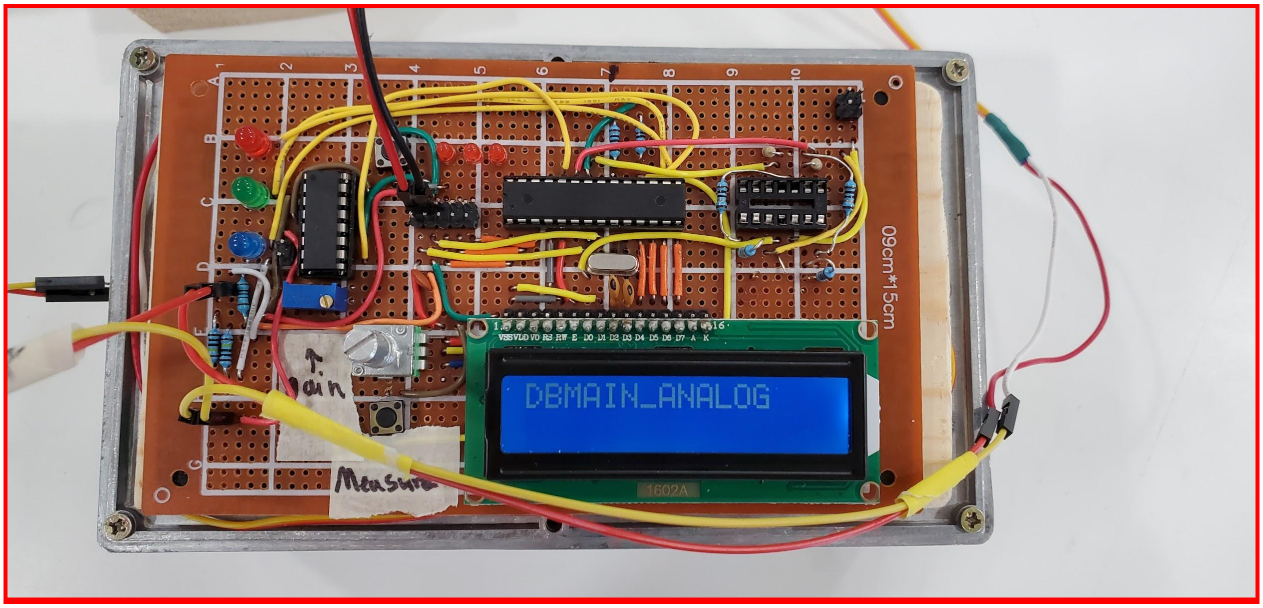
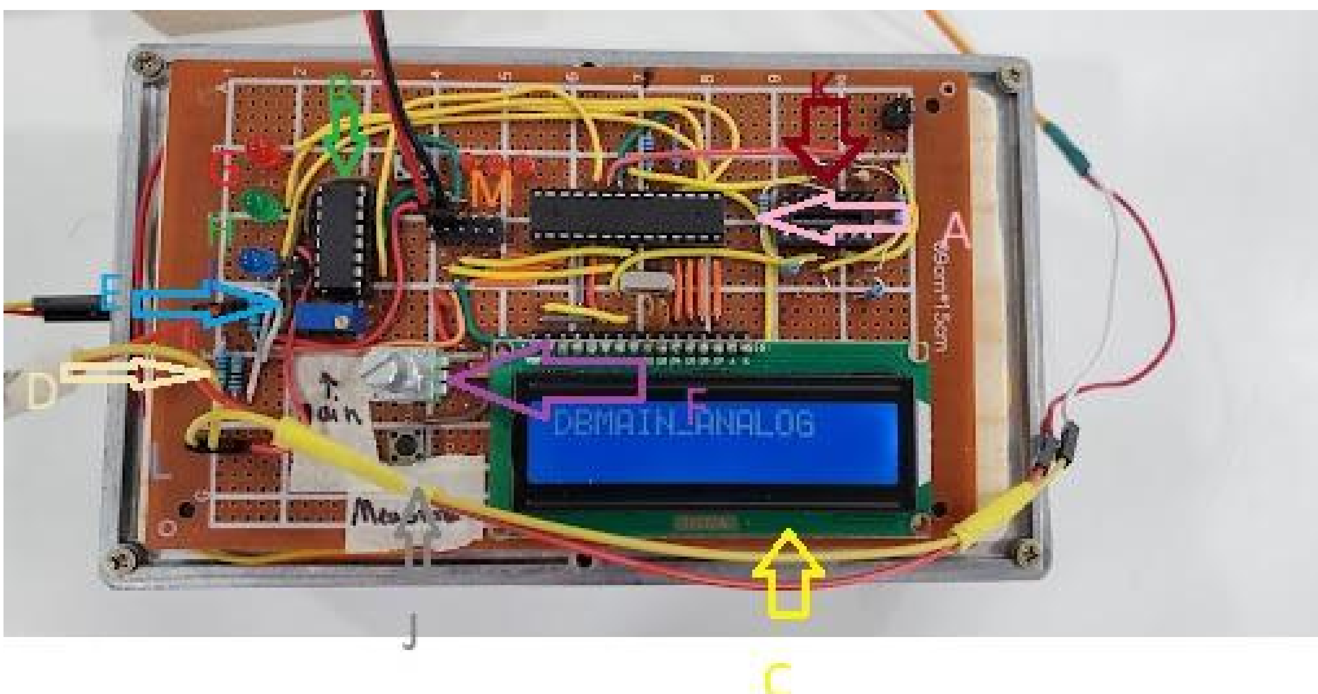
Stuyvesant High School B
Team #27

