
Development of an Arduino based universal testing apparatus

Geasa M. M.*

Faculty of Agricultural Engineering, Al-Azhar University, Assiut, Egypt

Abstract

The mechanical properties of agriculture materials are critically important for a wide range of applications such as packaging, transporting, sorting, ...etc. A simple mechanical testing apparatus using off-the-shelf materials and open-source software for a total cost of less than 1000 Egyptian pounds was fabricated. The device consists of a steel frame supporting a stepper motor and its cooling fans, apart for converting motor rotary motion to linear motion, drill chuck fixed to screw that move linear motion, stage to place the tested sample and load cell to determine the force. To perform a mechanical test, a sample is placed on the base of the frame and the load cell. The required force is applied by the stepper motor; many types of grips can be fixed in the drill chuck. moving the main shaft down leads to pressing the sample. The displacement (deformation) precisely controlled by controlling step of stepper motor in the code of the program, while recording the force (measured by a load cell) in a SD card memory and also in a computer serial monitor. The load cell and stepper motor are linked to an Arduino microcontroller connected to a laptop through a USB port for data acquisition and analysis. NEMA 23 stepper motor can holding torque up to 19 kg-cm witch fit testing many of agriculture materials This device was easy to assemble. Because of its low cost and ease of use, this Arduino-based universal material tester can be an acceptable device to introduce the concepts of mechanical properties, among other concepts, to researchers in numerous fields.

Keywords: universal testing machine, Arduino, mechanical properties, rupture force and deformation.

*Corresponding author: Geasa M. M.,
E-mail address: m.geasa@gmail.com

1. Introduction

The mechanical properties of agriculture materials, including mechanical stress, are critical in determining a material's suitability for different applications. Universal material tester is the most common procedure used to measure these mechanical properties, it is suitable for testing wide range of material for bending, compression, tension and shearing. Which include the Young's modulus, yield strength, and ultimate tensile strength, among others. Commercial universal material tester is highly accurate, but their cost and size make them unavailable for many researchers Furthermore, they often require costly proprietary software to operate with restrictive software licensing agreements. Not commercially available or otherwise too expensive Hardware /software systems recently made by open-source electronics Among them, Arduino has already taken its place in controlling scientific hardware for research purposes. The search objective was to develop an inexpensive and portable mechanical tester that could be used for accurate measuring of mechanical properties. Because of its flexibility, ease of use, wide range of successful applications, and low cost, Arduino microcontroller used to develop the tester, combining it with simple available components. Arduino microcontroller has already proven effective in controlling scientific hardware for research purposes, an electronic inexpensive and portable mechanical tester that could be used for accurate measuring. Because of its flexibility, low cost, ease of use, and wide range of successful applications. Duarte *et al.* (2019)

developed an innovate device for mechanical tests in membranes under the modality biaxial tension: torsion, the device has environmental parameters control (temperature and relative humidity). The device is simple and is built with a low cost, All the code for the system control is written in a free and open-source software (Arduino). Simbeye (2016) designed electronic universal testing machine control system and realized basing on the analysis of the related technologies and requirements. his system solves the determination of mechanical properties of materials such as tensile, elongation, force, deformation and displacement of essentially all metallic and non-metallic materials and it assumes good performance. Macedo *et al.* (2018) reported that Arduino microcontroller is an open-source electronics platform, now it is the brain of thousands of projects, from common objects to complex scientific instruments. The most used and documented board is the UNO, so that, it has been selected to control this device. UNO is based on the ATmega328P controller, with 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, and a reset button providing enough specifications to cover the needs. Jarkovsky *et al.* (2018) proposed an experimental device to determine the elastic tensile and compressive modulus of materials simultaneously through the deformation and displacement measurement in the split test. Arduino platform used to electronics controlling in experimental device. Kaswan *et al.* (2020) mentioned that Arduino is very easy to use, powerful single board computer and open-

source programmable board. It that has gained a lot of popularity in the hobby and professional market. It is containing an Integrated Development Environment (IDE) to write and run the programs, program is known as sketch in Arduino and a microcontroller. Arduino boards are able to read inputs like light on a sensor, a finger on a button, or temperature and turn it into an output -run a motor, turning on an LED, or else. they also added that Arduino UNO is the commonly used board that is also known as classic Arduino. Uno board has a USB connection, 14-digital I/O pins, where 6-pins can be used as PWM, 6-analog inputs, a reset button, a power jack, and more.

