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Homogenous Mixing of Two Materials in an Integrated Pellet Metering System

Christian Stefan Tindula

HOMOGENOUS MIXING OF TWO MATERIALS
IN AN INTEGRATED PELLET
METERING SYSTEM

by

CHRISTIAN S. TINDULA

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Special thanks to Dr. Paul Davidson of the UTA LAMMA Lab. This is a continuation of a senior design project to create an automated portion of his large scale 3D printer that consists of a pellet extruder head attached to an industrial robotic arm. Special thanks to the Pellet Extruder Senior Design Team. Logan Hutton, Elliott Andress, and Khang Tran. Without them none of this could have been created.

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ABSTRACT

HOMOGENOUS MIXING OF TWO MATERIALS

IN AN INTEGRATED PELLET

METERING SYSTEM

Christian Tindula, B.S. Mechanical Engineering

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Faculty Mentor: Paul Davidson

UTA's LAMMA Lab has created a pellet 3D printer by attaching a Massive Dimension Pellet Extruder head to the end of a Kuka 6 degree of freedom robotic arm. The printer must have constant access to two pellet reservoirs and be able to print a two-material structure or a mixture of the materials. A batching system was created that distributes pellets using a lead screw conveyor to an enclosed metering plate. When the weight of the pellets distributed to the plate is equal to the specified weight of the batch, the conveyor stops, and the enclosure shifts moving the entire batch into the pellet extruder head. A mixed batch is created by alternating small pulses of the lead screws of the materials desired in the mixture. The mixed batch is not uniform but will allow for a granulate batch blender to be added below the batching system.

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INTRODUCTION

1.1 Motivation

Fused Filament Fabrication (FFF) printed parts are revolutionizing prototyping throughout the world due to the wide range and low cost of both the materials and the extrusion systems. The current revolution in FFF printing is the capability to change the material being printed mid-print. Changing the material mid-print allows for parts to be made with a variety of materials all fused together. The current solutions on the market are slow and waste a significant amount of material.

The LAMMA has recently purchased a Massive Dimension pellet extruder for the printer. This pellet extruder lowers the cost of use by one-tenth due to printing straight from the bulk material as opposed to printing from spooled filament. This system requires the correct weight of pellets to be fed into the hot end in such a way that the hot end is always extruding. The printer must be able to create single prints with multiple materials. This requires a system that can accept different materials from separate storage systems, and then batch the desired amount of material for each section in the correct order to be extruded from the hot end in a timely manner.

Large scale polymer-based 3D-printing is quickly adopting the use of polymer pellets as the input material rather than filament spools due to three primary reasons. The first primary reason is the economics of spool-based filaments versus pellets. Pellets are one tenth the price of filament wound on spools on a per weight basis. Spools of filament have a practical upper limit to how much filament can be on each spool [1]. Large scale 3D printers can easily use more than a spool's worth of material, which causes pauses in the prints and a manual change of the filament spool. Pellet based systems can store their pellets in large silos and refill said silos while the printer is printing. The last reason to use pellets is the ability to work directly with polymer manufactures to customize a polymer blend that works best for an application.

Granular media is second only to water as the most handled material in global industry [3]. However, there is no well-understood theoretical model for predicting the behavior of granular systems. Particle-by-particle simulations can be used, but these quickly become computationally impractical. The difficulty in simulating granular media comes from its behavior switching from solid-like, to gas-like, and to liquid-like [3].

Strain gauges are electrical conductors tightly attached to a film in a zigzag shape [4]. When this film is pulled, it – and the conductors – stretches and elongates [4]. This change in shape changes the resistance of the conductors and with this change of resistance the weight of the object stretching the film can be determined. The most common configuration for a strain gauge is to have four strain gauges connected in a configuration called a Wheatstone Bridge circuit [4]. This configuration allows the resistance changes of each strain gauge to combine into one resistance change. To read this change of voltage a load cell is used [4]. This signal can then be filtered by a programmable logic controller to increase accuracy and sensitivity [4]. Strain gauge-based weighing systems are the most commonly used due to their high accuracy, long term reliability, variety of shapes and geometry, and low cost [4].

An advantage that pellet extrusion has over filament extrusion is the ability to mix pellets together to create a larger variety of final extrusions. This can allow for the mixing of two different colors of materials to gain a third color for the purpose of testing organization as well as mixing two qualities of plastic to create a unique plastic with a combination of quality.

