Alternative Power Source for Dental Hygiene Device

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Project Proposal

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1. Problem Statement

1.1. Introduction

For this project, our team needs to build a potable power source for a dental hygiene device, Wig-L-Bug for NAU Department of Dental Hygiene. Wig-L-Bug is used to mix dental filling material.

1.2. Background Research

The NAU Department of Dental Hygiene provides humanitarian services in some remote areas around the world. Sometimes, these areas have limited access to electricity. In December, a team of students and professors of the Department of Dental Hygiene will be travelling to Mainpat in India to work on teeth. To get the work done, they will need to use the Wig-L-Bug, a device that can mix dental filling material, but there is still no power source for this device.

1.3. Needs Identification

Currently, there is no electric power available for Wig-L-Bug in these remote areas. However, it is impossible to mix dental filling material by hand, without Wig-L-Bug. Therefore, NAU Department of Dental Hygiene needs a portable power source for this dental device.

1.4. Project Goal and Scope of Project

The goal of this project is to design and build a portable power source for dental device. This power source would be produced not for a commercial scale but for one or two units.

1.5. Objectives

In this design, our team needs to design and build a power source for a dental device, which is durable, portable, inexpensive, and powerful. The basis of measurements is shown in Table 1 for each objective.

Table 1 Objective Chart

Objective	Basis for Measurements	Units
Durable	Drop from a certain height	m

Long Life Span	Number of charge cycle	cycles
Low Cost	Manufacturing cost	$
Portable-Size	Dimension of the power source	in×in×in
Portable-Weight	Weight of the power source	lb
Energy Capacity	Energy	Wh

1.6.Constraints

In the process of designing and building power source, our team needs to meet some necessary requirements of our sponsor. Firstly, this power source should be able to have stable AV voltage output of 110V at 60Hz and a current output of 1.2A. In addition, it is required to power dental device continuously for 10 hours. In order to make it portable, this power source cannot weigh more than 26lb and can fit in a 22in×18in×10in container. Moreover, it cannot take more than eight hours to charge power source from 0% to 100%.

Table 2 Constraint Chart

Constraint	
Weight	26lb
Size	22in×18in×10in
Voltage Output	110V AV 60Hz
Current Output	1.2A

1.7.Criteria Tree

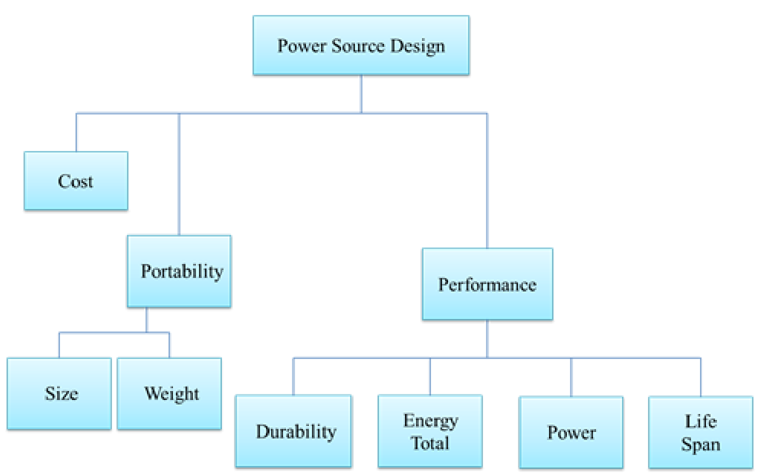

Figure 1 Criteria Tree

1.8.Quality Function Deployment

		Engineering Requirements								
		Output Voltage	Output Current	Dimensions	Engergy Density	Charging Current	Charging Voltage	Cost	Weight	Life Time of Battery
Customer Requirement	Powerful	x	x							
	Durable							x	x	
	Long Life Span							x		x
	Portable			x	x					
	Fast charged				x	x	x			
	Has Large Energy Capacity			x	x			x	x	
	Low Cost			x	x			x	x	x
	Safe	x	x	x		x	x		x	
	Units	V	A	cm*cm*cm	Wh/kg	A	V	$	kg	Cycles
		110	1.2	56*45*25	150	6	220	500	12	150