Columbia Invitational 2023
Detector Building Design Log

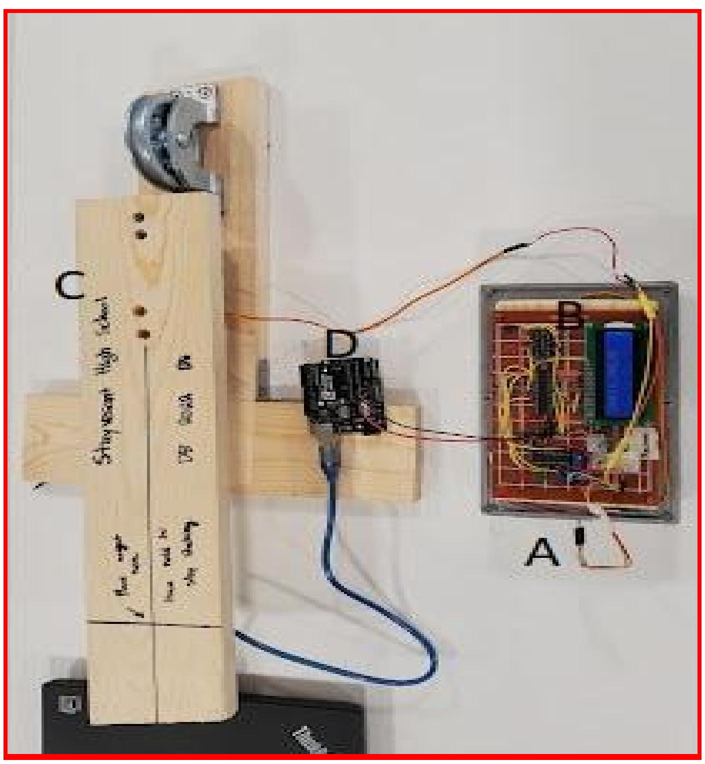




MAIN BOARD:
A: atmega328p - microcontroller used to measure and display data
B: INA125P - instrumentation amplifier
C: HD44780 LCD - 16x02 LCD display used to display data. Operating in 4 bit mode
D: Wheatstone half bridge - used to measure the change in resistance from the strain gauge in terms of voltage
E: 2k trim potentiometer - used to change the gain of the instrumentation amplifier

F: 10k potentiometer - changes the contrast of the LCD display
G: Red LED
H: Green LED
I: Blue LED
J:"Measure" button - signals microcontroller to read data from the sensor
K: Socket for LM324 - amplifier used in early iterations of our design
L: Connector for stressed strain gauge
M: Connector for unstressed strain gauge

The circuit was first prototyped on a breadboard, and then soldered to a 9x15cm perfboard, which provided more consistent readings from the sensor. IC sockets are used to ensure that ics can be quickly replaced. Initially a LM324 quad op-amp was utilized to amplify the voltage from the wheatstone bridge, However we switched to using a INA125P instrumentation amplifier to carry out this task. We decided to leave in the socket for the LM324 as an alternative amplifier if the INA125P were to fail during competitions.