1.2 Pellet Distribution System

The Pellet Distribution System was designed and fabricated by the Pellet Extruder Senior Design Team to correctly batch specific weights of non-mixed material, and consisted of two subsystems: the lead screw conveyor, and the metering and distribution system.

1.2.1 Lead Screw Conveyor

Pellet material is fed into the top of the first granular flow system, which is a lead screw conveyor. They consist of a bushed DC motor that is coupled to lead screw as a linkage. When the DC motor rotates, the lead pushes material forward into the metering and distribution system. There are two lead screw conveyors each with a dedicated material that are attached to the top of the full system. They operate in 50 millisecond pulses to distribute a consistent and controllable stream of material with high torque efficiency.

1.2.2 Metering and Distribution System

The metering component will measure the weight of the pellets that is dispensed from the top system by using a strain gauge load cell. The system will be mounted onto the tray from the distribution system below the cylinder that holds the pellets while is its being weighed and cannot interfere with how the distribution system moves the pellets after this process. This system must also be rigid enough so that miscalculations do not occur by the impact of pellets being dropped onto its loading plate surface.

The metering system needed to be implemented in a way that would fit into the bottom distribution system. The first step was to determine which type of load cell was going to be used to meet the requirements needed. These requirements include that the system can measure at least 503 grams, have an accuracy of .05%, and have an analog voltage of 3.3 or 5V to be compatible with most microcontrollers available. Based on what was available and fit the needs of this system, the TAL220B cantilever load cell was selected. This load was connected to an Arduino board that calibrates the cell to take measurements.

The TAL220B load cell output voltage is on the microvolt scale while the Arduino reads voltages in on the voltage scale and is accurate up to 5 thousandths of a voltage. This necessitated the need for an amplifier to amplify the signal coming from the TAL220B. The amplifier chosen is the readily available HX711 load cell amplifier. This amplifier is made specifically for load cells and microcontrollers such as an Arduino.

There is an open-source library for the Arduino that is built for this amplifier. This open-source library has a multitude of useful features such as: taring, easily changeable calibration factor, and moving average weight readings. The author of the open-source library has an open-source calibration code that was utilized in calibrating the load cell.

The next step was to build a system around the load cell to replicate a weighing scale so that pellets could be measured. This system would connect to the distribution system tray so that the pellets could be dispensed right after the desired weight was reached. To reach a better understanding of how this was going to be approached, existing weighing scales were dissected and observed as to how the load cell in those systems were mounted and stabilized. However, there were constraints to the meter system set by the distribution system. These constraints were that the top loading plate was to have a diameter less than 3.25 inches and that the system needed to be mounted to the tray section of the distribution system.

