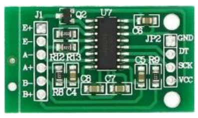
The electronic units acquire force variations on load cells and transfer acquired data to the PC. The developed measurement system has ability to collect field data remotely with using RF signals. A robust and reliable RF module [3] used to communicate between field units and remote units.

LabVIEW software was used to analyze and monitor acquired field data. The developed user interface has capability for monitoring factor, offset and force variation graphics for each transducer interactively.

MCU (Microcontroller Unit) used to acquire field data and transfer this data to the PC (Personal Computer). ADC (Analog Digital Converter) used for converting analog force values to digital numbers. USB (Universal Serial Bus) interface used to connect receiver RF module to PC.

Electronic components that used in this project are listed below with short descriptions:

Table 1: Electronic Components of the Measurement System

Electronic Unit	Model	Figure	Description
Wireless Communication	DRF7020D27		GFSK transceiver Module -27dBm 433Mhz transparent RF module.
Microprocessor	At32MDB01		We used our development board as a Data Acquiring Unit.
LabVIEW	LabVIEW Software		Graphical based Interface for monitoring of the field data
ADC	HX711 Module		24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales
USB to serial UART interface	FT232RL FTDI		USB to serial UART interface

III. Methods

A. Mechanics

Mechanic design parameters of 3-D Force Transducer for load cells considered as shown in Fig. 3.

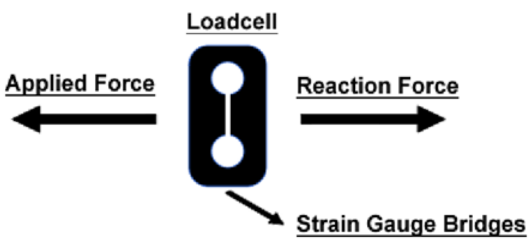


Figure 3: Force Equilibrium of the Load cells

B. Electronics

The 3D force measurement system has been developed to measure forces on three-point linkage with using load cells.

Here the developed system has three load cells, an ADC, an MCU, an RF Module and a PC. For sensing force variations on the three-point linkage the load cells were instrumented with strain gauges. For signal conditioning Wheatstone bridge were used on load cells. The analog voltage outputs on bridges are converted to digital by using 24 bit ADC. Digitalized values processed by the MCU and transferred to PC via RF signals. The PC provides us graphical monitoring the processed field data in real-time. The developed measurement system shown as a block diagram in Fig. 4.

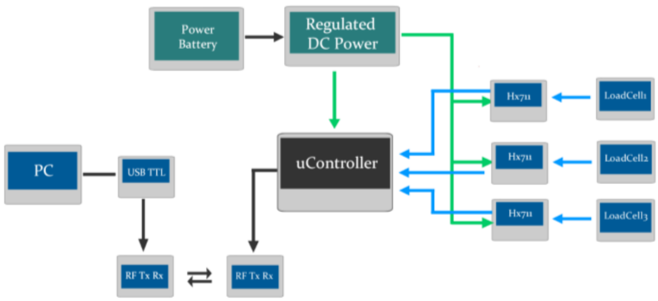


Figure 4: Block Diagram of the Measurement System

In this system, regulated DC power sources used for supplying bridges on load cells. Each load cells supplied separately with using a dedicated power unit. Analog signal generated on bridges of load cells collected with use 24 bit ADCs. Signals converted to digital by ADC and output transferred to microcontroller via serial communication. The microcontroller broadcasts the obtained information by using RF module. And the receiver part of the system receives the information for transferring to PC via USB.

In order to decrease noise on Load cells, regulated DC power source has been used for supplying Wheatstone bridge. And also for this purpose cable shields have been connected to the ground as shown in Fig. 5:

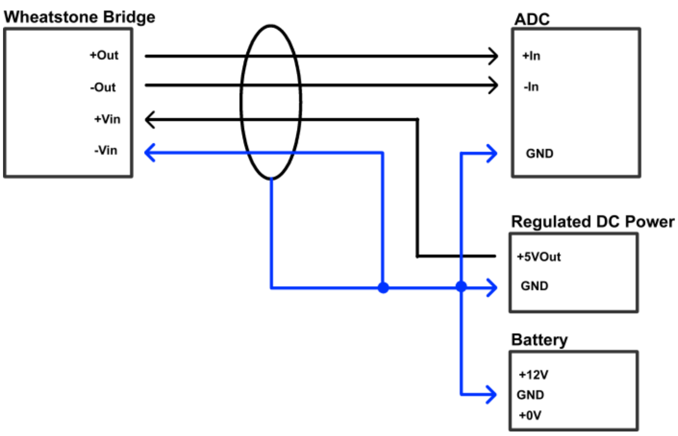


Figure 5: Shield Grounding for Noise Reduction

The developed system has a full bridge strain gauges shown in Fig 6. on load cells for thermal compensation. 5V excitation voltage used for supplying bridges and resistance of strain gauges is 120Ω.

