

Open-Source Hand-Crank Phone Charger

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Abstract

A mobile phone is an essential tool of communication, not only can it be used to connect with friends and family but more importantly to call emergency services in life-threatening situations. Therefore, it is important to make sure that mobile phones do not run out of charge, especially during power outages. This paper reports on the development of a portable hand-crank charger. The goal is to make everyone be able to make a call even when there is a no power, so this paper presents detailed instructions on constructing a portable hand-crank phone charger. The objective is to outline all the steps in such a manner that a person with no engineering background could assemble a similar device. This paper uses as many 3D printed parts as possible and describes each step of the design and assembly explicitly. Calculations include the required input rpm and gearbox ratio determination. The final device has a common USB type A output and is capable of charging any modern smartphone.

Keywords

Generator, microcontroller, buck-boost converter, portable charger, hand-crank generator

Introduction

Whenever natural or man-made disasters occur, it can often lead to a power outage. Everyone has heard of massive outages like the ones in California or Texas, however, there are thousands of people experiencing power failures every day in the United States [1]. People tend to take it for granted that they can call emergency services at any point, but if there is no power and one's mobile phone has already died, what are the practical solutions? There are few options available when it comes to emergency sources of energy. Hand-cranked systems are the easiest, most reliable, and one of the oldest ways to generate electricity. However, there are not many options available on the market. The way the design has been presented in this paper allows anyone with components similar to ours, to construct the portable manual phone charger.

There have been attempts previously to design similar devices. However, all of them lack some prominent features. Some of the chargers do not have power-keeping elements built-in [2]. This means the user has no option to charge the emergency charger in advance. Having a battery installed makes it possible to charge the battery in free time to later use the device as a charger. Moreover, the battery on board would be charging more efficiently, than the phone's battery connected directly to generator, as it is not losing any charge to power the motherboard [3]. In the paper [4] the authors assumed that the output from the generator will be always around the same value, not considering that a person is not capable of always spinning the handle at the same speed. Others focus only on the motor design, which is too complicated for the general public to understand [5]. Moreover, the authors do not discuss the electrical circuit to charge the mobile phone and therefore it is not particularly useful for those interested in building the device

as a whole. Since the purpose of the device is to be used in emergency situations, having a reasonable size is important, so that people can charge the phone on the go. The presented design can also be used by volunteers to distribute chargers in affected regions. Keeping all that in mind, the papers written prior to this do not meet this limitation with the chargers being so huge that they need separate bag for transportation [6]. By using a buck-boost converter in the presented design, even if the user rotates the handle slightly below the required rpm, the battery accumulates the power; opposing the designs which only have the buck converter [7]. And finally, the objective is to have everyone intrigued to be able to build their own device, that is why pre-used components that are easily available were used. Authors of the paper [8] made manual chargers that use the axial flux topology for the generators. Even though it leads to a higher efficiency of the overall system, axial flux generators are not as common, so it is hard to find one. The design of this paper uses the more common radial flux topology motor.

The design and creation of this charger was a group project for Wentworth's first-year Introduction to Engineering Design class. This paper incorporates multiple fields of engineering: electrical, computer, and mechanical. Since it was an in-school project, students had an opportunity to use various lab equipment necessary to not only design but built and test each prototype. At the conclusion of the project group members became more knowledgeable in their respective fields, and they also expanded their understanding of their partners' disciplines and roles.

Application

The production process has been divided into different subsystems. This paper describes each step of production in details, explaining all the calculations and required techniques. The motor and voltage regulator represent the generating circuit system, the microcontroller and liquid crystal display (LCD) represent the logic system, and the gear box is the mechanical system.

A. Design

The design of this device has a few key steps: picking a DC motor and determining Voltage to RPM ratio, designing a gear box, designing the electric circuit, and picking the components. After that is done, 3D models are to be made and printed, knowing the needed dimensions.

B. Determining voltage to RPM ratio of the motor

The process started with picking the radial flux permanent magnet DC motor available in the laboratory. All the characteristics of the motor were unknown, except for the maximum voltage. The characteristics needed for the calculations later are the voltage at which the motor operates and the RPM at this value. In order to obtain the value of the RPM the stroboscopic tachometer was used as shown in Figure 1. By supplying the maximum voltage, 6 volts, and then by adjusting the regulator, the stroboscopic effect was achieved, which occurs when the frequency of the flash aligns with the rotating object and the latter appears motionless.