2. Materials and methods

2.1 Design and construction

The testing device was designed to determine the stress-strain curves of various materials including many of agriculture products such as fruits and vegetables. Figure (1) shows the developed apparatus. The testing device is composed of four main parts:

1. The main frame includes two rectangular bases with 25 cm wide, 23 cm length, and 0.5 cm thickness, and four 60 cm vertical parallel screw columns with its nuts used to support and control. the device height Figure (2a) shows a 3D illustration of the designed device.
2. The drive system consists of stepper motor and its circuit. NEMA 23 stepper motor was used for its specification like it is a high torque (19 kg-cm) hybrid bipolar stepper motor with a 2.3 × 2.3-inch (This

is where its name NEMA 23 came from) faceplate. This motor has a step angle of 1.8 deg., this means that it has 200 steps per revolution and for every step it will cover 1.8°. By using a stepper motor driver TB6600; the number of motor steps, speed of rotation, and direction of rotation were fully controlled. The TB6600 stepper motor driver is a powerful and professional driver with 4.5A operating current (5A peak) and voltage range from 8 to 42V. It is easy to use and combatable with micro-controllers including Arduino. Figure (3) shows a stepper motor used circuit.

3. The movable crosshead electro mechanical linear actuator was made to convert stepper motor rotary motion into linear motion. The used mechanism includes the lead screw driven by stepper motor, rotating of screw tends to the fixed nut moves in a straight line up and down according to stepper motor rotational direction; another screw was fixed in the nut to transmit stepper motor force to study sample, a straight-line movable screw has at its end drill chunk so many shapes of grips can be used as shown in Figure (2b).

4. The load cell and its circuit A load cell is a transducer that can translate pressure (force) into an electrical signal. a strain gauge load cell used, which is a mechanical element of which the force is being sensed by the deformation of several strain gauges on the element. In bar strain gauge load cells, the cell is set up so that torque is applied to the bar and the four strain gauges on the cell will measure the bending distortion, two measuring compression and two tension.



Figure (1): developed apparatus picture.

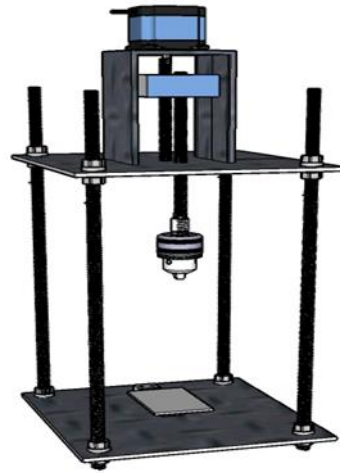


Figure (2a): 3D illustration of the designed device.



Figure (2b): the movable crosshead and mechanical linear actuator.

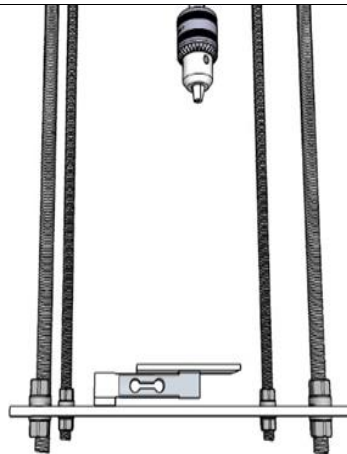


Figure (2c): Installing a weight cell in the frame.

When these four strain gauges are set up in a Wheatstone bridge formation, it is easy to accurately measure the small changes in resistance from the strain gauges. In most load cells and weight sensors the output range of a strain gauge is very small and thus the signal needs to be amplified before processing to prevent

introduction of errors. Load cell amplifier - HX711 used for amplifying the weight sensor and converting its analog sensor to digital one, therefore increasing the measurement accuracy. SD module used as data logger; Figure (2c) shows how a load cell fixed in apparatus frame and Figure (4) shows a load cell circuit.