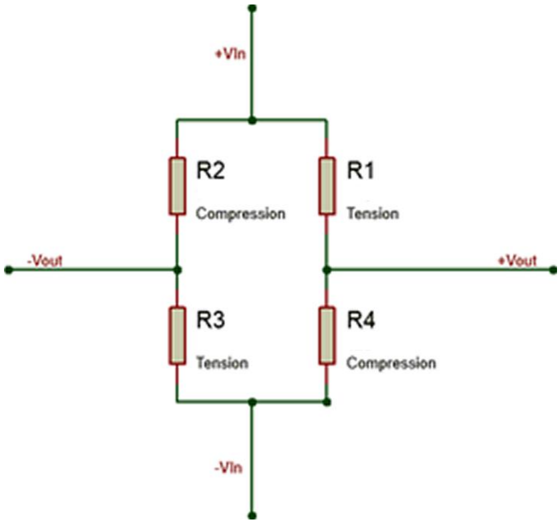


Figure 6: Wheatstone Full Bridge Circuit

In this study, before the electronic system and mechanical design part, theoretical calculations were made and upper – lower limit of measurement system were specified in order to obtain desired measurement range and step response.

In the direction of theoretical calculations, the characteristic of the mechanical transducer and electronic systems were made a decision that would be developed.

In design stage theoretical calculations are evaluated for full bridge strain gauge load cell. The result of these calculations shown at Table 2 and 3. This tables shows desired voltage output for minimum load and up to maximum load.

Table 2: Applied Force versus Tension & Compression

Weight (Kg.)	Tension	Compression	▲R (Ω-Tens.)	▼R (Ω-Comp.)
7000	1,44E-03	1,79E-03	0,34608000	0,42984000
5000	1,03E-03	1,28E-03	0,24720000	0,30720000
2500	5,15E-04	6,40E-04	0,12360000	0,15355200
1000	2,06E-04	2,56E-04	0,04944000	0,06141600
500	1,03E-04	1,28E-04	0,02472000	0,03072000
100	2,06E-05	2,56E-05	0,00494400	0,00614160
10	2,06E-06	2,56E-06	0,00049440	0,00061416
1	2,06E-07	2,56E-07	0,00004944	0,00006142

Table 3: Resistance versus Voltage Output

Active (Tens.)	Active (Comp.)	Active (Comp.)	Active (Tens.)	Result
R1(Ω)	R2(Ω)	R3(Ω)	R4(Ω)	Vout(V)
120,34608000	119,57016000	119,57016000	120,34608000	0,01617064
120,24720000	119,69280000	119,69280000	120,24720000	0,01155289
120,12360000	119,84644800	119,84644800	120,12360000	0,00577472
120,04944000	119,93858400	119,93858400	120,04944000	0,00230962
120,02472000	119,96928000	119,96928000	120,02472000	0,00115503
120,00494400	119,99385840	119,99385840	120,00494400	0,00023095
120,00049440	119,99938584	119,99938584	120,00049440	0,00002310
120,00004944	119,99993858	119,99993858	120,00004944	0,00000231

Calibrating Apparatus

BY801 Load cell model was used that manufactured by Baykon Company [7] for calibrating the designed 3D force transducers. The calibration system shown in Fig. 5. This apparatus has hydraulic pumps to set tension and compression. Applied force by apparatus can be investigated both transducers simultaneously.

Improved testing system was shown in the Fig. 5 in order to calibrate. In this mechanism, tension and compression forces are applied both load cells at the same time with using hydraulic pump and results can be read simultaneously. During the calibration stage, tension and compression tests were realized that each load cell was placed end to end in the test mechanism. 20 values were taken for each measurement when performing these tests. We recorded the acquired data from the both test mechanism and custom designed load cells. Obtained digital values and the corresponding real values, which were taken from test mechanism, were specified respectively for each load cell (L1, L2, and L3) as shown in the Graphs 1-8.