Figure 1 - Determining the motor's RPM when 6 volts are supplied to it.

Knowing that the motor is capable of making 11,500 RPM at 6 volt, the next step is to obtain the voltage to RPM ratio to determine the required RPM for generating purposes.

$$\frac{\text{Voltage}}{\text{RPM}} = \frac{6}{11500} = 5.22 * 10^{-4} \text{ V : RPM} \quad (1)$$

With the ratio, the amount of RPM required to generate 5 volts can be calculated. Five volts is the voltage required to charge the battery (see Application section D). However, when used as a generator, the motor is not as efficient. Its efficiency will be around 80%, therefore the ratio needs to take that into account. The RPM needed to generate 5 volts:

$$\frac{\text{Voltage needed}}{\text{V : RPM generator}} = \frac{5}{5.22 * 10^{-4} * 0.8} = 11990 \text{ RPM} \quad (2)$$

Understanding that an end-user is not capable of making 11,990 RPM, the next step was to design a gearbox that would increase the RPM cranked by user.

C. Designing the gear box

A series of experiments were conducted to come up with the average number of rotations a person can do in a minute, which was calculated at around 150 RPM. Figure 2 shows the process of determining the average RPM, students were "rotating the handle" for a couple of minutes, and then the average was determined. In order to boost it so that the driven gear makes 11,990 RPM, the factor of multiplication for the gear box is around 80.



Figure 2 – Students determining the average RPM

Figure 3 shows the gear topology; the driver gear is the largest one with 100 teeth. It drives the gear with 12 teeth. This gear is axially connected to the gear with 95 teeth, which drives the gear with 10 teeth.

To calculate the number of teeth needed for the gear multiplication factor, the following ratio is used for any two connected gears:

$$\frac{RPM_{driven}}{RPM_{driving}} = \frac{Number\ of\ Teeth_{driven}}{Number\ of\ Teeth_{driving}} \quad (3)$$

The smallest gear possible to print is the one with 10 teeth, the smallest gear needs to be the driving one. Since space is limited inside the gearbox, the largest gear having 100 teeth will be the driven gear. The remaining two gears were selected to achieve the overall 80 gear box factor.

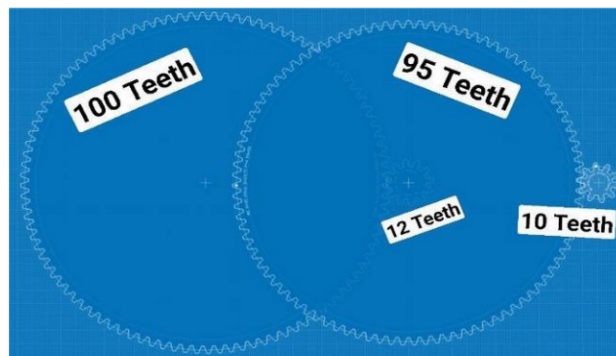


Figure 3 - Final gear ratio used for the design. 12 and 95 teeth gears are axially connected

To prove the design, one can calculate the RPM ratio.

$$Ratio\ 1 = \frac{100}{12} = 8.3; \quad Ratio\ 2 = \frac{95}{10} = 9.5 \quad (4)$$

Where 8.3 multiplied by 9.5 is 78.85, which is the PRM multiplier for the gear box.

D. Designing the electric circuit

First, the right components need to be selected. Since the battery is being charged, the key components would be the battery itself and the charging controller. The controller takes in 5 volts DC; however, the motor would never be able to generate stable 5 volts, due to users being unable to keep a steady and consistent crank rate of 150 RPM. Therefore, the buck-boost converter is used, which would stabilize the voltage to a steady 5 volts DC. Moreover, it would prevent the system from losing energy by converting not only the energy generated above 5 volts, but even below that. Lastly, the percent charge is displayed, to do so the microcontroller and an LCD are used.

