Green Energy Tent-Light with GPS Locator: A Real Product for a Real Customer

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Green Energy Tent-Light with GPS Locator: A Real Product for a Real Customer

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Abstract

A Team of four Raritan Valley Community College (RVCC) students were tasked to design, prototype, and deliver a real product to a real customer. The product was a backpacking tent-light that provided battery-free light for two people to comfortably read for 30 minutes and contained a GPS receiver/Cell transmitter to send location coordinates to a home-base. The objective of the course was to expose students early in their academic careers and under "authentic engineering" conditions, to vital skills and practices used in industry. A secondary goal was to give students experiences in-depth to relate to potential internship and professional employers.

Keywords

Authentic, Customer, Hands-on, Engineering, Energy

Introduction

In late January of the Spring 2017 semester, a Raritan Valley Community College (RVCC) Authentic Engineering Experience Team of three engineering and one computer science student sophomores received a request from a Customer, an avid backpacker, for a tent light which provides readable light for two people for thirty minutes without the use of batteries. In addition, the tent light would also function as a GPS receiver/Cell transmitter sending location coordinates to a phone or web-site at the Customer's home. Other constraints, such as weight, dimensions, and water resistance were defined, but the Customer did not indicate or suggest how to achieve the required product performance – those decisions were left entirely to the student Team. The Customer required a finished product by the delivery date of May 1, 2017.

The student Team members were treated as Professional Engineers in an Engineering-Solutions company – not as students. Although guided by industry-experienced staff, the overwhelming emphasis was for the student Teams to reach their own designs, experience their own failures and successes, resolve their own communications conflicts, and respond to critical Customer comments.

The objective is for students to be exposed early in their academic careers and under "authentic engineering" conditions, to vital skills and practices used daily by professional Engineers. Most importantly students are taught – and experience first-hand – that success comes from never giving up. These experiences differentiate students and gives them an authentic story to relate to potential internship and professional employers.

The spirit of this project is aligned with previous and on-going efforts to expose and engage students in "authentic" engineering experiences and environments through, for example, Hands-on projects[1-5], Project Based Learning[6], Service Learning[7], Learning Factories[8], and Capstone Projects[9].

Industry Skills Focus

All project activity was hands-on and "live" – without classroom lectures or Labs. Principles and skills were experienced first-hand. The focus was for the student team to learn by doing. Concepts and skills emphasized were those directly useful for engineers in a professional/industry environment and included:

- Focus on the Customer - Communicate with the customer, understand, and negotiate the customer's needs, conduct interim demonstrations, and deliver on-time.
- "Do what you say you will do" – Teamwork, division of labor, project planning, task execution, leadership, and responsibility.
- Engineering Prototyping – Idea generation, start simple then improve, face high-risk problems first, think through each step in-detail to reduce risk
- Grit– Never ever give up, ever.

Voice-of-the-Customer

The Authentic Engineering Experience Team of three engineering and one computer science student Sophomores was not informed of any of the details of the project until they sat in front of the Customer to learn the details of the product request and specifications.

The full Customer requirements were a battery-free backpacking tent-light that provided light for two people to read for 30 minutes without recharging and a GPS receiver/Cell transmitter sending location coordinates to a home base (Fig. 1). The initial charging time was required to be less than 2 minutes and only 1 minute for further recharges. Additionally, the tent-light must fit inside a 10cm-sided cube, weight less than 300g, have "high", "low", and "flashing" LED light options, and be waterproof under direct rain conditions.

Focus on the Customer

The Team started by focusing on the Customer's need for light to read and worked backwards. The first questions addressed were how many of what lights were needed and in what configuration to provide sufficient light? Questions that followed were how much power is required for 30 minutes of illumination, how to store the electrical energy, how to generate the "green" power and then deliver it? In parallel, the Team asked how to receive GPS signals and transmit them by cell at low power? And finally, how to package everything into a 10cm cube!

