ChargeForge: a Gang Charging System for Physiological Sensors

BME 200/300
University of Wisconsin-Madison
Department of Biomedical Engineering
7 October 2024

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7 October 2024

Abstract

Aptima Inc. and their partner VigiLife Inc. are developing a device that monitors the physiology of Marines such as their heart rate and respiration in order to prevent heat illnesses or other related afflictions during training. There is currently no way to transport and charge these devices at a large scale. Pelican cases, which are hard-shelled carrying cases, are being used to transport devices now, but there is nothing within the cases to organize the devices nor is there a way to connect the devices to a charger. To combat this, a tray is being designed that will be able to be inserted into a Pelican case where the devices can be slid into slots on the tray and be connected to their charger. It will ideally accommodate 40-50 devices, and be able to withstand extensive travel, high temperatures and low temperatures, and other harsh conditions. The material chosen for this tray is ABS, as it is impact resistant, durable, and simple to manufacture and prototype. Ultraviolet radiation may also be used in order to disinfect the tray and devices. The tray will be tested in its device attachment and protection as well as durability through a drop test, and the charging characteristic will be tested through a time functionality test. The results will illustrate the effectiveness of the tray in accomplishing the clients requirements.

Table of Contents

Introduction

Motivation and Global Impact

The development of a wearable physiological monitoring device addresses critical safety concerns in high-risk occupational environments, such as those involving heat stress or confined spaces. Workers in these conditions face significant health risks, and real-time monitoring of physiological data can help prevent accidents, reduce illness, and ensure timely intervention. The lack of an efficient charging and transport system for multiple sensors hinders consistent and reliable usage. This project aims to design a gang-charging system to address the practical need for sensor charging, transport, and disinfection, improving workplace safety on a global scale.

Existing Devices/Current Methods

Masimo Corp filed a patent on a physiological device charging station. This design includes a multiple-level system that holds the trays for the devices. The design has a charging port that protrudes from the bottom of the station to provide charge to the devices. However, this design is very large and not made for easy transportation [1]. One of the main requirements for the design is that it is very easy to transport.

The MSTJRY USB charging station pictured in figure 1 is a 5-port USB charging station designed for consumer devices like phones and tablets. While it offers multiple charging slots, it lacks the durability, UV disinfection, and sensor-specific design needed for physiological monitoring devices in harsh environments. Additionally, it doesn't support large-scale sensor charging or backup power for consistent use.

Figure 1: *MSTJRY USB Charging Station for multiple devices. [2]*

The Belkin BoostCharge Pro pictured in figure 2 is designed for personal use. This wireless charger supports up to three devices but falls short in scalability, lacking the capacity to charge 40-50 sensors and offering no ruggedness, temperature resistance, or UV disinfection.

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Figure 2: *Belkin 3-in-1 Wireless Charging Port. [3]*

The Pasco Wireless Sensor charging station shown in figure 3 is designed for educational sensors, but its capacity (charging up to 10 sensors) is insufficient for the scale of the project. It also lacks features such as UV disinfection, temperature resistance, and backup power that are essential for occupational safety applications.

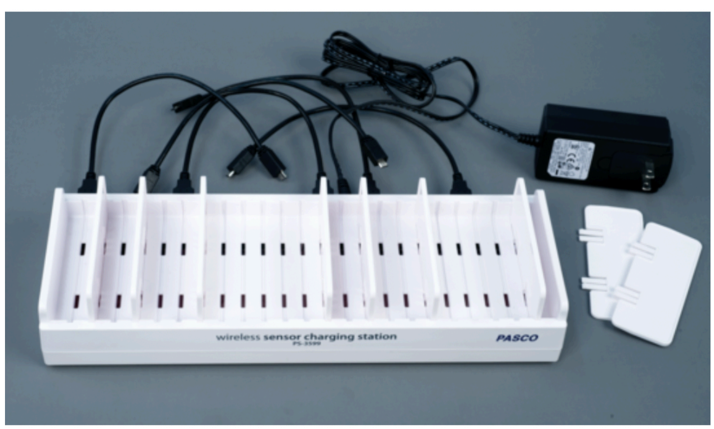


Figure 3: *Pasco Wireless Sensor Charging Station [4]*

Problem Statement

A new wearable device for physiological monitoring, specifically designed for occupational safety in environments like heat stress and confined spaces, is currently being developed. The design contains a hard-shelled carrying case which provides protection but lacks trays that can connect physiological sensing devices with charging cables. Thus, the team is tasked to design and fabricate a gang-charging system to help solve this problem effectively and efficiently. The design should consist of a tray to house the physiological sensors paired with a charging system to ensure constant power supply to the sensors. Overall, the design should be able to transport, charge, and recuperate 40-50 sensors. The charging system ideally should indicate charge and UV levels. The final design should balance cost, durability, and manufacturability.