The buck-boost converter is used to produce a stable 5 volts with the current output being around 1 to 1.5 amperes. In the converter's datasheet the minimum operating voltage indicated is 2 volts and the maximum is 16 volts. For this application, these specifications are perfect.

For the prototype, 3500 mAh capacity 18650 battery were used, which is commonly used in such applications. It is important to have a charging controller to prevent destruction of the battery. The charging controller has a 5 volt and 1 ampere rated input and output, which is enough to charge one 18650 battery. It has a red led on board so that user can see when the battery is charging. Based on the charging controller current output and the 18650's capacity the user can expect to have it fully charged in 4 hours. That sounds like a lot, however, in emergency situations, the battery does not need to be fully charged. Theoretically, to charge a modern smartphone up to 10%, you would only need to generate power for 15 minutes.

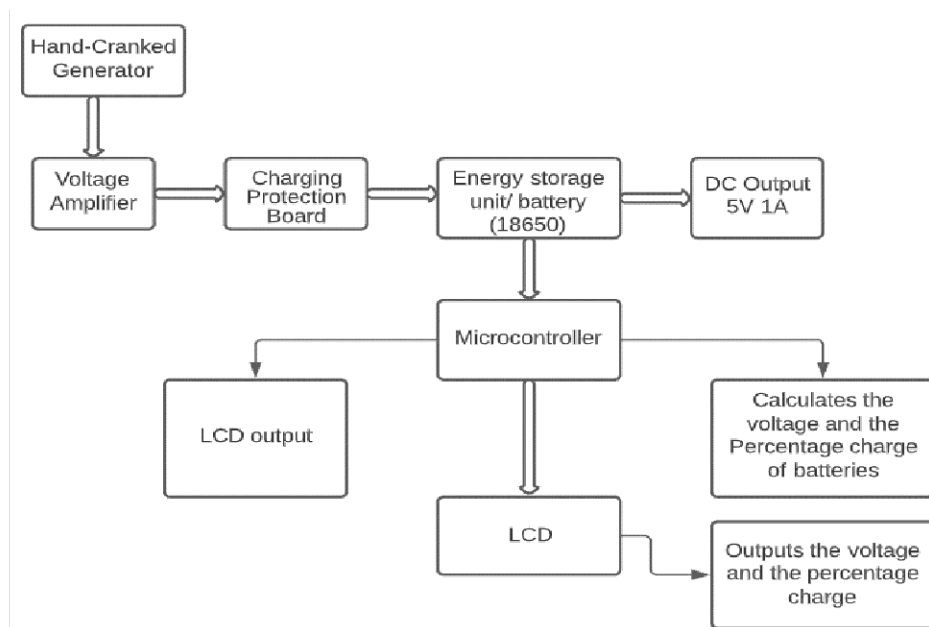


Figure 4 - Diagram of the electric circuit used in the design.

The microcontroller is used to measure the voltage across the battery and then to display it and the percent charge on the LCD.

E. Writing the script for microcontroller

Only the pins required for the LCD to work were used. The power is supplied from the 5 volt output onto the charger controller. The battery's positive pin is connected to the analog pin. Below is the script's flowchart which is used to measure the voltage across the battery and to display the percent charge on the LCD. To make sure that the LCD is not consuming too much current, a button that turns on the LCD for 5 seconds was added.