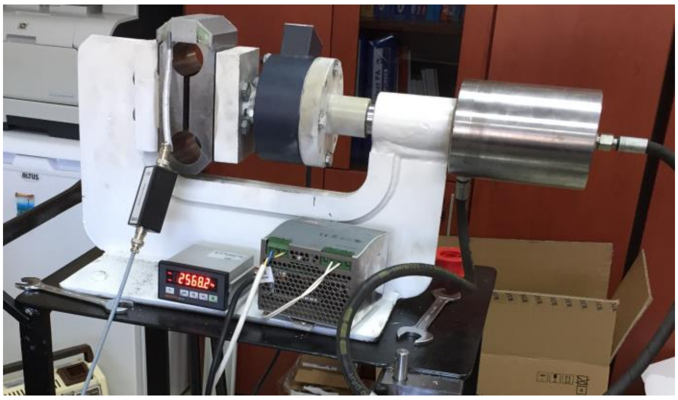


Figure 7: Hydraulic Test Apparatus for Determining Tension and Compression Coefficients

IV. RESULTS

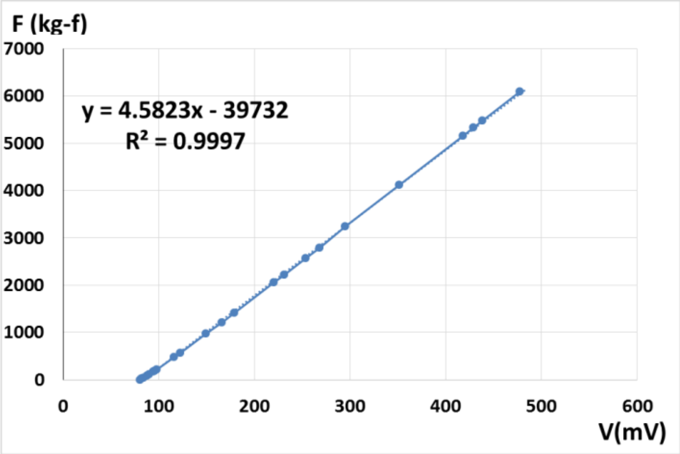


Figure 8: Load cell 1 Compression Test Results.

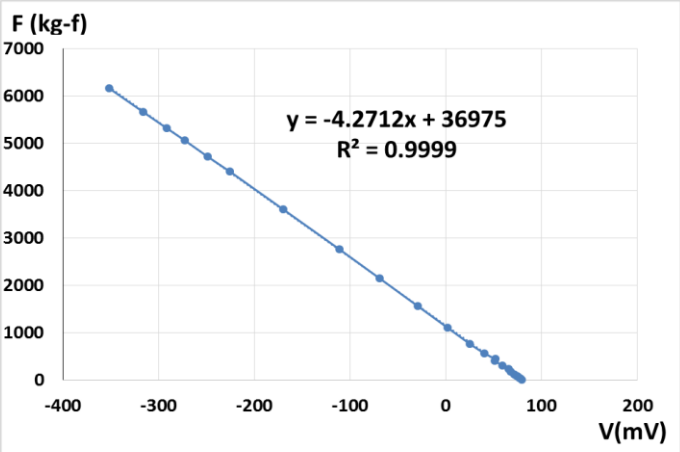


Figure 9: Load cell 1 Tension Test Results.

The calibration results for load cell 1 are given in Figures 8 and 9 for compression and tension, respectively. The R^2 values very close to 1 indicate high correlation between voltage and force. Here we can understand that there is a factor and an offset value for the calibrated load cell which is acquired from voltage values against force variations. The factor value of this load cell is 4.5823 and offset is minus 39732 and the force formula is y = 4.5823x - 39732 for compression. The factor value of this load cell is -4.2712 and offset is 36975 and the force formula is y = -4.2712x + 36975 for tension. Here y means force values in Kg. x means acquired voltage values of the load cell.

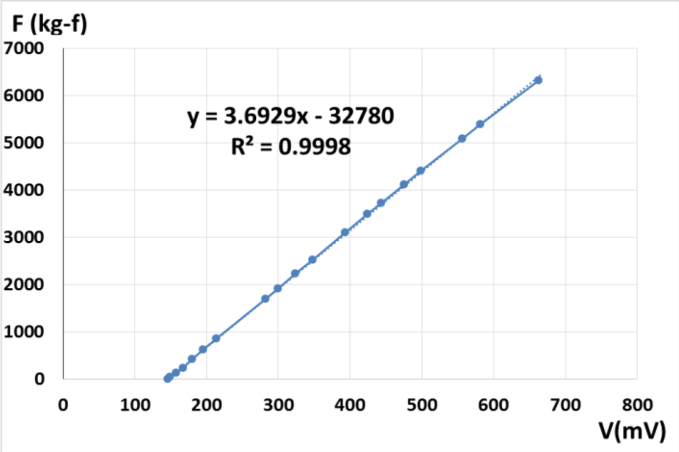


Figure 10: Load cell 2 Compression Test Results.