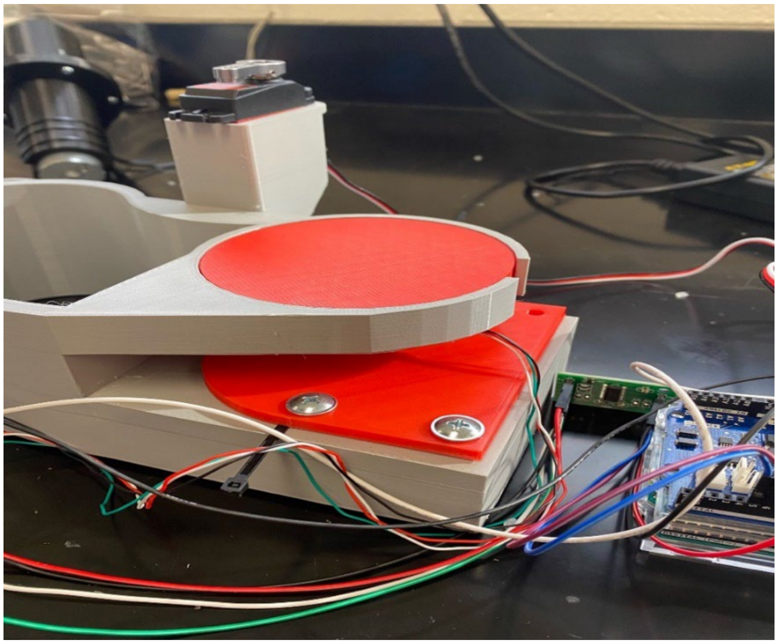

Figure 1.1: Metering System in Prototype

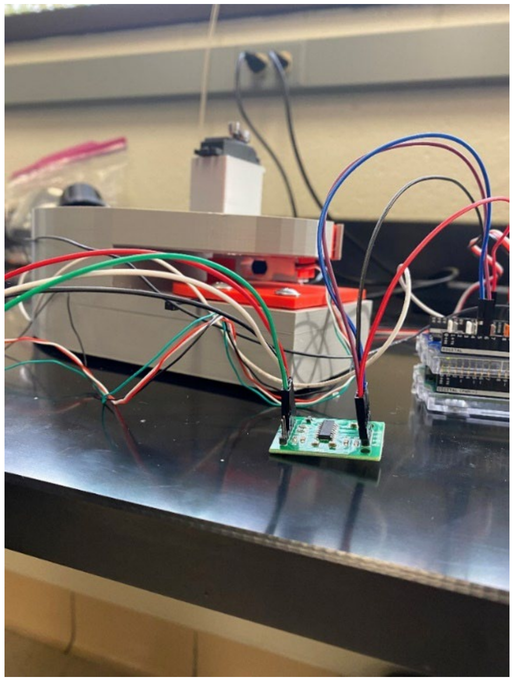

Figure 1.2: Load Cell Amplifier

As shown in Figure 1.3, the parts that are colored green will be 3D printed and the part colored in gray is the load cell, TAL220B, which is bought Commercial off the Shelf. The two top parts of the assembly will use a twist lock mechanism so that the surface of the plate will be smooth for pellets to rest on. The load cell is manufactured with M5 holes, so the holes designed will be for an M5 screw that is countersunk to even the surface. This system will rest on the tray of the distribution system as shown in figure 24 where the gray is colored grey, and the meter system is represented by the color red. The metering system will be held down by 3 screws into the tray to fortify the system's stability. The load cell in this system will be connected to a HX711 amplifier that will connect to an Arduino uno board so that it can be calibrated to measure pellets.

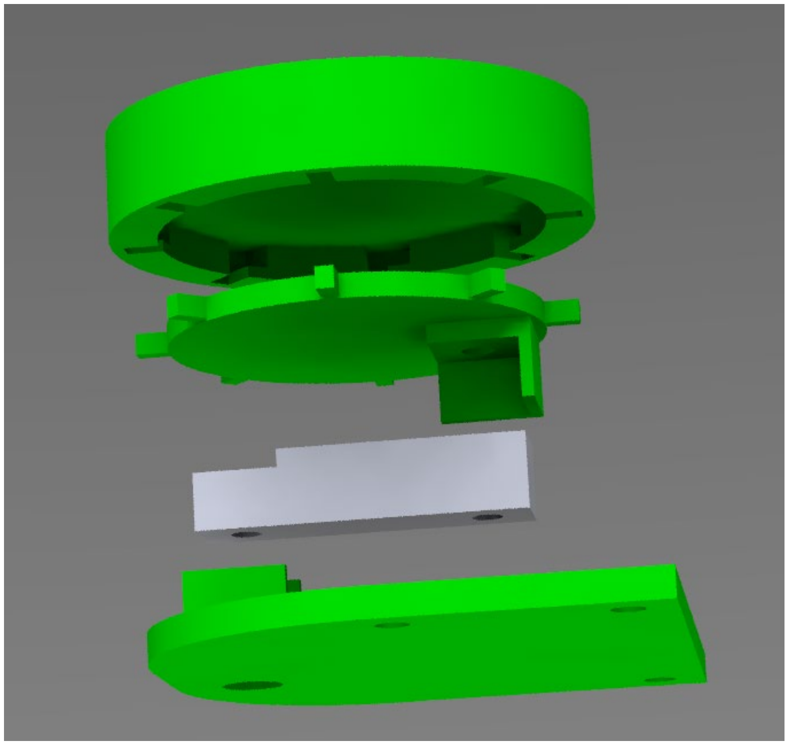

Figure 1.3: 3D Model of Metering System with Load Cell Exploded View

Once the correct weight of pellets has been measured by the metering system, the distribution system will move the pellets into the pellet extruder. The distribution system must move all the pellets measured by the metering system to the pellet extruder to minimize additional error. The distribution system must not affect the rigidness of the load cell in the metering system by impulse or any other metric as that will affect the calibration of the load cell. The distribution system must also be able to transfer the maximum number of pellets that can go through the system, 503 grams.