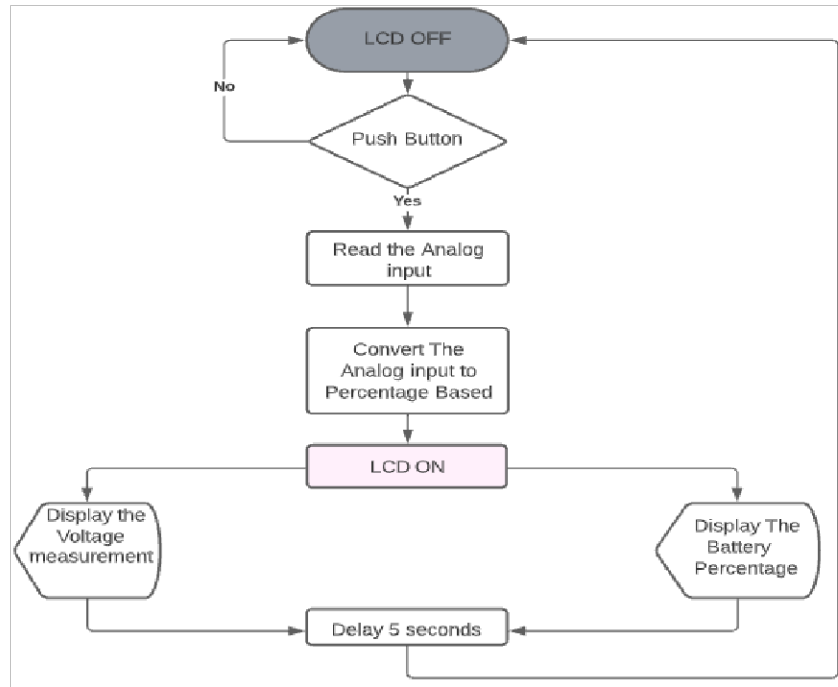


Figure 5 – Script's flowchart

F. Making 3D models using SolidWorks

The 3D models were made using the SolidWorks software. By using the built-in gear maker, the following models were obtained:

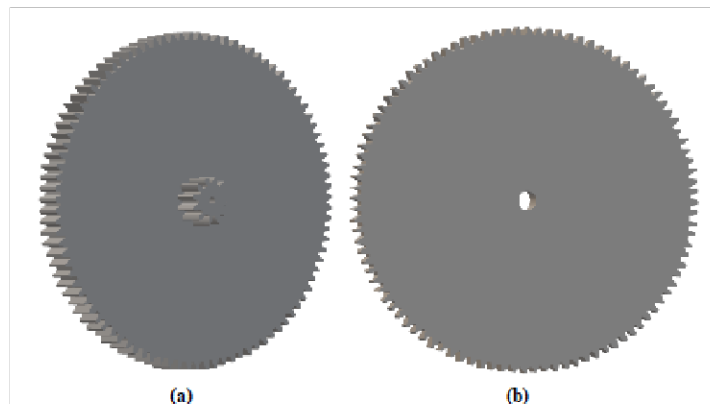


Figure 6 – (a) Two axially connected gears (b) The driven gear

After obtaining all the components, the measurements were done, and the dimensions were used to start designing the housing box. It consists of three main parts: the gear box, electronics box, and motor cover. Below are the 3D models for these parts.

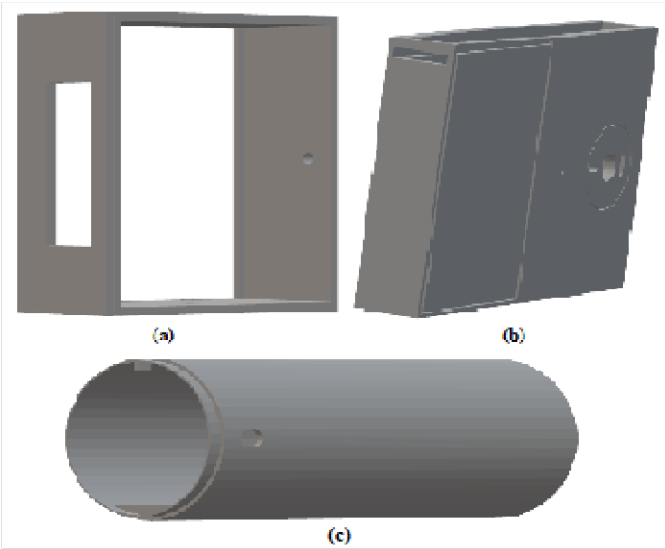


Figure 7 - Housing box 3D models. (a) Electronics box, (b) Gear box, (c) Motor cover

G. Fabrication and Assemble

Finally, the parts were 3D printed and the prototype could be assembled. The buck-boost converter was glued to the back of the motor to save the space.