Background

Relevant Physiology and Biology

The device is predominantly used by the Marine Corps to monitor the heat stress that a soldier experiences in training and combat. This is because high temperatures mixed with the physical activity that soldiers are subjected to every day put them at a higher risk of heat stroke and other heat-related illnesses. In 2021, there were 1,864 incidents of heat-related illness and 488 cases of heat stroke in the US military[5]. Heat-related illnesses are due to heat stress that elevates a person's core and skin temperatures[6]. The symptoms of heat-related illnesses can vary very much based on how severe the conditions that someone is subjected to. The least severe symptoms of heat illness are cramps, rash, swelling caused by heat, and fainting. An increase in the severity of the heat illness leads to heat exhaustion which causes headaches, vomiting, and weakness of muscles. And, finally, if the severity increases more it can lead to heat stroke which causes a person to have an altered mental state, slurred speech, seizures, and even death [7]. The symptoms that come from heat-related injuries can drastically affect each soldier's alertness and ability to focus on the mission at hand. This can be very dangerous since soldiers are put in very stressful situations. In many of these situations the lives of themselves, their units, and civilians are at stake. Ultimately the physiological devices will be able to monitor the core and skin temperatures of soldiers, to prevent heat stress-related illnesses from impacting a soldier in the field.

The physiological device will be predominantly kept at the US Marine Corps bases. Throughout the world, there are 39 US Marine Corp. bases all with very different climates and conditions that could damage the charging station and the devices inside. These conditions include wind, sand, snow, rain, and a high fluctuation of temperatures. This could very easily lead to damage to the charging station and the devices if not properly protected. The Pelican Case solves this concern because it provides a durable, and waterproof housing unit for the charging station and devices.

Client Information

The clients are Isabel Erickson and Kevin Durkee from Aptima Inc. as well as Vigilife and the Marine Corps.

Product Design Specification

The goal of the gang charging system is to provide accurate connection and constant charging of physiological sensors. The tray itself must be made of a material that is durable, easily fabricated, and lightweight. The overall design must be easy and intuitive to operate, safe, durable, as well as it must fit within a Pelican Case of unspecified dimensions. The client requires that the final product house and charge 40-50 sensors and be able to withstand a wide range of temperatures and consistent usage, hundreds of uses per day. Additional requests by the client include a charge display, a UV disinfection system, and internal backup power. Refer to Appendix I for a more detailed explanation of the Product Design Specifications.

Preliminary Designs and Materials

Refer to Appendix X for budget analysis.

Proposed Tray Biomaterial

Acrylonitrile butadiene styrene

Acrylonitrile Butadiene Styrene (ABS) is a popular thermoplastic polymer used as a 3D printing filament due to its strength, durability, and ease of post-processing. ABS exhibits excellent mechanical properties, including high impact resistance, toughness, and good dimensional stability, making it suitable for a tray design. It has a Young's Modulus between 1.9 and 2.5 gigapascals (GPa) [8] and a tensile strength of 45 MPa [9], making it an excellent shock and vibration absorber while resisting cracking and fracturing under loading. ABS has approximately 12.6 kJ/m^2 of impact resistance [10] and a melting point of 473.15 - 513.15 K [11] which allows it to withstand moderate temperatures before deforming. However, ABS releases potentially harmful fumes, including styrene, when heated during the printing process, which necessitates adequate ventilation or the use of an enclosed printer with proper filtration. It is also slightly hygroscopic, meaning it should be stored properly to avoid moisture absorption, which can impact printing quality [12]. ABS's combination of toughness and thermal stability makes it ideal for printing functional prototypes and end-use parts, but safety precautions should be taken during use.

