# Improving a Power Measuring Device

St. Olaf College Engineering Design Practicum 2019

Partner: Compatible Technology International

Kayla Gephart, Owen Grimm-Howell, Thabiso Mabote, Eric Spear, Oscar Weber

## Goals

This report paper contains detailed description of the work we did to fulfill several goals we were given by Compatible Technology International (CTI). These goals consisted of:

- Fixing inconsistencies with angular velocity measurements
- Creating an adapter so that the power device could be used with the thresher
- Taking data on power needed to process different types of grains

In addition to these three goals, we gave ourselves secondary goals, which were:

- Adding Bluetooth capabilities
- Creating a second device

## Angular Velocity Measurements

The angular velocity as reported by the gyroscope was consistently inaccurate. We tested this by timing how long it took us to turn the handle ten times and calculating the angular velocity, and comparing that average angular velocity to the one reported by the device. For both devices, we found a consistent error of 27%. To correct this we inserted a multiplier of 1.37 to the code. Making this change led to an error of less than 2%, which can be attributed to imprecision in our timing.

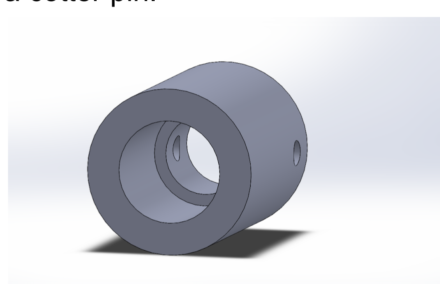
Because the error was the same for both devices, it gave us a clue that the error was the result of the way the gyroscope handles units. We found that the angular velocity was returned in an arbitrary scaled unit. This is what caused the error, and we determined that the inclusion of a multiplier was the best way to correct it.

## Adapter

The device, when we received it at the beginning of the term, could not be used with CTI's thresher. This is because when the device is used with the grinder, it attaches to the crankshaft with a cotter pin that goes through a hole in the shaft. The thresher, on the other hand, has no hole through its shaft because it is designed to be turned by one-way bearings that allow the shaft to continue spinning when the handle stops turning. Our task, therefore, was to design an adapter that attached to our device with a cotter pin on one side and could transfer torque to a smooth shaft.

We decided to make use of two one-way bearings in our design to grip the shaft. Our design consists of two main pieces: a 3D-printed housing for the two one-way bearings, and an aluminum rod attached to the housing with a cotter pin. We assembled the adapter by force fitting the rod and bearings into the housing with an arbor press.

The 3D-printed housing component seen below is a simple cylindrical piece with room for two one-way bearings to fit very tightly on one side of it. The other side has a smaller radius opening that fits the 20 mm aluminum bar. This side also has a hole all the way through the piece to accommodate a cotter pin.



The aluminum bar (seen below) was machined using a lathe and drill press. It contains two holes for cotter pins attaching it to our device on one side and the printed adapter piece on the other. It is the same diameter (20 mm) as the crankshafts of CTI's grinder and thresher, except for a small lip at one end which extends to the radius of the one-way bearings. When the aluminum piece is inserted into the 3D-printed housing, the lip fits at the very back of the space for the one-way bearings. The purpose of this design is to make it possible to remove the bearings from the plastic housing without destroying the printed piece or damaging the bearings. However, removing and replacing the bearings weakens their fit in the plastic and makes them more likely to slip. Ideally, the bearings will never have to be removed from their housing.

In the process of designing and prototyping the adapter we encountered issues with slipping, strength, and damage to bearings. Our solutions to these issues guided the design of the adapter to its current form.

Our first prototype did not make use of an aluminum rod and instead had a longer 3D-printed piece that fit into our device. When testing our prototype, we found that the bearings slipped in the housing and the adapter transferred no torque to the crankshaft. We solved this problem by reprinting the adapter with a smaller inner radius that fit the bearings more tightly.

When we fit the bearings into the second adapter, we noticed that the plastic was stretched and damaged. In addition, when we tested the adapter, it was unable to handle the stress and broke in half at the bottom of the bearing housing. After this failure, we redesigned the adapter with an aluminum piece which increased the strength. We also slightly increased the inner radius of the bearing housing and increased the thickness of the walls. This was to prevent the plastic from becoming damaged by forcing in the bearings and to prevent the plastic from stretching and allowing the bearings to slip.