The distribution system is a rotating cylinder system that has a bottom flush with, but not supported by, the metering system. Pellets go into the open top and are measured by the metering system, and then fall out the bottom of the cylinder when it slides over an opening. This will ensure a rigid weight sensor. An unrigid weight sensor could lose calibration and make the system nonfunctioning.

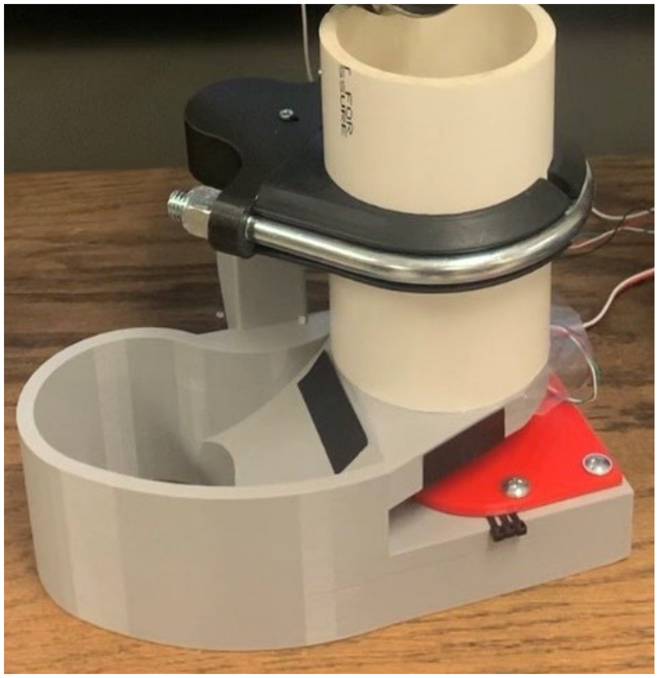

Figure 1.4: Distribution System Prototype

With the dimensions of the cylinder constrained by the volume of the maximum number of pellets which was determined by the packing factor experiment, the system can be modeled. The cylinder is COTS PVC pipe, with an inner diameter of 3 inches and an outer diameter of 3.5 inches. To attach this cylinder to a motor bracket a U-Bolt with a rubber seal and an inner diameter of 3.5 inches was chosen.

The cylinder needs to be supported separately from metering system, so that the moving weight of the cylinder is not included in the metering system's calibration. The bottom of the distribution system needs to be closed off so that the minimum number of pellets escape the system.

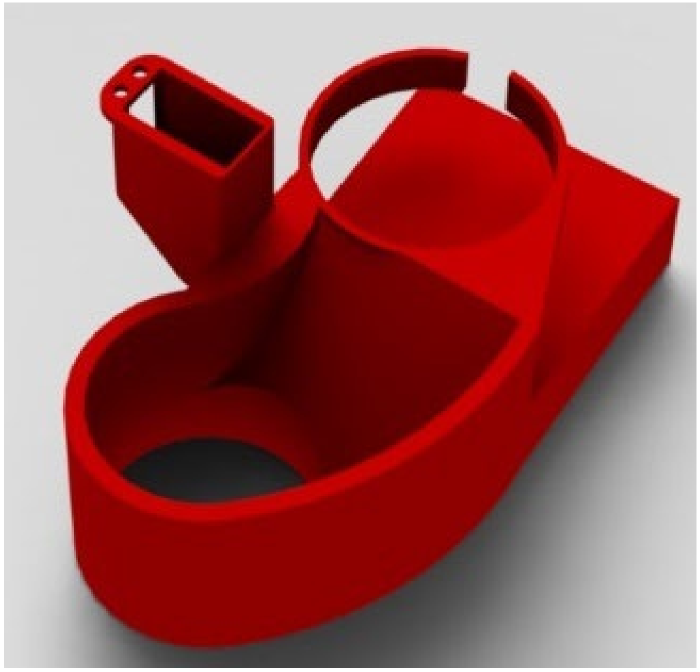

Figure 1.5: Tray

Figure 1.5 shows the solution for that, the Tray. The cylinder lies flat on the top of the tray and rotates 90 degrees. During the time of that rotation the pellets slide down the ramp and through the hole into the pellet extruder. This ramp and slow sweep will prevent jams that a straight drop might cause. The metering system will fit into the slotted hole and be supported from rectangular outcropping at the bottom of the tray. The slot in this hole allows for the load cell to slide through the hole for easier assembly. Holes are drilled into the bottom of the tray to align with the bottom of the metering system.