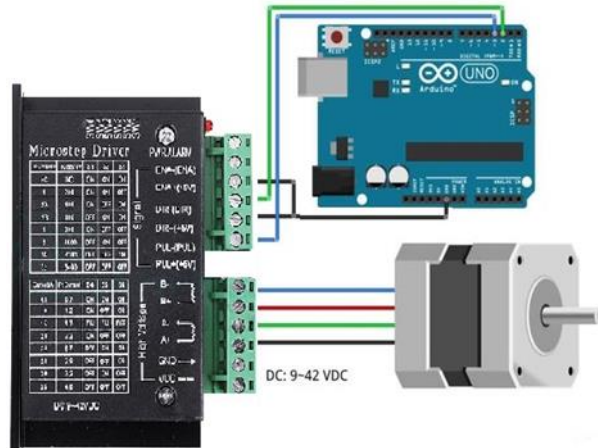


Figure (3): Stepper motor circuit diagram.

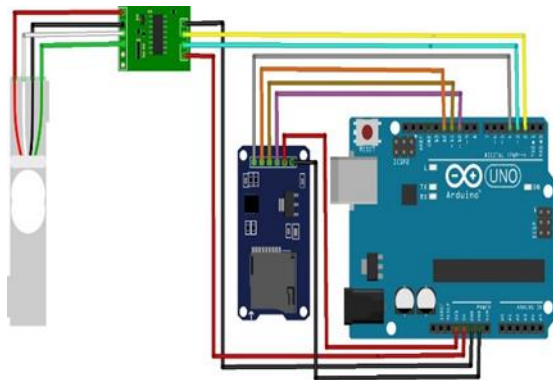


Figure (4): Load cell circuit diagram.

2.2 Description of the testing procedure

The testing equipment and procedure used was electromechanical device which uses a combination of a motor and screw reduction system to move a crosshead up and down to provide force to the sample. The speed of the stepper motor controls the speed of the crosshead. Different grips may attach to the crosshead. Depending on the material, geometry and strength of

test specimens, grips are selected accordingly. For example, in tensile testing, the specimen is held securely in the upper grip and lower at the load cell fixed on base plate of the load frame. In compression testing, selected grip fixed on drill chunk to apply loads to the specimen which is placed on the plate fixed on load cell. It must be taken into consideration load cell capacity (which can be changed according to the required

capacity) in compression testing. The device is capable of testing samples up to 30 cm of length and up to 15 cm of wide.