Testing of our final iteration was successful. We found that the bearings slipped intermittently when tested on the fully tightened grinder, but there was no sign of slipping when the adapter was used for its intended purpose on the thresher. Moreover, the adapter appears robust and shows no signs of damage in either the plastic piece or the aluminum piece.

**Thresher Testing**

After fixing the angular velocity error and creating the adapter, we took data using the thresher. With the device and adapter attached to the shaft of the thresher, stalks of pearl millet were sent through the thresher.

The device outputs power by measuring the angular velocity and the torque, using the following equation:

$$Power = Angular\ Velocity * Torque$$

In this calculation, and in the values for angular velocity given by the device, units of radians/second are necessary. However, revolutions per minute are a more intuitive unit, and in this section angular velocity will be referred to in units of RPM.

To calculate the work from the power, it's necessary to find the average power over the time that the crank is turned, and multiply it by the total time. This comes from the equation:

$$Work = Power * Time$$

Therefore, work is related to the angular velocity (or how fast the handle is turned), torque (or how much force is used to turn the handle), and time (or how long the handle is turned for). An increase in any of these three quantities leads to an increase in work. As a result, to minimize the amount of work it takes to use the thresher, the handle should be turned as close to the minimum required angular velocity as possible. In addition, stalks of pearl millet should be fed into the thresher as quickly as possible, without causing a backup inside the thresher.

It takes familiarity with the thresher to develop an intuition as to how quickly the handle needs to be rotated, and how quickly pearl millet can be fed into the thresher. Due to time constraints, our group did not have enough time with the thresher to develop this intuition, but we gathered some preliminary data on the work needed to thresh pearl millet. We predict that the total work will decrease further as more familiarity is gained with the machine. Table 1 in the appendix shows our results when 10 stalks of pearl millet were used.

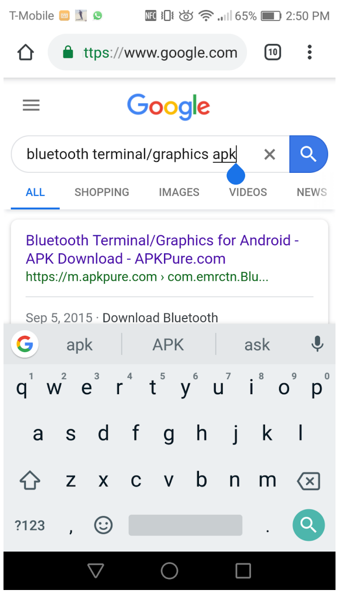
Table 2, also in the appendix, gives estimations. Using the data we gathered, we were able to predict how much power is required to turn the thresher handle with a certain angular velocity. For example, in order to rotate the thresher handle at 60 RPM, around 59 W of power is required.

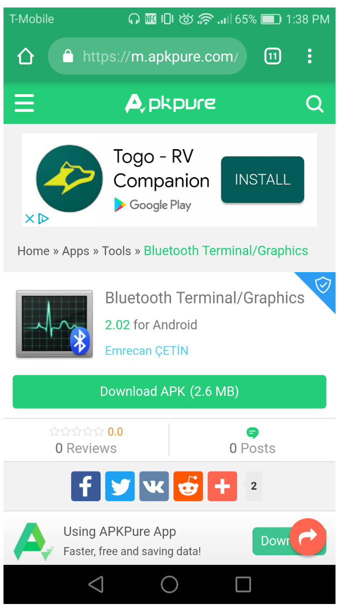
In Table 3 in the appendix, we generated another table of hypothetical data. The top row gives different values for the average RPM, and the left-most column gives different values for the time it takes to thresh each piece of millet. In the box where a certain RPM and time line up, the amount of work per stalk of millet is shown. For example, if somebody rotates the thresher handle at 60 RPM and feeds in a stalk of millet every 4 seconds, they will do about 237 J of work.

**Bluetooth**

On top of the goals given to us by CTI, one of our goals was to make the device user friendly, and so we added a new feature to it: Bluetooth. Bluetooth will enable CTI to see real-time measurements while grinding the grains. In order to add bluetooth without making any changes on the previously custom-made circuit board, we simply attached the HC-05 Bluetooth serial pass-through module directly to the Teensy board.