High-Density Polyethylene

High-Density Polyethylene (HDPE) is a versatile and lightweight thermoplastic commonly used as a 3D printing filament due to its excellent chemical resistance, durability, and flexibility. HDPE offers good mechanical properties, A Young's Modulus that ranges from 600 to 1500 MPa [13] and a tensile strength of approximately 35 - 40 MPa [14] as well as a low density, approximately 930 to 970 kg/m^3. [15], which contributes to its strength-to-weight ratio. It also exhibits high impact resistance and good flexibility, making it useful for applications requiring durability under mechanical stress. HDPE has a relatively low melting point, ranging from 390 - 410 K [16], giving it good thermal stability for cold environments. HDPE is chemically inert and resists moisture, but due to its warping tendencies during 3D printing, careful attention to bed adhesion and temperature control is necessary. From a safety standpoint, HDPE does not emit toxic fumes during printing, making it a safer option compared to filaments like ABS.

Polyethylene Terephthalate Glycol

Polyethylene Terephthalate Glycol (PETG) is a popular 3D printing filament that combines the strength and durability with the ease of printing. PETG is known for its excellent mechanical properties, including high tensile strength of 31.3 Mpa[17], a Young’s modulus of 2.01-2.11 GPa [18], good flexibility, and impact resistance, making it ideal for functional parts that need to withstand mechanical stress. It also has excellent chemical resistance and is less prone to warping compared to other 3D printing filaments. PETG's thermal properties include a melting point between 538.5 K [19] allowing it to maintain stability at higher temperatures. PETG prints well without the need for a heated enclosure and has good bed adhesion, reducing the risk of warping. In terms of safety, PETG is a relatively safe filament to print with as it produces minimal odors and no toxic fumes. Its combination of strength, flexibility, and ease of use makes PETG a popular choice for both prototyping and functional parts.

Proposed Tray Design

Design 1

This tray is designed with a rectangular profile, tailored to fit within a Pelican Case of unspecified dimensions. It features 20 recessed divots, each specifically designed to securely hold physiological sensors of unknown dimensions. Integrated magnetic mechanisms within each divot ensure stable positioning of the sensors, maintaining continuous contact with the underlying charging system. The charging system is designed to be wireless, utilizing inductive charging technology, and will be seamlessly incorporated beneath the tray, housed within the Pelican Case. This ensures that the sensors remain charged and operational while securely stored, offering a streamlined and efficient solution for both transport and recharging.

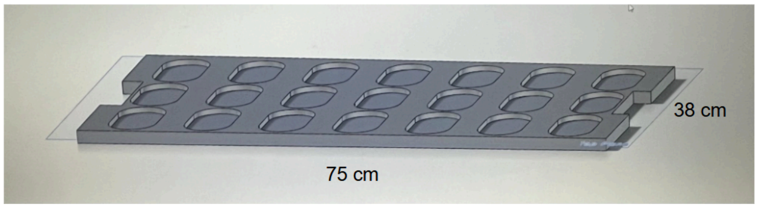


Figure 4: *Shows Design 1 and an idea of its dimensions*

Design 2

This design features a compact charging dock intended to fit within a Pelican Case provided by the client of unspecified dimensions. The dock is capable of holding and charging multiple physiological sensors, which are positioned vertically into individual charging slots and held in place using magnetic mechanisms. Each slot is designed to accommodate a sensor securely, with the dock ensuring a stable connection for efficient charging. The charging unit connects to a power source via USB cable, which is attached at the back of the dock. The charge will be distributed to each sensor via inductive charging. The ergonomic design allows for easy insertion and removal of the sensors, providing a streamlined and organized charging solution that complements the overall system within the Pelican Case.