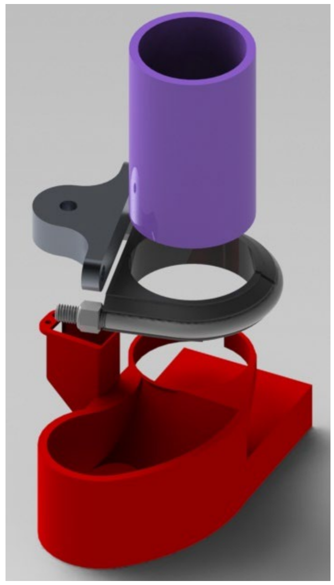

Figure 1.6: Cylinder, Tray, Motor Bracket, and U-bolt

1.3 Homogeneity Motivation

With the full Pellet Distribution System two materials can be weighed and batched into pellet extruder head to create pellet 3D prints. This brings the full system to the equivalent of a two-filament 3D printer, but the use of pellets instead of filament allows for the mixing of materials to create different plastics which filament printers are incapable of doing. Thus, for the Honors addition to the normal batching capabilities of the Pellet Distribution System, a mixed batch capability must be tested with an industrially created homogenous mixture of pellets as a comparison.

CHAPTER 2

METHODOLOGY

To create a mixture from the material, separate batches of the Pellet Distribution System and an exterior mechanical blender would be used and run for a certain amount of time to get a certain percentage of mixing. To bypass or decrease the exterior mixing time required for a batch mixture to reach homogeneity, the existing Pellet Distribution System Code was adjusted to include the capability of a homogenous batch.

2.1 Homogeneity Code

The batching code of the Pellet Distribution System works reading an array containing information on the material to use and the weight in grams needed of that material. It will create as many batches as there are arrays to read, with a 1 to call to the first material and a 2 to call to the second material lead screw. The lead screws will do 50 millisecond pulses into the metering and distribution system until the specified weight of material is in the distribution tube, after which the tube will rotate distributing the material.

To create a mixture of materials, both lead screws are pulsed at the same time. For usage in the code a 3 is put in the array instead of a 1 or 2 to signify mixing. The initial plan of the homogenous code adjustment would be to decrease the pulse time of both lead screws so that the stream of material would be the same as if a single lead screw was operating. However, during testing the decreased pulse time did not provide enough torque to the motors to rotate the lead screw, so the original pulse time of 50 milliseconds was kept. This means that the approximate stream of material will be double for the mixing usage, and will introduce error into the percentage mixed from the lead screw conveyor systems alone.

The separation of the two-lead screws will result in material bias on either side of the tube. Material one favoring the left side and material two favoring the right side. However, the mixture rolling down the tray of the distribution system will introduce further mixing into the mixture and remove that bias before the mixture reaches the exit point. The homogeneity of the mixture was measured using discrete values to determine how well this process works for mixing the pellets together.

2.2 Homogeneity Measurement

To discretely measure the mixture quality of the output of the mixture code, random groups of the mixture were extracted and separated into the two materials they contain. A perfectly homogenous mixture measured using this discrete method would have an equal amount of each material for each randomly removed group. This was performed on a test mixed batch, where the difference in material type pellets for each discrete group was calculated. The average difference between material quantities of all discrete groups was 2.29 pellets. The average amount of pellets in each discrete group was 8.31 total pellets. Using this as culmination of the entire mixture the mixture was 72.5% homogenous. This data was plotted in a Gaussian distribution.