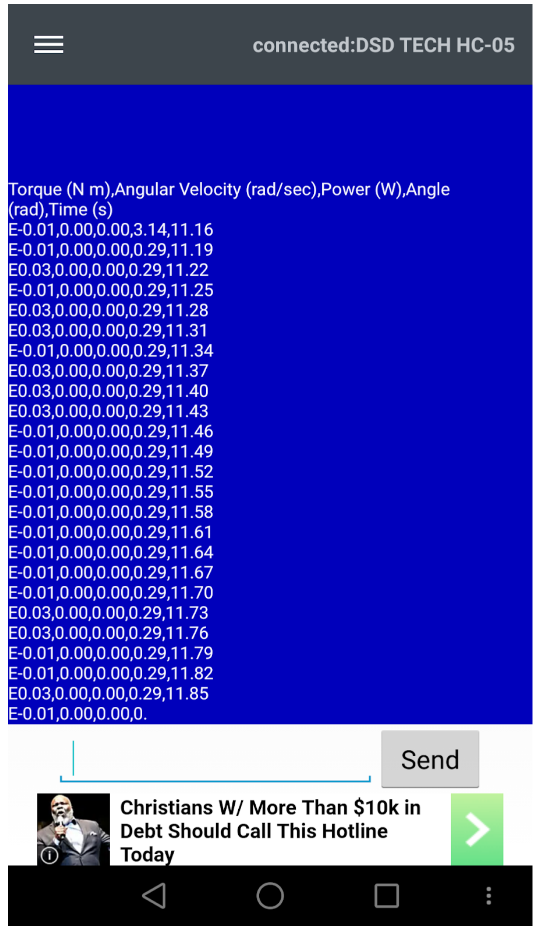
We downloaded the Bluetooth Terminal/Graphics 2.02 app on an android phone: Bluetooth Graphics. A free version of this app can be downloaded online as an apk (shown below) instead of downloading it from the google play store. Here is the link to download the app: https://apkpure.com/bluetooth-terminal-graphics/com.emrctn.BluetoothGraphics



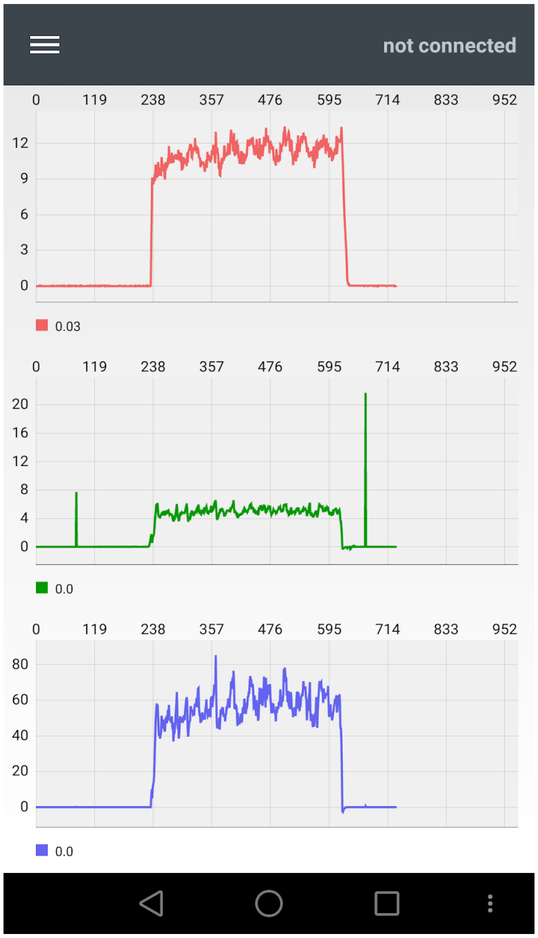




This app allows us to switch between displaying the real-time measurements of the device numerically and graphically on the Terminal.

On the portion of the arduino code that prints out the measurements on the app, we decided to change the order of the measurements from Time, Torque, Angular Velocity, Angle, and Power, which is how these measurements are recorded on the SD card, to Torque, Angular Velocity, Power, Angle, and Time for the bluetooth (as shown in the screenshot below).