2.3 Experimental

The core of the developed apparatus is based on a Screw-Driven Linear Actuator System with a moving sledge. Moving sledge end connected with drill chunk where can custom-made grips can be attached on it. Load cell fixed on bottom base plate under moving sledge both of which are carefully aligned to each other. The developed apparatus described here is designed with a 100 N load cell. The sled is driven with a NEMA 23 stepper motor and controlled by a stepper motor driver TB6600 connected to custom designed electronics. The calibration of the load cell was conducted by collecting data of different known applied loads (weights) and measuring its corresponding output readings. A series of calibrated loads were applied to obtain the equation describing this relationship. After setting the load cell and SD card reader connections as shown in Figure (4), Used sketch as following read the force from load cell and record readings into text file named "test.txt" storage in SD card. Code explanation appears after remark sign // in the code

```
#include "HX711.h"
#include <SPI.h>
#include <SD.h>
File myFile;
const int LOADCELL_DOUT_PIN = 2;
const int LOADCELL_SCK_PIN = 3;
```

```
HX711 scale;
void setup() {
  Serial.begin(9600);
  Serial.println("HX711 Demo");
  Serial.println("Initializing the scale");
  scale.begin(LOADCELL_DOUT_PIN,
  LOADCELL_SCK_PIN);
  Serial.println("Before setting up the
  scale:");
  Serial.print("read: \t\t");
  Serial.println(scale.read()); // print a raw
  reading from the ADC
  Serial.print("read average: \t\t");
  Serial.println(scale.read_average(20)); //
  print the average of 20 readings from the
  ADC
  Serial.print("get value: \t\t");
  Serial.println(scale.get_value(5)); // print
  the average of 5 readings from the ADC
  minus the tare weight (not set yet)
  Serial.print("get units: \t\t");
  Serial.println(scale.get_units(5), 1); //
  print the average of 5 readings from the
  ADC minus tare weight (not set) divided
  // by the SCALE parameter (not set yet)
  scale.set_scale(2280.f); // this value is
  obtained by calibrating the scale with
  known weights; see the README for
  details
  scale.tare(); // reset the scale to 0
  Serial.println("After setting up the
  scale:");
  Serial.print("read: \t\t");
  Serial.println(scale.read()); // print a raw
  reading from the ADC
  Serial.print("read average: \t\t");
  Serial.println(scale.read_average(20));
  // print the average of 20 readings from the
  ADC
```

```
Serial.print("get value: \t\t");
Serial.println(scale.get_value(5)); // print
the average of 5 readings from the ADC
minus the tare weight, set with tare()
Serial.print("get units: \t\t");
Serial.println(scale.get_units(5), 1); //
print the average of 5 readings from the
ADC minus tare weight, divided
// by the SCALE parameter set with
set_scale
Serial.println("Readings:");
while (!Serial) {
}
Serial.print("Initializing SD card...");
if (!SD.begin(10)) {
Serial.println("initialization failed!");
while (1);
}
Serial.println("initialization done.");
// open the file.
myFile = SD.open("test.txt",
FILE_WRITE);
// if the file opened okay, write to it:
if (myFile) {
Serial.print("Writing to test.txt...");
myFile.println("This is a test file :)");
myFile.println();
// close the file:
myFile.close();
Serial.println("done.");
} else {
// if the file didn't open, print an error:
Serial.println("error opening test.txt");
}
}
void loop() {
Serial.print("one reading:\t");
Serial.print(scale.get_units(), 1);
Serial.println();
```

```
myFile = SD.open("test.txt",
FILE_WRITE);
myFile.print("one reading:\t");
myFile.print(scale.get_units(), 1);
myFile.println();
myFile.close();
delay(10);
}
Used stepper motor typically has a step
angle of 1.8° it means full revolution 360°
done by 200 steps
Used sketch as following controls both the
speed, the number of revolutions, the
spinning direction of the stepper motor
and the time of press on the sample.
#define dirPin 2
#define stepPin 3
#define stepPerRevolution 200
void setup() {
// Declare pins as output:
pinMode(stepPin, OUTPUT);
pinMode(dirPin, OUTPUT);
}
void loop() {
// Set the spinning direction clockwise:
digitalWrite(dirPin, HIGH);
// Spin the stepper motor 10 revolution
slowly:
for (int i = 0; i <10* stepPerRevolution;
i++) {
// These four lines result in 1 step:
digitalWrite(stepPin, HIGH);
delayMicroseconds(2000);
digitalWrite(stepPin, LOW);
delayMicroseconds(2000);
}
delay(1000);
// Set the spinning direction
counterclockwise:
```

```
digitalWrite(dirPin, LOW);  
for (int i = 0; i < 10 * stepPerRevolution;  
i++) {  
  // These four lines result in 1 step:  
  digitalWrite(stepPin, HIGH);  
  delayMicroseconds(2000);  
  digitalWrite(stepPin, LOW);  
  delayMicroseconds(2000);  
}  
delay(1000);  
}
```

2.3 Code explanation

After setting the stepper motor connections as shown in Figure (3), and defined a `stepPerRevolution` constant the driver set to a standard 200 steps per revolution stepper motor. In the `loop()` section of the code, the motor spin 10 revolutions slowly in the CW direction and 10 revolution in the CCW direction. one motor revolution tends to move the device grip 1 mm up or down depending on the motor turn CW or CCW. To control the spinning direction of the stepper motor we set the DIR (direction) pin either HIGH or LOW. For this we use the function `digitalWrite()`. Depending on how you connected the stepper motor, setting the DIR pin high will let the motor turn CW or CCW.

2.3.1 Control number of steps or revolutions

The four loops control the number of steps

the stepper motor will take. The code within the for-loop results in 1 (micro)step of the stepper motor. Because the code in the loop is executed 200 times (`stepPerRevolution`).

2.3.2 Control speed

The speed of the stepper motor is determined by the frequency of the pulses we send to the STEP pin. The higher the frequency, the faster the motor runs. You can control the frequency of the pulses by changing `delayMicroseconds()` in the code. The shorter the delay, the higher the frequency, the faster the motor runs. In order to test the developed apparatus crosshead displacement, and the applied load, a specific experiment was conducted by compression testing by using unshelled peanut samples; samples divided into three groups; groundnut pods with one kernel; two kernels and three kernels were randomly selected from the local market every group containing 30 pods, and their three principal dimensions, were measured. After that each pod tested in the developed apparatus to determine a stress–strain data which represents the behavior of a peanut sample during mechanical testing. By using stepper motor rotational speed 18.5 rpm and screw thread step 1mm the linear speed of sledge was 0.31 m/s. Strain was measured simultaneously by the machine crosshead displacement and by a load cell recorded force.