Technology Selection, Prototyping, and Design

<u>LEDs and LED Pattern</u>: The number of LEDs and LED pattern was determined by suspending different configurations of LEDs at a height of 3ft above the floor in a dark room to simulate a mountain tent. The students sat within a 6-ft diameter circle and attempted to read text on a sheet of paper. Every effort was made to minimize the number of LED lights to minimize the power consumption since all energy ultimately needed to be generated on-site by the Customer. Multiple reflector designs were attempted to angle the LEDs, use reflective materials, and direct

light to the Reader. The combination of 3D-Design software (Inventor) and a 3D-Printer (Makerbot) made rapid prototyping and testing possible. The final configuration was 6 clear (no-color) LED (“High) and 3 LED (“Low) lights, tilted at 20 degrees outwards, around the circumference of a circle of 5.0cm in diameter, and used “ultra-white” reflective paint.

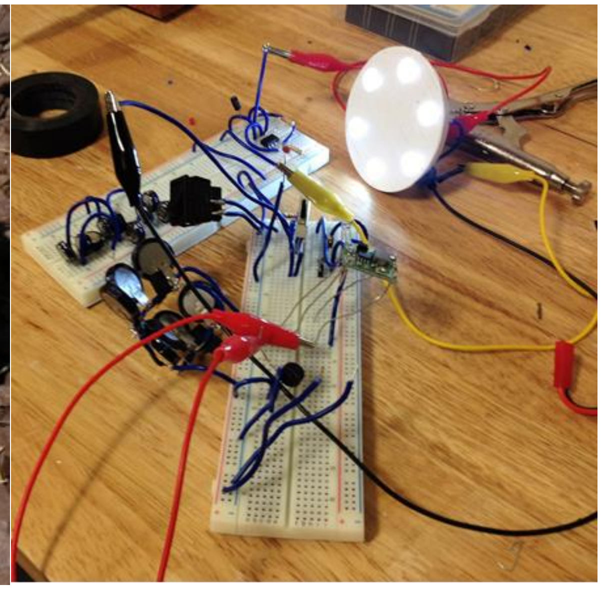

Figure 1(left): The Tent-Light product showing the 3D-Printed knurled case, circular LED light configuration, activation switch, deployable charging handle (shown folded), and waterproof solar power auxiliary input port (far right) and Figure 2 (right): prototyping to determine the required number of capacitors for 30 minutes reading light.

Power Requirement and Energy Storage: The electrical power required to generate light for the full 30 minutes was first estimated by multiplying the LED voltage (3.0V) and current (20mA) yielding 60mW of power per bulb. But multiplied by the 30-minute operational time gave a required energy far beyond expectations. The reason, determined by the Team, was that the LEDs did not need to be driven at maximum power to provide sufficient light for reading. An alternate approach was to charge capacitors using a power supply and time the duration of useful bright light for 6 LED lights (Fig. 2). The result was a linear relationship with a slope of 5 minutes of reading light per Farad of capacitance – or 6 Farad total capacitance for 30 minutes.

Energy Generation: Charging capacitors with a DC power supply or batteries is not a challenge. But the Customer wanted battery-free light. So, the Team evaluated different potential power generation methods to select the most effective and convenient for use at the end of a day by a fatigued Customer completing a long and arduous trek.

> *Piezoelectric* – Piezoelectric energy generation uses special materials that transform mechanical deformation energy into electrical energy. The students found that tapping on a piezoelectric disk created a significant transient electric voltage, but not enough current to charge a capacitor in the amount of time required.
>
> *Thermoelectric* – Thermoelectric cells generate electricity because of a temperature difference between the cell faces. The small temperature differences expected between body heat and the ambient air was too small to produce more than 10s of millivolts of potential and

so was not sufficient to charge a capacitor above the required 3V. The Team's experimentation did find that the use of a heat-gun at 300C and ice-packs on the cold side did produce enough power to light the LED lights, but was not a practical solution.

Electromagnetic Induction – The relative movement between an electrical conductor and a magnetic field generates a voltage and current through induction. Capitalizing on the availability of low-cost and high-quality DC electric motors, The Team experimented by mechanically rotating the motors as generators. This approach was identified to be the best technology because of its ability to continuously generate significant electrical power and the flexibility to add gearing to the motor for different charging rates, and was chosen as the primary tent-light charging method.

Solar – Solar was chosen as an auxiliary energy source and further designs incorporated a water-proof electrical port that allowed a small robust solar panel to be plugged into the tent-light for longer term charging of the GPS/Cell locator circuit.