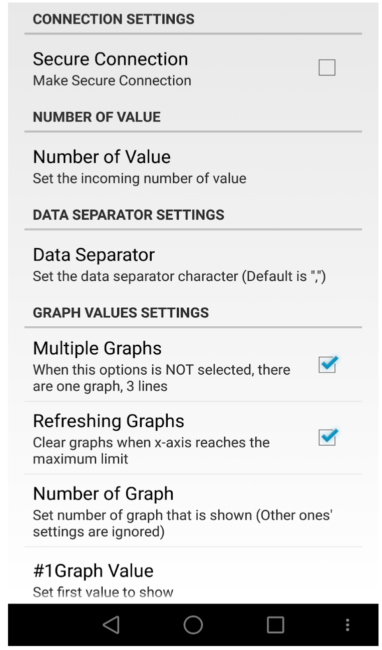



This change was made because our free app can only graph the 3 first measurements sent to it (as seen in the screenshot below), and our 3 most important real-time measurements were Torque, Angular Velocity and Power.

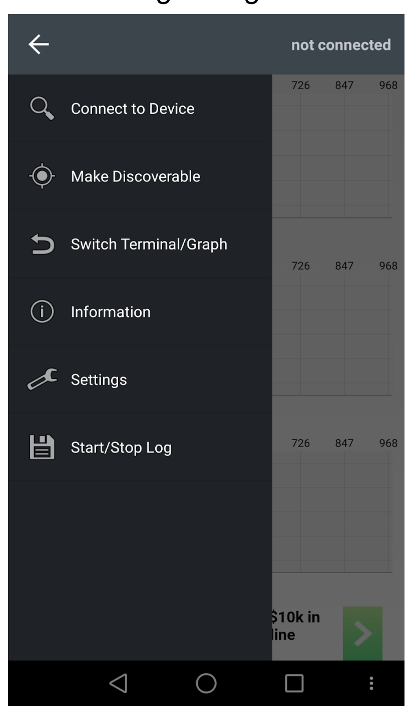



The top graph displaying a red line represents the Torque, the middle graph displaying the green line represents the Angular Velocity and the bottom graph displaying the blue line represents Power.

The default setting of the app is such that one graph is displayed with 3 lines of different colors. Because the measurements have different units, this setting should be changed such that 3 separate graphs are displayed, and this is done by ensuring that Multiple Graphs is selected in the settings. We also recommend selecting Refreshing Graphs so that the graphs are cleared when the x-axis reaches the maximum limit (shown below).




All 5 measurements can be recorded as numbers, while displaying the 3 real-time graphs, by hitting Start/Stop Log (shown below) to start logging just before grinding and hitting Start/Stop Log to stop logging when done grinding.




The logged data will be saved as a .txt file, with the measurements separated by commas on the phone.

### Building Another Device

While exploring and learning about the device that already existed we decided that it would be interesting and useful to build a second version as well as making the corrections to the existing one. Our goal was to make it possible for the devices to be more widely used as to be able to collect more data as needed. There were a few changes that we made in the design of the second one.

First off, the new device is red with a black top, which is useful in distinguishing the two devices. We also relocated two of the external ports. On the front flat panel, there is a row of three ports. From left to right they are the LED, the switch, and a micro-USB port for charging the battery. On the reverse side there are now two ports. The one on the bottom is for a micro-SD card, and above it is a USB-C port that provides access to the teensy microcontroller. The change of location of the USB port and the switch served to create more space in the middle of the device for the bluetooth chip.

The basic functionality is the same as the device that we were given at the start of the month. That entire process will be listed later in the paper in the operation guide.

We paid close attention to the components that were in the original device and did our best to purchase and use the exact same parts. All of these are listed in the parts list. None of the parts should need replacing nor are they particularly easy to replace. The active components are a gyroscope, clock, force sensor, bluetooth chip and a Teensy microcontroller. All the other parts are there to control those components and record data.

The code on the Teensy controls the outputs of the device by augmenting the data collected by the force sensor (force measured in N) and gyroscope (angular velocity in rad/sec) to calculate power. The clock serves to name files on the SD card with eight numbers: month, day, and time in 24-hour format. For example, 01291647 (mmddHHMM) would be 4:47 pm on January 29th.