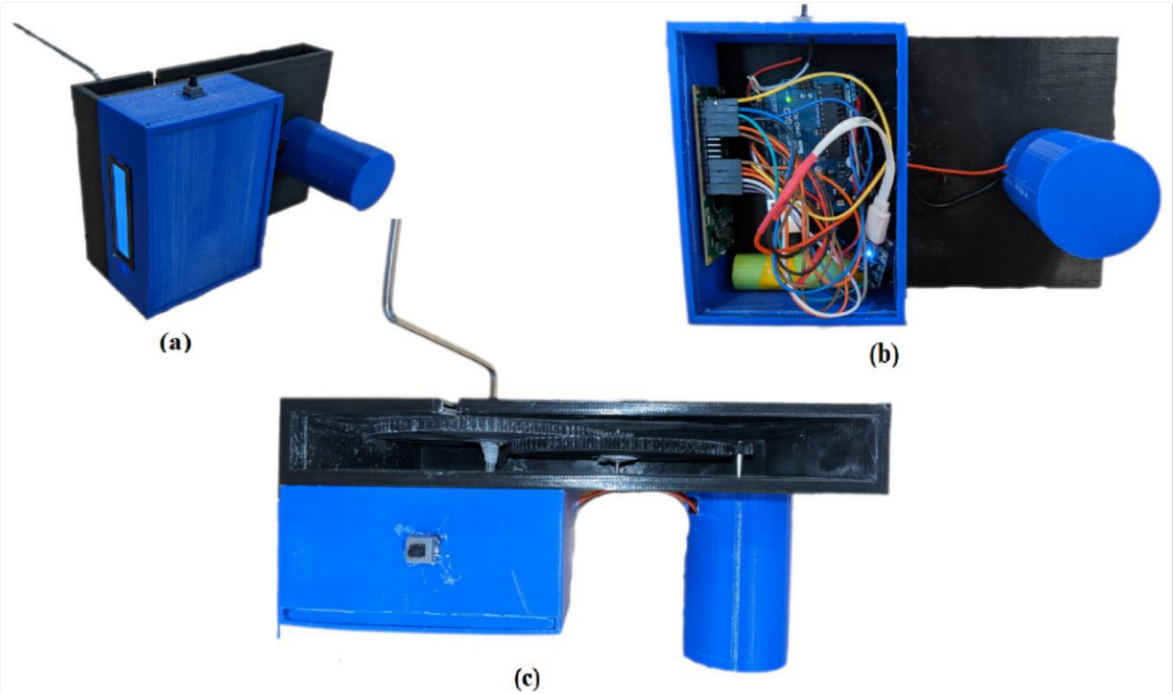


Figure 8 - Assembled device. (a) Side view of the whole device, (b) Electrics box, (c) gear box.

H. Testing Procedures

Each subsystem was tested individually. First, the device was tested to see if it is charging the battery on board. For that, the buck-boost converter output was connected to the battery's charging controller and the user started spinning the handle. To test the Microcontroller, LCD, and the battery, a fully charged device was used, then a phone was connected to drain the battery. The battery percentage on the LCD was observed every 10 minutes until it reached 0%.

Results

All the tests conducted showed that the prototype works. The LED on the battery controller lit up when the user was rotating the handle, as can be seen in Figure 9, confirming that the battery was being charged. Therefore, the gear box calculations were right, and the buck-boost converter supplied enough power to charge the battery. The LCD displayed the percent charge correctly, and over time the percent charge decreased, which proves that it can correctly display the data. Correctness of voltage measurements was also confirmed using digital multimeter. Lastly, when a smartphone was hooked up using the usual USB cable, it started charging.