ENTIRE SETUP:

A: Housing for main board and unstressed strain gauge
B: Main electronics board
C: Force/mass sensor
D: arduino board used to program and provide power to the whole device

FORCE/MASS SENSOR:
A: Strain gauge
B: 6062 Aluminum plate
C: Measurement mechanism
D: Counterweight

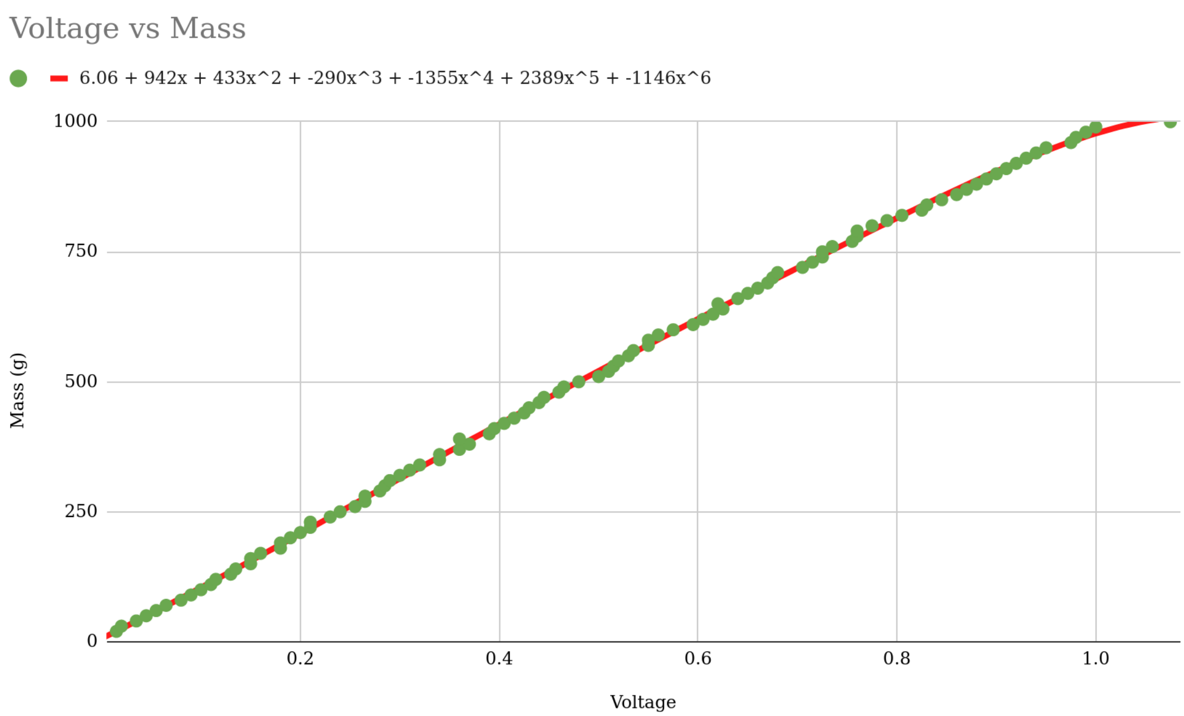
A singular strain gauge was glued to a plate of 6061 aluminum to measure forces acted upon it. Because of the relatively high rigidity of the aluminum, a lever mechanism is used to increase the amount of force acting on the aluminum. Because of the size of the lever, a counterweight is needed in order to keep the sensor secured. Another strain gauge identical to the first was glued to the metal housing and no force would be acted upon it. Due to the fact that the resistance of strain gauges can vary with temperature, in order to produce consistent results, 2 strain gauges are used to counteract temperature fluctuations.