Figure 2 Quanlity Function Deployment

	Output Voltage	Output Current	Output Power	Volume	Energy Density	Cost	Weight	Lifetime	Total Energy
Output Voltage									
Output Current	-								
Output Power									
Volume			+						
Energy Density									
Cost			+	+	+				
Weight			+	+		-			
Lifetime						+	+		
Total Energy				+	+	+	+	+	

Figure 3 House of Quality

The net power output equals the product of output voltage and current. Thus, the power output increases as output voltage or current grows. The durability greatly depends on the manufacturing quality and properties of material. If we want higher durability this would definitely affect the total cost and weight. The life time of the power source is determined mainly by the life time of batteries because batteries have shortest life time in overall system. In order to extend the life, a better has to be used and this contributes to total cost. To be portable means the power source has small weight and size. But it still needs to provide sufficient energy. As a result, a battery with higher energy density is expected. In case that the power source depletes during our client's work, the team is conservative in estimating the desired energy capacity. The drawbacks of a battery with large capacity are quite obvious. It weights and costs more. The energy capacity is also a function of energy density. Though there is no constraints for total cost the system should be inexpensive without compromising its full function. In fact, cost is almost related to every other criterion. The major cost of building such system comes from the battery, packaging so it depends on energy density, energy capacity, and life time of the battery as well as the dimensions of overall system. Safety is also important in our system. Lower output voltage and current lead to a better safety. For the same reason, charging current and voltage also contribute to the safety of the system. The electrical properties of materials will also have an impact on safety. Different materials have different density and this causing the weight to change.

2. Concept Generation

In order to solve the problem we have encountered, we have come up with 10 designs, in which we choose three as our final possible designs. These three designs are: Combination of manual alternator and lithium battery, combination of solar generator and lithium battery and lithium battery only.

Design 1: Combination of manual alternator and lithium battery

- **Description**

  A crank with a chain or belt turns a small automobile or motorcycle alternator. The alternator is wired in parallel with a lightweight scooter battery. A DC to AC inverter is run off of the battery. The battery is capable of powering the Wig-L-Bug for about 20 minutes. The pedals will require around 100 watts of input power for 60 watts of output. A person in average shape could reasonably do this for around an hour. A simple model shown in Figure 3 could be built to be to be dissassembled for easy transportation.

Figure 4 Design 1

- **Parts Details**

  In the Table 3, there is a list of all of the parts required to build a combination of manual alternator and lithium battery system.

Table 3 Components of Hand Generator Design

Component	Cost	Weight (lb)
Alternator	75	8
Battery	100	1
Inverter	50	1
Frame	75	8
Gears, Cranks, Pulleys, etc	150	5
Wiring, electronics, etc	50	1
Total	500	24

1. **Alternator**

Figure 5 Alternator

A small alternator can be bought with 50 - 75 dollars. Ideally, we obtain a small unit rated for less than thirty amps. While these units are not very efficient (about 60%), they are small, cheap, and very durable. Used in this application, an alternator in good shape should last forever. The main disadvantage of the alternator is the low efficiency. The person pedaling will have to work harder than if a more efficient DC generator was used.

2. **12 Volt Battery**

Figure 6 Battery

A lithium Ion Battery built to power scooters,motorcycles, and ATVs would be charged by the generator. These batteries are rated for 2000 discharge cycles, meaning if it was allowed to completely drain and then recharged every twenty minutes, it would be good for 600 hours of use. The lifespan would be longer if the generator was pedaled constantly. We will look into this.

3. **Inverter**

An off-the shelf device that converts the battery power into a form usable by the Wig-L-Bug.

4. **Frame**

   An Aluminum tube frame would be welded up out of square tube stock. We will need to come up with some designs to determine the actual size and weight. Ideally, the frame will have hinges or pins to allow the frame to fold up or disassemble.

5. **Gears, Cranks, Pulleys, etc.**

   This is the mechanical part of the design. Most of these parts could be scavenged from old bicycles. Certain items may need to be fabricated for the application. This could potentially be cheaper than the estimated price.