3. Results and Discussion

3.1 The peanut pods three axial dimensions

The values of pods length (L) ranged from 32.9 to 49.8 mm with a mean value of 41 ± 9 mm. The values of width (W) ranged from 23.65 to 13.55 mm with a mean value of 19.9. The values of the thickness (T) ranged from 6.75 to 12 mm with a mean value of 9.9 as shown in Table (1). Table (1) also shows a standard deviation

in the pods thickness (T) at low value compared with standard deviation of other axial dimensions it means that its data was clustered around the mean, on the other hand standard deviation value of pods length (L) was higher than other dimensions it means its data are more spread out. The coefficient of variation values for three axial dimensions almost the same as shown in Table (1) it means the dispersion of the data points in the data of three axial dimensions around the mean value was almost similar.

Table (1). Peanut pods axial dimensions.

	Maximum	Mean	Minimum	S.D.	C.V. (%)
Length	49.8	41	32.9	4.9	11.9
Width	23.65	19.902	13.55	2.2	10.9
Thickness	12	9.8824	6.75	1.1	10.7

Figure (5) shows the frequency distribution curves of three axial dimensions of peanut pods (L, W, and T). The highest frequencies of L, W and T were 18 % at (36.3 – 38 mm), 56 % at (9–11 mm) and 31% at (9–10 mm), respectively.

3.2 Rupture force and deformation

The results of the rupture force and deformation are presented in Table (2). The results showed that the rupture force and deformation differed in three groups.

The pods contain one seed has lower rupture force and deformation values. On the other hand, the pods contain three seeds have higher value of rupture force and deformation. This finding indicated that more pod seeds need to more energy for hull rupture. But, at the same time, it played an important role for storage. Compared the results in table 3 with previous studies like Bagheri *et al.* (2011), Hongmei *et al.* (2016), Choudhary *et al.* (2020), Uguru *et al.* (2020) and others, show great compatibility, which leads to approve the readings of the developed apparatus.

Table (2): Rupture force and deformation.

Properties	Number of pods	Maximum	Minimum	Mean	S.D.	C.V. (%)
Deformation, mm	One	2.16	0.77	1.39	0.40	52.49
	Two	2.62	1.23	1.90	0.46	37.29
	Three	5.86	2.47	3.96	1.21	49.04
Rupture force, N	One	71.34	31.29	54.03	13.03	41.65
	Two	86.26	41.33	56.41	15.11	36.56
	Three	88.43	33.50	64.85	21.36	63.76