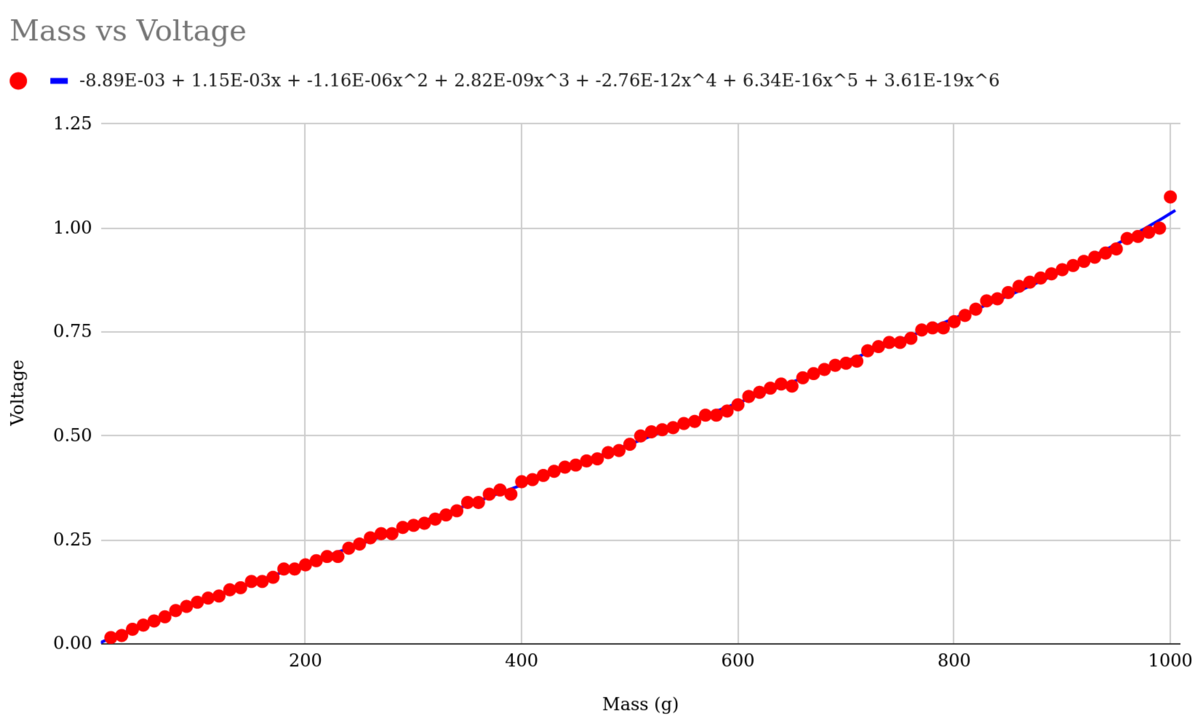
Mass (g)	Digital	Analog	Digital1	Analog1	Digital avg	Analog avg
20	3.87	0.02	2.31	0.01	3.09	0.015
30	4.12	0.02	4.24	0.02	4.18	0.02
40	7.22	0.04	6.51	0.03	6.865	0.035
50	8.39	0.04	9.67	0.05	9.03	0.045
60	10.69	0.05	12.2	0.06	11.445	0.055
70	12.08	0.06	14.48	0.07	13.28	0.065
80	15.7	0.08	15.39	0.08	15.545	0.08
90	17.94	0.09	17.82	0.09	17.88	0.09
100	19.74	0.1	19.55	0.1	19.645	0.1
110	22.42	0.11	22.17	0.11	22.295	0.11
120	23.43	0.11	23.96	0.12	23.695	0.115
130	26.03	0.13	26.16	0.13	26.095	0.13
140	26.22	0.13	27.69	0.14	26.955	0.135
150	30.33	0.15	30.11	0.15	30.22	0.15
160	31.4	0.15	31.53	0.15	31.465	0.15
170	33.46	0.16	32.63	0.16	33.045	0.16
180	36.26	0.18	36.01	0.18	36.135	0.18
190	36.5	0.18	36.15	0.18	36.325	0.18
200	39.11	0.19	38.14	0.19	38.625	0.19
210	41.31	0.2	40.59	0.2	40.95	0.2
220	42.7	0.21	41.97	0.21	42.335	0.21
230	43.61	0.21	42.88	0.21	43.245	0.21
240	47.62	0.23	47.45	0.23	47.535	0.23
250	49.27	0.24	49.51	0.24	49.39	0.24
260	51.37	0.25	52.33	0.26	51.85	0.255
270	53.29	0.26	54.49	0.27	53.89	0.265
280	54.11	0.26	54.23	0.27	54.17	0.265
290	56.96	0.28	56.38	0.28	56.67	0.28
300	57.99	0.28	58.65	0.29	58.32	0.285
310	59.16	0.29	59.85	0.29	59.505	0.29
320	61.92	0.3	61.92	0.3	61.92	0.3
330	63.96	0.31	63.07	0.31	63.515	0.31
340	65.91	0.32	66.48	0.32	66.195	0.32
350	69.6	0.34	69.45	0.34	69.525	0.34