<u>DC Motor Selection:</u> A range of 12V and 24V DC brushed motors with gear-trains were obtained and tested for power generation and torque. A meeting was held with the Customer to define the acceptable range of torque the Customer was willing to accept to charge the tent-light for 2 minutes. A higher gear ratio allowed a greater number of motor turns and resulting electrical power generated per gear revolution, but also greater torque. A sustainable rotation rate of 30 -60rpm was determined to be acceptable.

The Team conducted further motor characterization by plotting the electrical power generated as a function of the input torque for a variety of commercial motor brands and types to select a motor with the highest electrical power-out for torque-in while maintaining a reasonable cost. The Team had to think from the customer's point of view and look for solutions to minimize torque by changing the cases and choosing the correct motor. The final selection was a Uxcell 12V 95:1 gear ratio DC motor that generated 10.8W for 8kg-cm torque at 50rpm.

<u>Energy Storage and Delivery Circuit:</u> The initial circuit design used a RC-Circuit combination of 3X1-Farad and 9X(1/3)-Farad capacitors totaling 6 Farad of capacitance and a small 10 Ohm resistor. The capacitors were of the high-capacitance/low voltage electric double-layer type (SuperCaps). All capacitors were soldered in a parallel circuit formation to maximize energy storage at low voltages. This circuit provided 30 minutes of light, but at too low intensity for comfortable reading. After further research, the 1F capacitors were found to possess one-half the internal resistance than the 1/3F capacitors and so a new 6X1 Farad circuit, without an external resistor, was made to give satisfactory brightness for 30 minutes of reading. This is the solution used in the tent light.

A 4-way switch and wiring was used to control the "high" brightness (6-LED), "low" brightness (3-LED). A 555-timing transistor was added to control the requested "blinking" mode.

<u>GPS/Cell Circuit and Code:</u> Significant research was conducted into low-power solutions for the GPS location coordinate system required by the Customer. Sending the signal by an on-board dedicated radio was determined to be energy prohibitive. Since global coverage was not a requirement for the product, the focus changed to using an established company with an existing local network that could be accessed with a smaller cellular-based module. Components for a GPS-receiver and cell transmitter were purchased separately (Adafruit) and tested.

The goal was to avoid using batteries also for the GPS/Cell locator part of the project and generate all the "green" power needed. But the cellular module required a continuous low power-on state and 90 second high-power consumption during the sending of the location coordinates every 20 minutes. The total power requirement was greater than the power needed for the LED lights, such that the decision was made to use an independent lithium-polymer battery and on-board charging circuit powered by a portable solar panel.

Initially, the GPS/Cell locator did not work, even in the optimal conditions of clear "viewing" of GPS satellites and strong Cell signal. With further testing it was realized that an additional antenna and signal boosters, that would have been included in a more complete module, were needed. Rather than adding these components, the new complete module was purchased (Adafruit FONA 808) and functioned as expected when tested using code that allowed us to test individual settings of acquiring location and transmitting a message. The software library utilized was developed for universal use, as adapting it to functions took more steps than anticipated, but the code-related problems encountered were easily fixed.

Case Mechanical Design and Final Tent-Light Assembly: The objective of the case design was a waterproof case that could be easily held by one hand allowing the second hand to rotate a handle to spin the DC motor to generate electricity. The combination of the 3D Design software (Inventor) and 3D Printer (Makerbot) allowed multiple case designs to be realized, evaluated, ands iteratively improved.

Designs included cases with varying degrees of roughness and patterning for better grasping, combinations of interlocking cylinders for ease of assembly and water-proofing, location and orientation of the DC motor, capacitors, circuits, and GPS/Cell locator components, and type of motor rotation handles. The case was highly space constrained to fit into a 10cm cube volume!