6. **Wiring, Electronics, etc.**

   We will probably add charge indicators, switches, circuit protection, etc.

Design 2: Combination of solar generator and lithium

- **Description**

  The solar power source concept converts solar irradiance into electrical energy, which is used to provide energy for Wig-L-Bug.

  In the Table 4, we analyze the advantages and disadvantages of a solar design.

Table 4 Disadvantages and Advantages

Advantage	Disadvantage
Powerful	Cannot work under poor light condition
Portable	Has to be manually set towards the sun directly in order to get maximum power
No need to charge at night	Cost of a solar panel is high

- **Parts Details**

  The following are the parts which will be used in this design.

1. **62 Watt Solar Charger**

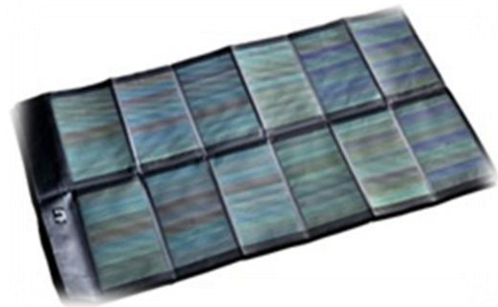

Figure 7 Solar Charger

The power source should be able to provide an output power of 62W. All power has to be captured from solar radiation. Thus, a solar panel of 62W is expected. Moreover, the size of a normal solar panel exceeds the limits. For this reason, a portable solar panel is the only choice.

2. **24V DC to AC 400W inverter**

   The output voltage of this solar charger is 24V DC. The input voltage of dental device is 110V AC. It is necessary to adapt the output voltage from the solar panel. The main function of an inverter is to rectify a DC power to a desired AC power. In addition, the inverter must have high efficiency, stable output voltage, and reliable manufacturing quality so that the Wig-L-Bug is not damaged by the inverter.

3. **Inverter Cable**

   In order to build the circuit, the team needs to cable to connect between inverter and batteries. The cable is provided by the manufacturer of the inverter. The cost is 30 dollars. Since the cable is light and small the weight and size of the cable is negligible.

4. **Cost Analysis**

Table 5 Summary of Solar Design

Component	Size(in)	Weight(lb)	Cost($)	Quantity	Total Cost($)
Solar Charger	8.5×14.5	3.2	940	1	940
24V Inverter Modified Sine-wave	5x2.25x7.25	4.2	40	1	40

Cable	5x9.5x2.5	0.8	30	1	30
Total	14.5x8.5x5	8.2			1010

Design 3: Battery only

- **Description**

  In battery design, we mainly use the battery as the power supply for the project. For the battery standard, we need four batteries and the standard voltage has to be 3.7V. So, the total will be 14.8V. The capacity has to 10-20 Watt hours. Charge current is 3 A, and discharge current is 7 A. In this project the weight is the most important factor which we have to consider because it has to fit the suit case in the airplane. So, the four batteries will be 7lb.

- **Parts Details**

1. **Charger**

   Charger is needed to charge the power source. In India the standard voltage is 220V. So, the charger will work with the voltage.

2. **Inverter**

   An inverter is used to convert the battery power so can be used by the Wig-L-Bug. And the quantity for that is one.

3. **Frame**

   For the frame, we mainly use the plastic board as a material, because it is insulated which can prevent workers from getting an electronic shock. At the same time it is a light weight that it would carry it without damage it.

4. **Cost Analysis**

Table 6 Summary of Battery Only Design

Parts	Quantity	Price ($)	Subtotal ($)
Battery	4	60	240
Charger	1	30	30
Inverter	1	20	20
Frame	1	20	20

		Total	310

3. Concept Selection

3.1. Raw comparison

We have three possible designs: Solar, Generator and Battery only. All three designs have different advantages and disadvantages. For the solar the uninterrupted power is 20% but for the generator and the battery only is 0%. The cost for the solar is almost 1000$ and for the generator is 450$. For the last one the battery is 310$.