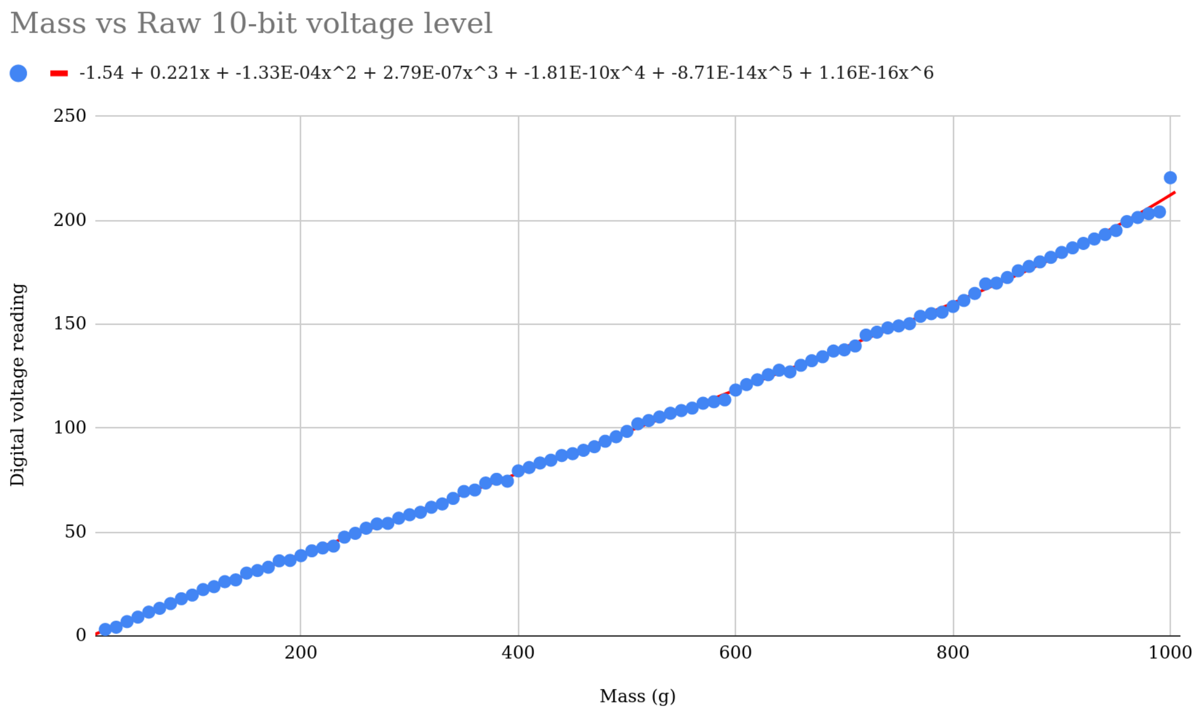
360	70.43	0.34	70.02	0.34	70.225	0.34
370	73.36	0.36	73.81	0.36	73.585	0.36
380	75.22	0.37	75.56	0.37	75.39	0.37
390	74.43	0.36	74.52	0.36	74.475	0.36
400	79.07	0.39	79.81	0.39	79.44	0.39
410	81.36	0.4	80.76	0.39	81.06	0.395
420	83.79	0.41	82.7	0.4	83.245	0.405
430	84.18	0.41	84.98	0.42	84.58	0.415
440	87.22	0.43	86.45	0.42	86.835	0.425
450	88.45	0.43	87.01	0.43	87.73	0.43
460	89.42	0.44	89.3	0.44	89.36	0.44
470	91.19	0.45	90.95	0.44	91.07	0.445
480	93.72	0.46	93.7	0.46	93.71	0.46
490	96.66	0.47	95.09	0.46	95.875	0.465
500	98.71	0.48	98.21	0.48	98.46	0.48
510	101.98	0.5	102.21	0.5	102.095	0.5
520	103.82	0.51	103.54	0.51	103.68	0.51
530	105.51	0.52	105.27	0.51	105.39	0.515
540	107.28	0.52	107.08	0.52	107.18	0.52
550	109.07	0.53	107.89	0.53	108.48	0.53
560	110.33	0.54	108.99	0.53	109.66	0.535
570	111.72	0.55	112.28	0.55	112	0.55
580	113.37	0.55	112.08	0.55	112.725	0.55
590	113.58	0.56	113.67	0.56	113.625	0.56
600	119.14	0.58	117.58	0.57	118.36	0.575
610	119.88	0.59	122.1	0.6	120.99	0.595
620	124.33	0.61	122.23	0.6	123.28	0.605
630	124.06	0.61	127.42	0.62	125.74	0.615
640	130.15	0.64	125.68	0.61	127.915	0.625
650	125.62	0.61	128.54	0.63	127.08	0.62
660	130.33	0.64	130.21	0.64	130.27	0.64
670	132.41	0.65	132.53	0.65	132.47	0.65
680	134.47	0.66	134.31	0.66	134.39	0.66
690	138.76	0.68	135.51	0.66	137.135	0.67
700	137.16	0.67	138.24	0.68	137.7	0.675