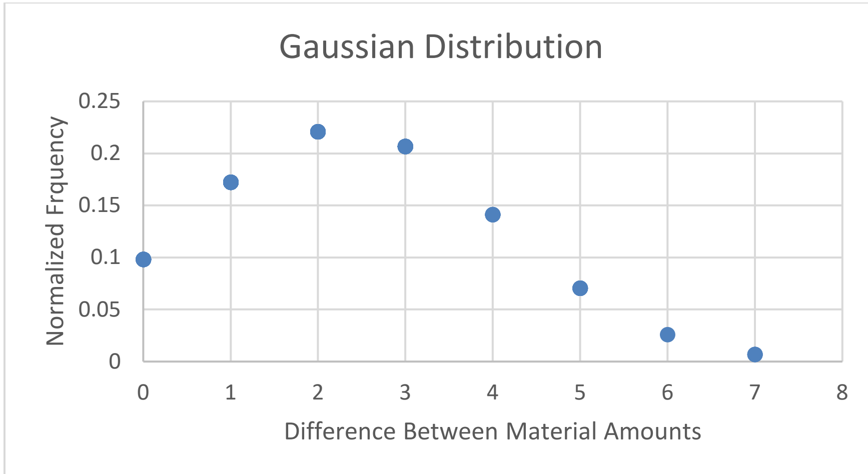

Figure 2.1: Gaussian Distribution

The Gaussian distribution imposed on the data gained from the discrete measurement does not take the form of a Gaussian curve. This is expected as the average difference of pellets is less than the average of the 8 data bins considered. Because of this the frequency of the differences per each difference was plotted in a bar graph to better represent the data.

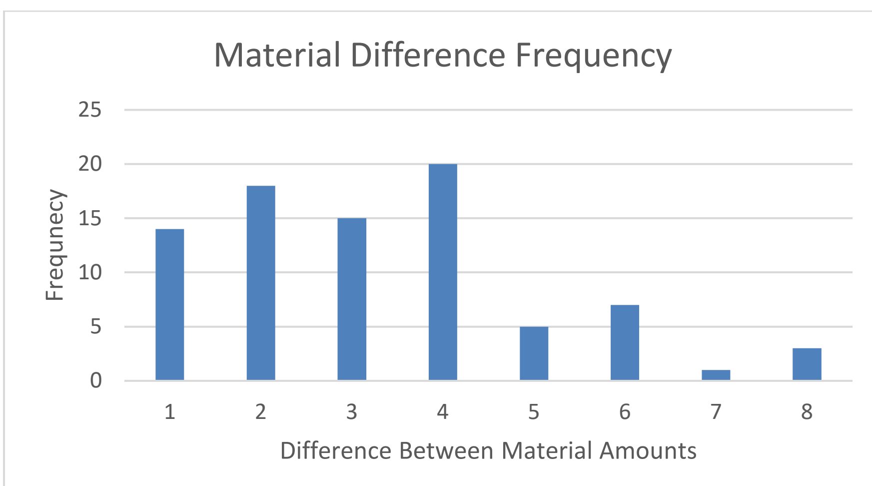

Figure 2.2: Material Difference Frequency

From this data, the 1 to 4 difference in material is much more frequent than the 5 to 8 difference in material. This contrast in amounts shows that the mixture tends to be more mixed together than less together over the entire mixture and creates a better symbology of the quality of the mixture than a comparison of averages.

CHAPTER 3

CONCLUSIONS

The mixing code adjustment does not create a homogenous mixture as required by the usage, so a secondary blender must be added to the bottom of the Pellet Distribution System. However, the quality of mixing in from this code addition is not insignificant. With 72% mixed by average and over half mixed by frequency inspection, an attached secondary blender would not have to run for a large amount of time to reach a homogenous state with the pellet mixture.