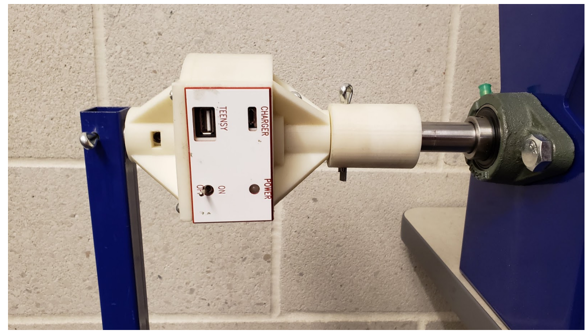
During our testing on the new device, we experienced an isolated incident of the device turning off on its own. Since that time we have closely looked at the internal circuitry and have done more extensive testing on the durability and reliability of the device. We have concluded that it was an isolated incident that should have no further impact on the functionality. We will go through basic troubleshooting and protocols further in the operation guide.

**Parts List For Main Body**

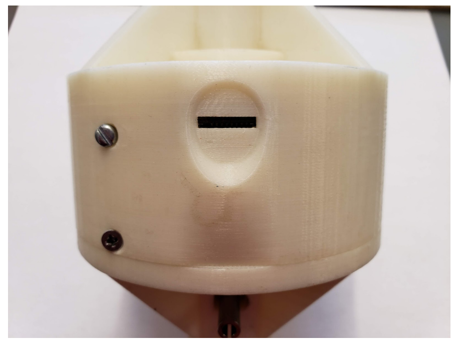
- 1 Teensy 3.2 Development Board - PJRC
- 1 Micro SD card adapter - PJRC
- 1 DS1307 RTC clock chip - Sparkfun
- 1 FC-23 Force Sensor - Digi-key Part Number: MSP6955-ND
- 1 NCP1402 5V step up - Spikenzie Labs
- 1 HC-05 Arduino Bluetooth Module Amazon
- 1 3.7V 900 mAh rechargeable battery 743040 - Amazon
- Lipo charger micro USB 10217 Sparkfun
- 1 MPU 6050 Gyroscope - Amazon
- Steel L-Bar
- Custom printed circuit board
- 8 6-32 ¾ in screws hold the top to the body
- 2 4-40 1 ¼ in screws hold the force sensor in place
- 1 4-40 ¼ in screw holds the gyroscope in place

**Operating Instructions**

In order to use this device, it must first be oriented correctly, and the microSD card must be inserted into the device. See the pictures below for the correct orientation of the handle and device. This orientation is the same for both the grinder and Thresher.

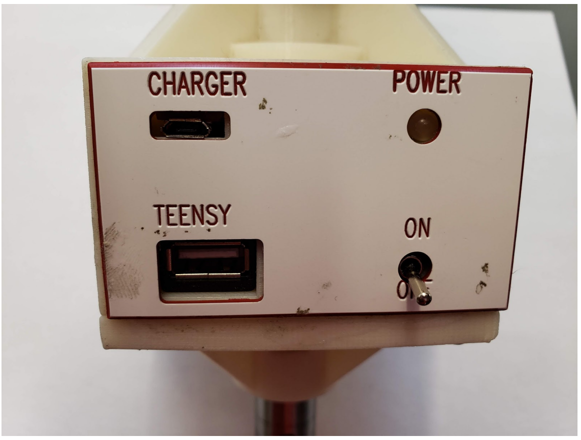


Below is the location of the microSD card port. The card must be fully inserted for proper function.



The on/off switch must be turned on in order to use the device. Once the device is turned on, it takes about 10 seconds to calibrate, during which the device should not be moved. During this time the LED will be flashing. Once the LED goes solid the device is ready to be used. When finished with the test you can simply turn off the device. To analyze data, the microSD card can be removed from the device and inserted into a computer. The data will be saved as a .csv file, which can be opened in Microsoft Excel, Google Sheets, or a similar spreadsheet software.

Other ports on the device will include the microSD port, a USB-C port and a microUSB port. See the picture below.