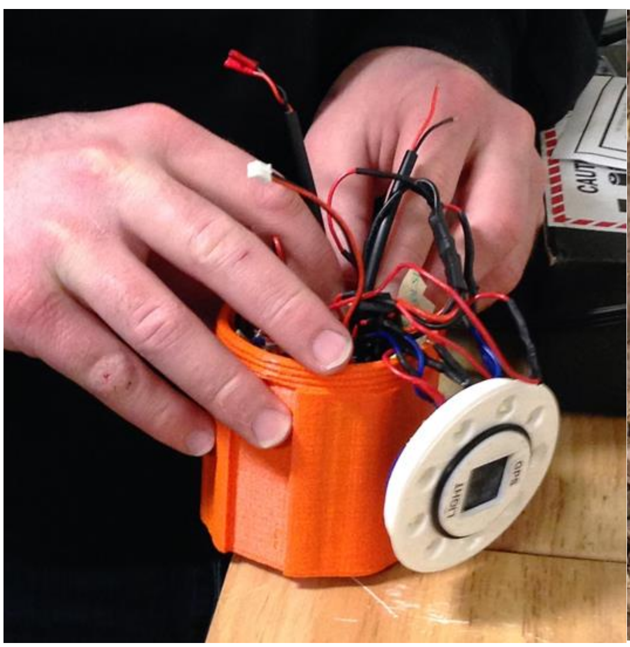


Figure 3(left): The Tent-Light product showing the challenge of fitting all components into the constrained product case and Figure 4 (right): the open-view of the completed Tent-Light product

For example, in one iteration, the motor was turned by using a freely rotating lower section of the case that was co-axial with the upper case. This design had the advantage that the entire tent-light function remained within the dimensions of the cylinder. The disadvantages were that to turn the case and motor, the Customer's hand would need to re-grasp the rotating cylinder after each rotation, thereby causing the electrical charging to be discontinuous, and the radius of the case was small requiring a greater applied force to achieve a higher torque.

Because it was advantageous to use the chosen higher-torque, higher-gear ratio, and higher power-output DC motor, the final design configuration was:

- A deeply grooved case for easy grasping, an off-axis mounted motor and gear-train
- Capacitors wrapped along one side of the motor cylindrical case
- LED lighting circuit at the top of the tent-light case
- The GPS/Cell module in the annular space adjacent to the motor and a deployable longer lever-arm hand crank that allowed continuous rotation and spinning of the motor using lower force and that folded into the case side when not in use.
- Waterproofing at all case joints using O-ring seals

Customer Demonstration

For the final meeting with the customer, the Team prepared and presented a customer "Fact Sheet" that was personalized to illustrate the tent-light features to the customer in a way that was less technically formal. This included a simple walkthrough of each of the functions, a list/description of the features and benefits, a troubleshooting section, and the Team's personal sentiments on completing and presenting the final product to the customer.

The Team achieved all the requirements of the Customer's initial product request with the exception that the weight was 450g instead of the target <300g. The scope of the project pushed the limits of what the students could accomplish in one semester and a real, near marketable product was the result.

The Customer was so impressed with the tent-light design and function that the product will be the basis for a new Fall 2017 Authentic Engineering Experience Team project in conjunction with the RVCC Graphic Design II class to further reduce the product volume, weight, and charge time.

Conclusion

A Team of four Raritan Valley Community College (RVCC) students successfully designed, made, and delivered to a real customer, a real backpacking tent-light product that provided battery-free light for two people to comfortably read for 30 minutes and contained a GPS receiver/Cell transmitter to send location coordinates to a home-base. The student Team learned and practiced hands-on in "authentic engineering" conditions vital skills and practices used in industry. The students also gained in-depth knowledge and experience to relate to potential future internship and professional employers.