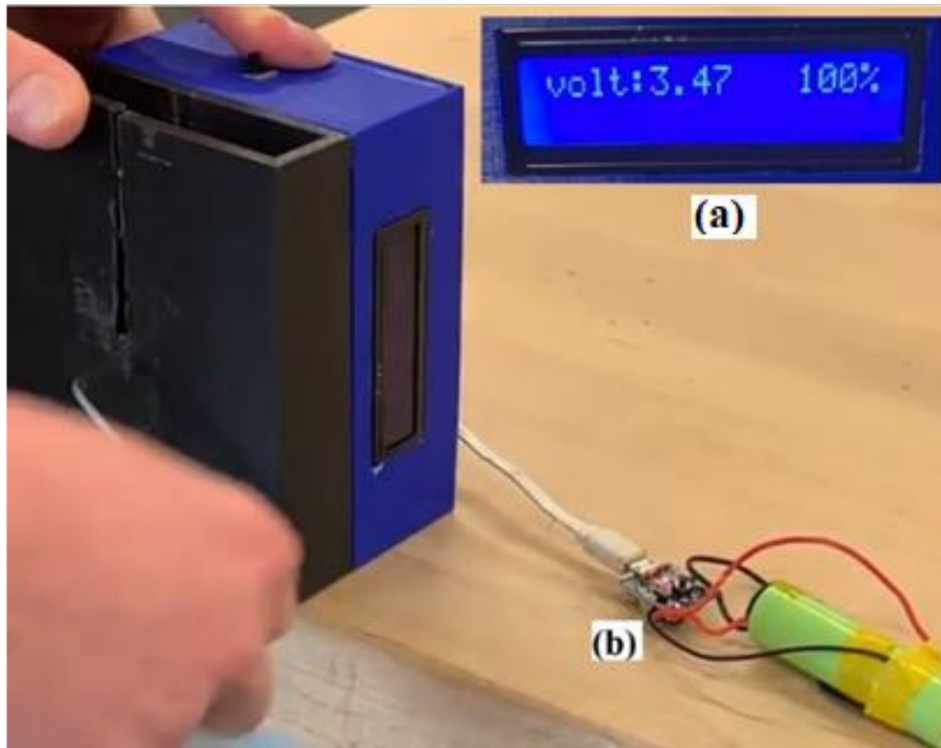


Figure 9 - Testing the assembled device. (a) LCD shows percent charge and voltage on the positive battery terminal. (b) The LED lights up as the handle rotates.

Apart from making sure the device works as intended, important parameter to keep in mind is the efficiency of the device, it directly influences the time needed to charge the prototype. As discussed in design section, it is expected to fully charge the battery in 4 hours, and in 15 minutes we should have enough to charge modern phone up to 10 percent. That is around 300 mAh supplied to smartphone. Since the battery used in the prototype has a capacity of 3500 mAh

at 3.7 volt, it is needed to charge battery on board to around the 10 percent of charge. That is taking into account the 90% efficiency of the controller and the fact that we need to convert the 3.7 volts to 5 volts.

In practice the 10 percent charge was achieved after 23 minutes of using the device. The error comes from the fact that we have microcontroller consuming power on the same line. The controller's efficiency might be even more than the 90 percent assumed. The buck-boost controller can output slightly less than expected one ampere.

Conclusions and Future Directions

The first-year projects like this can be a big open door for the students to learn about design and implementation of electrical and mechanical systems. The students can gain the experience of creating electrical and mechanical design; specifically, the importance of using charging controllers which prevents batteries from exploding, interpretation of analog signal by microcontrollers so that it can be use as voltage measuring devices, proper mechanical connection details, gear ratio calculations, etc. Most significantly how to apply the designing thinking process, and the importance of testing design ideas and components before assembling the device as whole was understood. This project was and can be very useful to acquire all the engineering skills specified on this paper.

The assembled prototype works and passes all the tests. The goal to charge the battery solely with muscle power was achieved, the phone charged with the common USB type A, and the LCD displayed the percent charge correctly. The way the product was designed makes it portable, and by using the buck-boost converter it can be sure that battery is charging even at lower than required RPM. The device may help those in emergency situations, and to assemble the device the user does not need an engineering background.

There are several changes that could be implemented in future versions of the device. First, the main gear, which is connected to the handle, should have a square port, to eliminate the need to glue the handle to the gear, this caused poor connection between parts. The gearbox should have a more open layout, to make the assembly easier for the end-user. It is not easy to assemble the gearbox with the layout as it is right now. The buck-boost converter heats to the point where it can melt plastic, so in future versions, it would make sense to add a passive radiator to cool it down. Microcontroller's power consumption should be reduced to a minimum by working on the standby mode of the LCD. The USB output might need to be changed to type C as it gets increasingly popular.

Acknowledgment

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