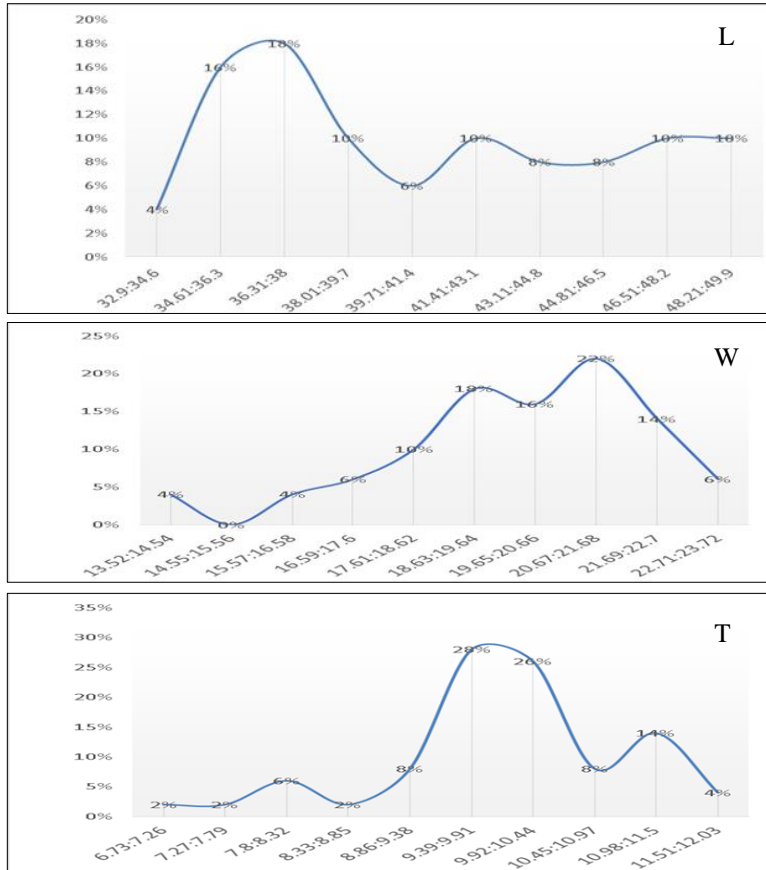


Figure (5): The frequency distribution curves of three axial dimensions pods length (L), width (W) and thickness (T) (dimension in mm.).

4. Conclusion

A low cost (below 1000 Egyptian pounds) tabletop universal testing machine has been demonstrated. All mechanical design, electronic circuits, and programming algorithms are accessible, customizable, and sourced locally. The simplicity and flexibility of the Arduino platform suggests that this is a practical, accurate system for hands-on demonstrations for the determination of the mechanical

properties of several different materials. Specimens can potentially be different types of materials including most of agricultural materials. The performance of apparatus is benchmarked by using a real data and compared with many references; the results are quite acceptable. These results should encourage the continued development of low-cost laboratory equipment for materials characterization, which may reduce the cost in materials research.

References

- Arduino - Home (2021), Available at: <https://www.arduino.cc/> (Accessed: 22 Jan 2021).
- Arrizabalaga, J. H., Simmons, A. D. and Nollert, M. U. (2017), "Fabrication of an economical arduino-based uniaxial tensile tester", *Journal of Chemical Education*, Vol. 94 No 4, pp. 530–533.
- Bagheri, I. Payman, S. H. and Ajdadi, F. R. (2011), "Mechanical behavior of peanut kernel under compression loading as a function of moisture contents", *Elixir Agriculture*, Vol. 36, pp. 3552–3557.
- Choudhary, V., Machavaram, R., Ravi, V. and Shankar, S. R. (2020), "Engineering properties of groundnut pods and kernels: a key role for designing the post-harvest processing equipment", *International Journal of Current Microbiology and Applied Sciences*, Vol. 9 No. 8, pp. 1751–1761.
- Duarte, L. M. Almaraz, G. M. Pacheco, C. J. and Tello, I. F. (2019), "Construction of a machine for biaxial mechanical tests: tension and torsion, destined to membrane materials", *International Journal of Mechanical and Production Engineering*, Vol. 7, pp. 2321–2071.
- Jarkovsky, R. and Rokitanského, C. (2018), "Testing device for tensile test based on Arduino", *WSEAS Transactions on Systems and Control Archive*, Vol.13, pp. 568–572.
- Kaswan, K. S. Singh, S. P. and Sagar S. (2020), "Role of Arduino in real world applications", *International journal of scientific and technology research*, Vol. 9, pp. 1113–1116.
- Macedo, S. Í., Lorza, R. L., Bobadilla, M. C., Gómez, F. S. and Cambero I. E. (2018), *Development of an Arduino based DAQ system to operate laboratory testing machines*, 10th International Conference on Education and New Learning Technologies Edulearn18 Proceedings, pp. 6324–6329.
- Simbeye, D. and Simbeye, D. S. (2016), "Computerized measurement and control system of the universal testing machine based on virtual instruments", *Journal of Information Sciences and Computing Technologies*, Vol. 5 No. 2, pp. 456–465.
- Uguru, H., OI, A. and OJ, I. (2020), "Fracture resistance of groundnut (cv. SAMNUT 11) kernel under quasi-static compression loading", *Scholars Journal of Engineering and Technology*, Vol. 8, No. 1, pp. 1–8.
- Xu, H. Yan, S. and Huang, Q. (2011), *Research on the effects of mechanical and physical characteristics on peanut shucking*, 5th Computer and Computing Technologies in Agriculture (CCTA), Beijing, China, pp. 603–611.