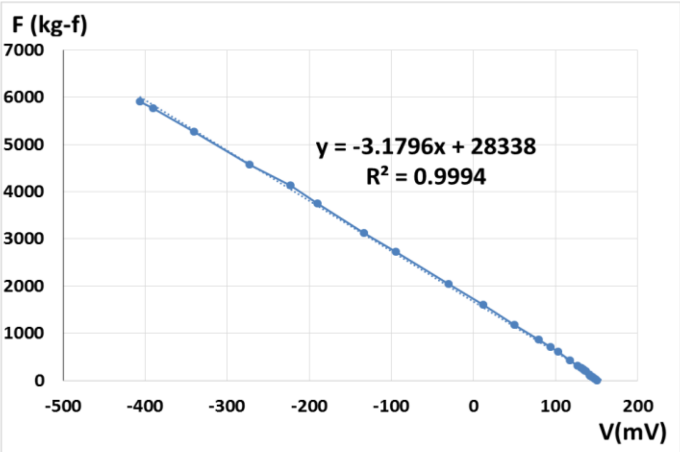


Figure 11: Load cell 2 Tension Test Results.

The calibration results for load cell 2 are given in Figures 10 and 11 for compression and tension, respectively. The R^2 values very close to 1 indicate high correlation between voltage and force. Here we can understand that there is a factor and an offset value for the calibrated load cell which is acquired from voltage values against force variations. The factor value of this load cell is 3.6929 and offset is minus 32780 and the force formula is y = 3.6929x - 32780 for compression. The factor value of this load cell is -3.1796 and offset is 28338 and the force formula is y = -3.1796x + 28338 for tension. Here y means force values in Kg. x means acquired voltage values of the load cell.

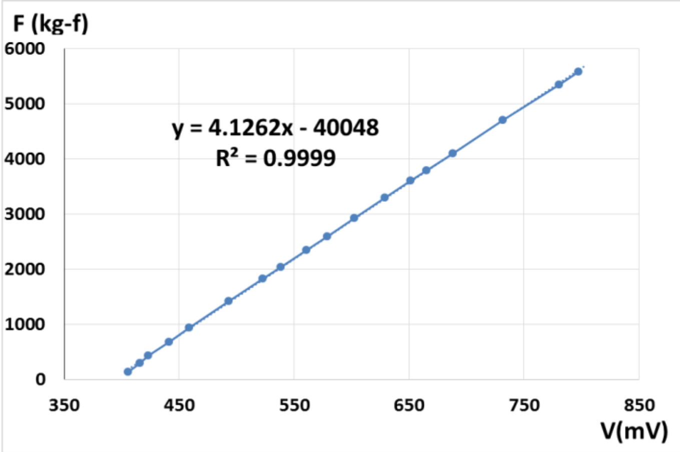


Figure 12: Load cell 3 Compression Test Results.

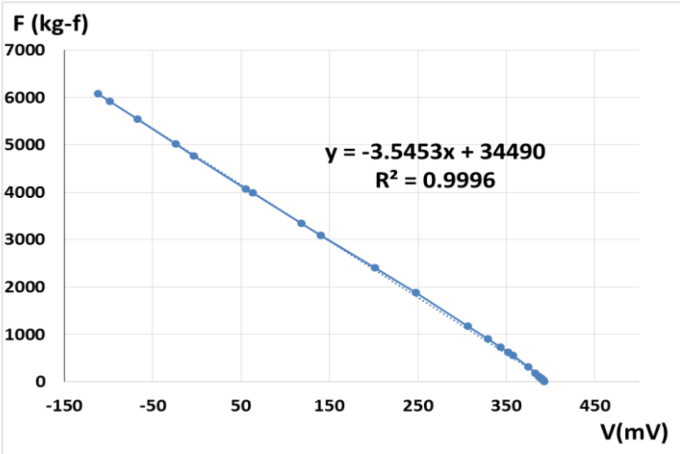


Figure 13: Load cell 3 Tension Test Results.

The calibration results for load cell 3 are given in Figures 12 and 13 for compression and tension, respectively. The R^2 values very close to 1 indicate high correlation between voltage and force. Here we can understand that there is a factor and an offset value for the calibrated load cell which is acquired from voltage values against force variations. The factor value of this load cell is 4.1262 and offset is minus 40048 and the force formula is y = 4.1262x - 40048 for compression. The factor value of this load cell is -3.5453 and offset is 34490 and the force formula is y = -3.5453x + 34490 for tension. Here y means force values in Kg. x means acquired voltage values of the load cell.

CONCLUSIONS

In this study a wireless force measurement system was developed. This system has ability to measure forces in three dimensions. Test results shows that the force measurement system has close results in compared to the commercially used load cell. Additionally, this system has ability to obtain field data with using wireless communication with a range of 5 km distance. Force measurement results can be monitored by graphic based program developed for this project.

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