Table 7: Raw Numbers

	Solar	Generator	Battery
Uninterrupted Power (% Down Time)	20	0	0
Cost ($)	1000	450	300
Weight (lb)	12	25	25
Life Span (hour)	500	500	1000
Size (Within 56 x 45 x 25 cm)	yes	yes	yes
Peak Output (watt)	120	400	250

3.2. Criteria Selection

The first step in comparing the criteria is to normalize the raw data. To do this, the numbers from Table 8 were converted to a 0-10 scale. The worst in each category received a zero, and the best received a ten. Numbers that were in between were scaled appropriately.

Table 8: Normalized Data

	Solar	Generator	Battery
Uninterrupted Power (% Down Time)	0	10	10
Cost ($)	0	7.5	10
Weight (lb)	10	5	5
Life Span (hour)	5	5	10

The next step was to rank each criterion in order of importance. To do this, the criteria were ranked in importance relative to other individual criterion. In the table below, the criterion in the row is ranked in importance to the criterion in the column. If the row criterion is much more important, it receives a three. If it is just as important, it receives a one.

Table 9: Weighted Criteria

	Uninterrupted Power	Cost	Weight	Lifespan	Raw Total	Normalized Total
Uninterrupted Power	1	2	3	3	9	0.425
Cost	0.5	1	3	2	6.5	0.307
Weight	0.33	0.33	1	2	3.66	0.173
Lifespan	0.33	0.2	0.5	1	2.03	0.096

Uninterrupted power was judged to be the most important compared to other design criteria. Our client only has a limited amount of time to get the work done. Any down time is wasted time, and that is unacceptable. Keeping cost low is important. If we can save money by adding a few pounds to the device, this is acceptable, as long as the power supply is still portable. Lifespan received the lowest ranking, because all of these designs will likely last for years. Table 10 shows each design ranked by the normalized and weighted criteria.

Table 20 Normalized and Weighted Criteria Chart

	Solar	Battery
Uninterrupted Power	0	4.25
Cost	0	3.07
Weight	1.73	0.865
Life Span	0.48	0.96
Total (Higher is Better)	2.21	9.145

Solar power is out of the question. High cost and inconsistent power delivery bring the score down to a non-competitive level. The manual generator and the battery are very close in score. At this point, the team will go ahead and design the battery. The manual generator will be considered for later construction at the sponsor's request.

4. Engineering Analysis

The dental hygiene device runs off of United States household electricity (110V 60Hz). To determine power usage, the device was tested in the CEFNS electronics lab. Figure 1 shows the results at different power settings.

Table 11: Power Consumption

Power setting	Peak Power Usage (W)	Continuous Power Usage (W)
Low	60	35
Medium	60	40
High	60	45

When set to run for 10 seconds, the power consumption would briefly spike at about 60 Watts and then settle down to the continuous power usage within one second. For our design, we will use the continuous power usage on the "High" setting to determine the necessary energy capacity of the storage device, and the peak power usage on the high setting for determining the necessary peak output of the storage device.

According to our Objectives/Constraints, the device will need to be run for a ten hour period. When used, the device will be loaded with a cartridge and run for 10 seconds. The cartridge will then be swapped out with a new one. It takes roughly ten seconds to swap out a cartridge, giving us an extreme case duty cycle of 50%.

The electricity stored in the power supply must be inverted from 12 VDC to 110 VAC. In order to do this, we must use an inverter. Using an inverter efficiency of 90%, we come up with the total energy capacity and peak power output of the storage device:

$$\frac{45W}{.9} \times .5 \times 10hr = 250\ Wh \qquad \text{Eq. 1}$$

$$\frac{60W}{.9} = 67\ W \qquad \text{Eq. 2}$$

Equation 1 is the minimum amount of energy the battery needs to store. Equation 2 is the minimum peak output of the battery.

5. Final Design

Team 15 has decided to go with a battery design. The battery was chosen over the other options due to being lightweight, cheap, and reliable. The main components of the design are the battery, the inverter, the battery charger, and the plastic housing.

The charger can be powered by 110V US household current, or 220V current used in other countries. It is capable of charging in 9 hours. The battery is a lithium ion pack that is regulated at 12 volts and has a capacity of 296 Watt-hours. The inverter has a pure sine wave output form, and can continuously put out 180 watts. All of these components are contained in a lightweight, durable plastic case.