710	138.99	0.68	140.15	0.68	139.57	0.68
720	143.8	0.7	145.8	0.71	144.8	0.705
730	145.48	0.71	146.93	0.72	146.205	0.715
740	148.81	0.73	147.74	0.72	148.275	0.725
750	150.16	0.73	148.31	0.72	149.235	0.725
760	150.41	0.74	150.17	0.73	150.29	0.735
770	153.08	0.75	154.62	0.76	153.85	0.755
780	154.67	0.76	155.59	0.76	155.13	0.76
790	155.81	0.76	155.87	0.76	155.84	0.76
800	157.86	0.77	159.33	0.78	158.595	0.775
810	161.53	0.79	161.42	0.79	161.475	0.79
820	163.52	0.8	166.2	0.81	164.86	0.805
830	168.25	0.82	170.67	0.83	169.46	0.825
840	170.14	0.83	169.54	0.83	169.84	0.83
850	171.82	0.84	173.26	0.85	172.54	0.845
860	175.64	0.86	175.92	0.86	175.78	0.86
870	177.97	0.87	177.8	0.87	177.885	0.87
880	179.66	0.88	180.45	0.88	180.055	0.88
890	182.23	0.89	182.24	0.89	182.235	0.89
900	184.53	0.9	184.66	0.9	184.595	0.9
910	186.96	0.91	186.66	0.91	186.81	0.91
920	189.01	0.92	188.9	0.92	188.955	0.92
930	191.18	0.93	190.99	0.93	191.085	0.93
940	193.26	0.94	193.2	0.94	193.23	0.94
950	195.16	0.95	195.17	0.95	195.165	0.95
960	199.29	0.97	199.63	0.98	199.46	0.975
970	201.42	0.98	201.43	0.98	201.425	0.98
980	203.31	0.99	203.2	0.99	203.255	0.99
990	204.38	1	203.86	1	204.12	1
1000	219.42	1.07	221.73	1.08	220.575	1.075

For each weight measurement, 2 trials were taken and averaged out. Digital is the raw digital values from the microcontroller's ADC, and Analog is the converted digital value into an analog one. Analog value = Digital value * (5/1023). Each data measurement is in itself the average value of 5000 individual measurements from the sensor.


Voltage vs Mass
6.06 + 942x + 433x^2 + -290x^3 + -1355x^4 + 2389x^5 + -1146x^6
1000
750
500
250
0
Mass (g)
0.2
0.4
0.6
0.8
1.0
Voltage


Mass vs Voltage
-8.89E-03 + 1.15E-03x + -1.16E-06x^2 + 2.82E-09x^3 + -2.76E-12x^4 + 6.34E-16x^5 + 3.61E-19x^6
1.25
1.00
0.75
0.50
0.25
0.00
Voltage
200
400
600
800
1000
Mass (g)



Equation for line of best fit:

$$\frac{1.16}{10^{16}}x^6 - \frac{8.71}{10^{14}}x^5 - \frac{1.81}{10^{10}}x^4 + \frac{2.79}{10^{7}}x^3 - \frac{1.33}{10^{4}}x^2 + 0.221\,x - 1.54$$

We used the equation for the raw digital value, because it is more precise to use the raw data from the microcontroller's ADC rather than to convert it first and lose the resolution of the data.