The microSD port, on the opposite side from the nameplate, is used to house the card which will record the data. The USB-C port (labeled "teensy" on the white-colored device) provides direct access to the Teensy microcontroller. This would only need to be accessed if the code running the device needs to be changed. The microUSB port (labeled "charger") is the charging port. The device must be charged regularly for proper functioning as the battery inside it is a rechargeable battery. If the device is plugged in and charging there will be a visible red light appearing from within the charging port. If that light turns off the device is fully charged.

To use the Bluetooth capabilities, download the android Bluetooth Graphics as previously explained in the bluetooth section. Ensure that the bluetooth is on and that the android phone is paired with the device. After turning the device on go to the Bluetooth Graphics app and connect to it. After the LED light appears solid, the user may hit Start/Stop Log to start logging data on the phone. The app will display either the numbers (separated by commas) or 3 graphs depending on what the user wants to display. After the test is over, if the Start/Stop Log was started, stop it and turn off the device by flipping the switch.

**Scope of Bluetooth**

Our thought behind adding Bluetooth capabilities was to make the device's data instantaneously accessible. This would allow a user out in the field to be able to monitor the measurements while in areas where it may not be convenient to be transporting a laptop for data interpretation. Seeing as the device will not work without a microSD card in it the potential benefits of downloading the data on a phone are slightly mitigated by the fact that all the data is more readily manipulated/interpreted on a computer where the SD card could be directly accessed. As well as the fact that data from tests is saved in distinct files on the microSD card all of the data can be downloaded at once, then interpreted as soon as computer access is feasible.

**Data Collection Instructions**

As explained earlier, data is given in a spreadsheet form. There are five columns. From left to right, they are labeled "Time (s)", "Torque (N m)", "Angular Velocity (rad/sec)", "Angle (rad)", and "Power (W)". Below is a screenshot of the first few rows in a set of sample data:

| Time (s) | Torque (N m) | Angular Velocity | Angle (rad) | Power (W) |
|---|---|---|---|---|
| 23.01 | 0.93 | 0.31 | -0.19 | 0.29 |
| 23.03 | 1.17 | 0.45 | -0.18 | 0.53 |
| 23.06 | 1.44 | 0.45 | -0.17 | 0.66 |

In order to work with the data, it is often necessary to delete rows of data that were taken before and after the device was in use. To calculate the total amount of work, the average power must be multiplied by the total amount of time. In Google Sheets, the formula to calculate work looks like this:

```
=average(E2:E1339)*(A1339-A2)
```

Where column “E” is the power, column “A” is the time, and rows 2 through 1339 span the full range of data. Other spreadsheet software would have similar, though slightly different, notations for the calculation of work.

### Basic Troubleshooting

Should any screws fall out they are fairly standard sizes and they are listed in the parts list.

If the device calibrates but then the LED goes out the problem will likely be that there is no microSD card in the port. The device will not collect data if the card is not inserted, or if the card is not inserted fully.

All holes in the shaft of the device and adapter are ¼ in. diameter and will accept ¼ in. cotter pins and screws.

**Appendix: Tables**

**Table 1:**

| Test # | Total Time (s) | Average RPM | Average Torque (Nm) | Work (J) |
|---|---|---|---|---|
| 1 | 44.21 | 90.08 | 12.25 | 5132.29 |
| 2 | 56.3 | 57.97 | 8.25 | 2815.26 |
| 3 | 42.15 | 69.22 | 9.72 | 2976.32 |

**Table 2:**

| RPM | 50 RPM | 55 RPM | 60 RPM | 65 RPM | 70 RPM |
|---|---|---|---|---|---|
| Power (W) | 41.225 | 49.88225 | 59.364 | 69.67025 | 80.801 |

**Table 3:**

| | 50 RPM | 55 RPM | 60 RPM | 65 RPM | 70 RPM |
|---|---|---|---|---|---|
| 4.5 s/stalk | 185.51J | 224.47 J | 267.13 J | 313.51 J | 363.60 J |
| 4 s/stalk | 164.9 J | 199.52 J | 237.45 J | 278.68 J | 323.20 J |
| 3.5 s/stalk | 144.28 J | 174.58 J | 207.77 J | 243.84 J | 282.80 J |
| 3 s/stalk | 123.67 J | 149.64 J | 178.09 J | 209.01 J | 242.40 J |
| 2.5 s/stalk | 103.06 J | 124.70 J | 148.4 J | 174.17 J | 202.00 J |