When tested together, the battery and inverter can power a 60 Watt Light bulb for four hours. This equates to roughly 5 hours of Wig-L-Bug operating time, meaning that 1500 – 2000 cavities could be filled on one battery charge.

6. Future Tasks

The Wig-L-Bug power supply is complete. It has received approval and been delivered to the sponsor. The sponsor has mentioned that she may require another power supply next year, but as far as we know right now, we are done.

7. Project Plan

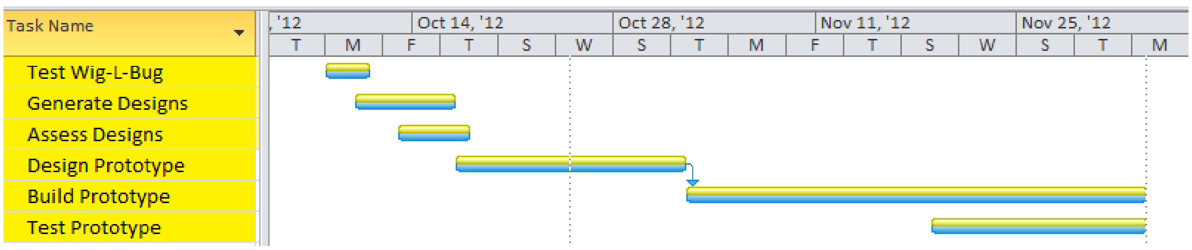

Figure 8 Gantt Chart

So far, we have finished our final prototype and demonstrated it to our sponsor. It provided sufficient power for Wig-L-Bug. In this semester, it took 3 days to test Wig-L-Bug in lab, and we got its working voltage, current and power. In the process of generating assessing designs, we came up with many concepts for power source, and three designs are mainly considered. Finally, we selected battery only design referring its weight, cost, reliability, and capacity. We spent about 22 days in building a prototype. We connected a battery, a charger, and an inverter properly, which are contained in a designed package. Finally, some of team members tested this power source with a 60W light bulb, and it supported about 4 hours' power for this bulb. In addition, it took about 8 hours to fully charge this power source.

8. Conclusion

In this December, a team of professors and students of NAU Department of Dental Hygiene will provide dental hygiene service in India but there is no electricity which can be supplied for their device. Therefore, it is quite necessary to design and build a portable power source for Wig-L-Bug. This power source should be durable, which our team plans to test by dropping it form a certain height. Our team would make sure a long life span, which is determined by the number of charge cycles. Another important factor is that it should be portable so that it is convenient to transport.

In the process of designing and building this power source, there are seven constraints we need to consider. It must have a stable AC voltage of 10 V at 60 Hz and the maximum output of 1.2 Amps. In addition, it must be able to power Wig-L-Bug continuously for 10 hours. In order to make sure its portability, it cannot weigh more than 12 kg and must be able to fit in a 56 × 45× 25cm container. Moreover, it must be able to be charged form 0% to 100% in eight hours on 220V at 50Hz.

Our team mainly considered three designs, battery only design, hand generator design and solar design. In battery design, we mainly use the battery as the power supply for this project. As for hand generator, a crank with a chain or belt turns a small automobile or motorcycle alternator. The alternator is wired in parallel with a lightweight scooter battery. A DC to AC inverter is run off of the battery.

Finally, Team 15 has decided to go with a battery design. The battery was chosen over the other options due to being lightweight, cheap, and reliable. The main components of the design are the battery, the inverter, the battery charger, and the plastic housing.

References

Sponsor:

Department of Dental Hygiene

Project Website:

http://www.cefns.nau.edu/interdisciplinary/d4p/EGR486/ME/13Projects/Concussion/

Resources:

- No Harmony in Harmonics. Wed. 26 Oct 2012. http://www.bomara.com/powerware/wp_harmonics.htm
- General Recommendations for Alternative Current and Hybrid Systems. Wed. 26 Oct 2012. http://www.stecasolar.com/index.php?Inverter_selection
- Safety Advisory for consumer Fireworks. Wed. 26 Oct 2012. http://safetravel.dot.gov/