Code that runs on the microcontroller:

```
/*DBCornell2022*/
#include <LiquidCrystal.h>
#define READPIN A1
const int RS=2, E=3, D4=5, D5=6, D6=7, D7=8; //LCD Pins
const int RED=11, GRN=10, BLU=9; //LED Pins
const int TOGGLE = 12;
/*Weight ranges in GRAMS, R1 <= R2*/
const double R1 = 67;
const double R2 = 705;
double offset = 0; //offset reading for sensor
const int TESTS = 5000;
const int INIT_TESTS = 1000;
; //amount of times for the microcontroller to measure data from the sensor. Its all averaged out

LiquidCrystal lcd(RS, E, D4, D5, D6, D7);

void setup() {
  double init_avg = 0;
  pinMode(RED, OUTPUT);
  pinMode(GRN, OUTPUT);
  pinMode(BLU, OUTPUT);
  digitalWrite(RED, LOW);
  digitalWrite(GRN, LOW);
  digitalWrite(BLU, LOW);
  pinMode(TOGGLE, INPUT);
  lcd.begin(16, 12);
  lcd.setCursor(0, 0);
  lcd.print("INIT...");
  delay(1000);
  for (int i=0; i<INIT_TESTS; i++) {
        init_avg += analogRead(READPIN);
  }
  offset = init_avg/INIT_TESTS;
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("DBMAIN_CORN");
}

double gx(double x);
double gx1(double x);
double newtonsmethod(double k);
```

```
void loop() {
  double finalsum = 0;
  double mass = 0;
  boolean interrupt = false; //button pressed?
  while (interrupt == false) {
        if (digitalRead(TOGGLE) == HIGH) {
        lcd.clear();
        lcd.setCursor(0, 0);
        lcd.print("Measuring...");
        lcd.setCursor(0, 1);
        delay(1000);
        for (int i=0; i<TESTS; i++) {
        finalsum += analogRead(READPIN) - offset;
        }
        finalsum /= TESTS;
        mass = newtonsmethod(finalsum);
        lcd.clear();
        lcd.setCursor(0, 0);
        lcd.print(finalsum*(5/1023.0));
        lcd.print("v");
        lcd.setCursor(0, 1);
        lcd.print(mass);
        lcd.print("g");
        if (mass < R1) {
        digitalWrite(RED, HIGH);
        digitalWrite(GRN, LOW);
        digitalWrite(BLU, LOW);
        }
        else if ((mass > R1) && (mass < R2)) {
        digitalWrite(RED, LOW);
        digitalWrite(GRN, HIGH);
        digitalWrite(BLU, LOW);
        }
        else {
        digitalWrite(RED, LOW);
        digitalWrite(GRN, LOW);
        digitalWrite(BLU, HIGH);
        }
        interrupt = true;
        }
  }
}
```

```
double gx(double x) { //g(x)
  return (1.16*pow(10, -16)*pow(x, 6)) - (8.71*pow(10,-14)*pow(x,5))-(1.81*pow(10,-10)*pow(x,4)) +
(2.79*pow(10,-7)*pow(x,3))-(0.000133*pow(x,2))+(0.221*x)-1.54;
}

double gx1(double x) { //Derivative of g(x)
 return (6.96*pow(10, -16)*pow(x , 5)) -(4.355*pow(10, -13)*pow(x , 4)) - (7.24*pow(10,
-10)*pow(x,3))+(8.37*pow(10,-7)*pow(x , 2)) - (0.000266*x) + 0.221;
}
double newtonsmethod(double k) {
  double x = 100;
  for(int i=0; i<30; i++) {
            x = ((gx1(x)*x)-(gx(x)-k))/gx1(x);
  }
  return x;
}
```

How we get a mass from voltage:

$$\frac{1.16}{10^{16}} x^6 - \frac{8.71}{10^{14}} x^5 - \frac{1.81}{10^{10}} x^4 + \frac{2.79}{10^7} x^3 - \frac{1.33}{10^4} x^2 + 0.221\, x - 1.54$$

$$\frac{d}{dx}\left(\frac{1.16\, x^6}{10^{16}} - \frac{8.71\, x^5}{10^{14}} - \frac{1.81\, x^4}{10^{10}} + \frac{2.79\, x^3}{10^7} - \frac{1.33\, x^2}{10^4} + 0.221\, x - 1.54\right) =$$
$$6.96\times 10^{-16}\, x^5 - 4.355\times 10^{-13}\, x^4 - 7.24\times 10^{-10}\, x^3 + 8.37\times 10^{-7}\, x^2 - 0.000266\, x + 0.221$$

In order to find the mass of a sample based on the voltage read from the sensor, we must solve for x in our mathematical model. However, solving for a polynomial of degree 6 is quite difficult and so we approximate our x value using Newton's method.