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References

1. H. Tawfik, Y. Ryu, and R. Kowalski, "Education through Applied Learning and Hands-on Practical Experience with Flex Fuel Vehicles", Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. June 2017, https://peer.asee.org/27417
2. K.M. Park, "Advanced Manufacturing Laboratory to Enhance STEM Learning", Paper presented at 2017 ASEE Mid Atlantic Section Spring Conference, Morgan State University, Baltimore, Maryland, April 2017, https://peer.asee.org/29247
3. D.J. Cox, "Development of Hands-on Laboratory Resources for Manufacturing Engineering", Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio, June 2017, https://peer.asee.org/28172
4. P.R. Stupak, S. Rumrill, B. S. Carlsen, T. George, and J. Suriano, "Authentic Engineering Experience: Electromagnetic-Induction Keychain for a Real Customer", Paper presented at 2016 ASEE NE Conference, University of Rhode Island, April 2016, http://egr.uri.edu/wp-uploads/asee2016/162-504-1-RV.pdf
5. P.R. Stupak, M. Romero, J. Sitarz, T. Skibik, E. Smith, N. Vuolde, J. Jannone, M. Zgorzynski, D. McManus (2017, April), "Illuminated Umbrella: An Engineering/Visual Arts Interdisciplinary Product Development", Paper presented at 2017 ASEE Mid Atlantic Section Spring Conference, Morgan State University, Baltimore, Maryland. April 2017, https://peer.asee.org/29257
6. M. Mosleh and M.C.J. Thom, "Design-Build, Project-Based Learning in an Engineering Materials Laboratory", Paper presented at 2017 ASEE Mid Atlantic Section Spring Conference, Morgan State University, Baltimore, Maryland, April 2017, https://peer.asee.org/29252
7. J.L. Huff, C.B. Zoltowski, and W.C. Oakes, "Preparing Engineers for the Workplace through Service Learning: Perceptions of EPICS Alumni," Journal of Engineering Education, January 2016, p. 43 – 69.
8. J.S. Lamancusa, J.L. Zayas, A.L. Soyster, L. Morell, and J. Jorgensen , "The Learning Factory: Industry-Partnered Active Learning," Journal of Engineering Education, January 2008, p. 5 - 11.
9. A.J. Dutson, R.H. Todd, S.P. Magleby, C.D. Sorensen, "A Review of Literature on Teaching Engineering Design Through Project Oriented Capstone Courses," Journal of Engineering Education, January 1997, p. 17 - 28.

Author Biographies

Colin Gray is currently a Junior at the University of Michigan studying mechanical engineering. Colin enjoys working on electrical circuits and working with dc motors. After completing the Tent-Light project, Colin worked at a solar engineering firm working on permit sets for New York city projects. Between modeling equipment and working on construction sets, Colin found himself immersed in real engineering work. Through his experience gained from the Authentic Engineering project, Colin successfully transitioned into being able to create professional work for an engineering company.

George Grabovetz is currently a sophomore in Mechanical Engineering at Raritan Valley Community College. After earning his Associates Degree in May 2018, he plans on attending the New Jersey Institute of Technology (NJIT) for Mechanical Engineering. George enjoys being part of the Engineering Club at Raritan Valley Community College and also enjoys working on and learning about cars and trucks.

Karl Gabrielsen is enrolled in his Junior year at Rutgers University this Fall 2017 working towards his Bachelor's Degree in Chemical and Biochemical Engineering. He takes a special interest in green energy inspired by his previous literature class. Karl has had the unique, second-hand opportunity to learn the demands of a professional engineer through his personal time spent learning from an employee of The Linde Group, a chemical gases company. He thoroughly enjoyed the experience he had with the Authentic Engineering Experience project and seeks to utilize his new skills on more engineering missions at the Rutgers New-Brunswick Campus.

Sam Lecin is currently a sophomore at Raritan Valley Community College. After earning his Associate's degree in Computer Science, he plans to continue studying for a Bachelor's degree at Rutgers University, and hopes to work as a programmer that writes code that controls physical machinery. In his spare time, Sam enjoys sculpting full-scale models of hand-held weaponry, both realistic and fictional, out of aluminum foil. He also volunteers as an alumnus mentor with the Bound Brook High School FIRST Robotics team, ROBBE.

Peter Stupak is an Assistant Professor of Engineering and Physics at Raritan Valley Community College (RVCC). His interests focus on exposing students, under "authentic engineering" conditions, to vital skills and practices used by professional Engineers. Prior to joining RVCC in 2014, Peter enjoyed a 22-year career in the fiber-optics manufacturing industry, living, and working in 7 countries. Peter's work involved him in R&D, Engineering, and Manufacturing culminating in the construction, start-up, and operation of an optical fiber factory in Suzhou, China where he remains the Chief Technology Officer. He holds a B.S. in Chemistry and M.S. and Ph.D. in Mechanical Engineering from the University of Massachusetts at Amherst.