APPENDIX A

HOMOGENOUS CODE

```
#include <Servo.h>
#include <HX711.h>

#define DOUT 22
#define CLK 23

HX711 scale;

Servo myservo;
float calibration_factor = -480; //-414
int pos = 1825;
int Spos = 0;
int weight = 0;
//int weightA = 0;
int i = 0;
//int weightdesired = 80;
int NumBatches = 1;
int Batch[3][3] = {{3, 50}};
//int flag = 1;
//int NumberInputs = 0;
int material = 2;
int CB = 0;
int CA = 0;
// notes 1850 is over metering system 1125 is over hole
//motors

// motor A

const int MotorPinA = 12;
const int MotorSpeedPinA = 3;
const int MotorBrakePinA = 9;
const int currentSenseA = A0;

//motor b
const int MotorPinB = 13;
const int MotorSpeedPinB = 11;
const int MotorBrakePinB = 8;
const int currentSenseB = A1;

void setup() {
  Serial.begin(9600);

  // motor A pin assignment
  pinMode(MotorPinA, OUTPUT);// define motor pin as output
  pinMode(MotorSpeedPinA, OUTPUT);//define motor speed control pin
  pinMode(MotorBrakePinA, OUTPUT);// define motor brake pin
  digitalWrite(MotorBrakePinA, HIGH);
```

```
  // motor B pin assignment
  pinMode(MotorPinB, OUTPUT);
  pinMode(MotorSpeedPinB, OUTPUT);
  pinMode(MotorBrakePinB, OUTPUT);
  digitalWrite(MotorBrakePinB, HIGH);

  scale.begin(DOUT, CLK);
  scale.set_scale();
  scale.tare();

  long zero_factor = scale.read_average();
  Serial.print("Zero factor: ");
  Serial.println(zero_factor);

  myservo.attach(6);
  myservo.writeMicroseconds(pos);
  delay(100);

  scale.set_scale(calibration_factor);
}

void loop() {
  for (i; i <= (NumBatches - 1); i++) {
    weight = scale.get_units(3);
    Serial.print(weight);

    while (Batch[i][1]-weight > 4) {

      weight = scale.get_units(), 1;
      Serial.print(" weight: ");
      Serial.print(weight);
      Serial.println();

       if (Batch[i][0] == 2) {

        myservo.detach();
        CB = analogRead(1);
        digitalWrite(9, HIGH);
        digitalWrite(13, HIGH);
        digitalWrite(8, LOW);
        analogWrite(11, 255);
        delay(50);
        digitalWrite(8, HIGH);
        delay(50);
        Serial.print(" | screw system B go |");
        Serial.print(" current motor B: |");
        Serial.print(CB);
```

```
else if (Batch[i][0] == 1){

  myservo.detach();
  CA = analogRead(2);
  digitalWrite(8, HIGH);
  digitalWrite(12, HIGH);
  digitalWrite(9, LOW);
  analogWrite(3, 255);
  delay(50);
  digitalWrite(9, HIGH);
  delay(50);
  Serial.print(" | screw system A go |");
  Serial.print(" current motor A: |");
  Serial.print(CA);
  //Serial.println();
   }

else if (Batch[i][0] == 3){

  myservo.detach();
  CA=analogRead(2);
  CB=analogRead(1);
  digitalWrite(12,HIGH);
  digitalWrite(13,HIGH);
  digitalWrite(8, LOW);
  digitalWrite(9, LOW);
  analogWrite(3, 255);
  analogWrite(11,255);
  delay(50);
  digitalWrite(9,HIGH);
  digitalWrite(8,HIGH);
  delay(50);
  Serial.print(" | Mixing System go |");
  Serial.print(" current motor A: |");
  Serial.print(CA);
  Serial.print(" current motor B: |");
  Serial.print(CB);
}
```

```
  }
  digitalWrite(8, HIGH);
  digitalWrite(9, HIGH);
  myservo.attach(6);
  for (pos = 1825; pos >= 1100; pos -= 25) {
    myservo.writeMicroseconds(pos);
    Spos = myservo.readMicroseconds();
    Serial.println("go to hole");
    delay(50);
  }
  delay(2000);
  for (pos = 1100; pos < 1825; pos += 25) {
    myservo.writeMicroseconds(pos);
    Spos = myservo.readMicroseconds();
    Serial.println("go back to metering system");
    delay(50);
  }
  delay(1000);
}
```

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BIOGRAPHICAL INFORMATION

Christian Tindula started at the University of Texas at Arlington with the goal to get a major in Mechanical Engineering and a minor in Nuclear Engineering to go to graduate school for Nuclear Engineering. However, after getting further in his course and starting his Nuclear Minor Christian realized that he was much better at Mechanical Engineering and enjoyed it much more. With this change he had to decide whether to go to graduate school for Mechanical Engineering. The deciding factor of this was that Christian felt as though he had not gotten enough from traditional academia and will be pursuing a Master of Science in Mechanical Engineering at Texas A&M to gain the knowledge from education, he feels he is lacking.