Figure 5: *Shows the proposed Design 2*

Preliminary Design Evaluation

Tray Material Matrix

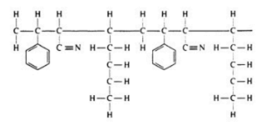
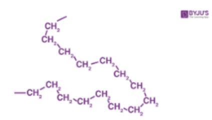
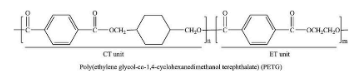
Materials Design							
Material		ABS		HDPE		PETG	
Pictures		 *Figure 1: Chemical Composition of Acrylonitrile-Butadiene-Styrene [1]*		 Figure *2: Chemical Composition of High-density Polyethylene [2]*		 Figure *3: Chemical Composition of Polyethylene Terephthalate Glycol [3]*	
Criteria	**Weight**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**
Durability	30	5	30	4	24	4	24
Manufacturability	20	5	20	4	16	5	20
Weight	20	4	16	5	20	3	12
Safety	15	3	9	3	9	5	15
Cost	10	4	8	5	10	4	8
UV Resistance	5	4	4	2	2	3	3
Sum	**100**	**Sum**	87	**Sum**	81	**Sum**	82

Figure 6: *The Design Matrix ranks the three designs based on durability, manufacturability, weight, safety, cost, and UV resistance with criteria weighted by importance. The final ranking shows that the ABS won.*

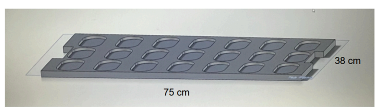
Proposed final design

After evaluating the design matrix, the proposed final design was to use Acrylic Butadiene Styrene (ABS) as a 3D printing filament to 3D print the tray. It possesses mechanical and thermal properties that meet the clients requirements for the final product. The density of the material causes it to be slightly heavier than HDPE but it is much stronger. The manufacturability also allows for the straightforward and repeatable creation of the tray using machines easily available at the University of Wisconsin-Madison.

See Appendix III for an in-depth analysis and criteria explanations for the Tray Material Design Matrix.

Tray Design Matrix

***Figure** 7: The Design Matrix ranks the 2 designs based on accuracy of connection, ease of use, durability, manufacturability, safety, and cost with criteria weighted by importance. The final ranking shows that Design 1 won.*

Proposed Tray Design					
Design		Design 1		Design 2	
Pictures					
Criteria	**Weight**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**
Accuracy of Connection	30	5	30	5	30
Ease of Use	25	5	25	4	20
Durability	15	3	9	5	15
Manufacturability	15	5	15	3	9
Cost	5	5	5	4	4
Safety	5	4	4	5	5
Sum	**100**	**Sum**	88	**Sum**	83

Proposed final design

After evaluating the design matrix, the team decided to proceed with Design 1. This design provides an easy to use solution that ensures accurate connectivity between sensors and chargers as well as sufficient durability. The durability may be more of a concern for Design 1; however, testing will be conducted to ensure proper thickness and strength.

See Appendix X for an in-depth analysis and criteria explanations of the Tray Design Matrix.

Fabrication/Development Process

Tray Materials

ABS (Acrylonitrile Butadiene Styrene):

- ABS was selected for its excellent durability, impact resistance, and ease of manufacturability through 3D printing. Its lightweight properties and cost-effectiveness make it an ideal choice for components that require both strength and affordability. ABS is also moderately resistant to UV exposure, making it suitable for environments with moderate outdoor use.

HDPE (High-Density Polyethylene):

- HDPE was chosen for its high durability and resistance to environmental conditions such as humidity and temperature fluctuations. Its lightweight nature makes it perfect for a portable system, while its non-toxicity and chemical resistance ensure safety in harsh conditions. However, its limited UV resistance may necessitate additional treatment or protection for long-term outdoor use.

PETG (Polyethylene Terephthalate Glycol):

- PETG offers a balance between durability and safety, with high impact resistance and non-toxicity. It is easily 3D printable, making it convenient for complex designs. Although heavier than ABS and HDPE, its superior heat resistance and flexibility in design make it a strong contender for applications exposed to high temperatures. However, its UV resistance is moderate, which could affect long-term performance.

Methods

Material Fabrication Methods

To construct the prototype of the gang charging system, 3D printing and injection molding techniques will be utilized depending on the chosen materials. ABS and PETG will be 3D printed in the Makerspace using precise design software and set specifications. HDPE requires molding processes such as injection molding and extrusion due to its material properties, which can be performed in the Engineering Centers Building.

The steps were as follows:

1. **Material Selection:** Based on the characteristics of material (ABS, HDPE, PETG), the most suitable material will be selected for specific sections of the tray.
2. **Conceptualization:** Brainstorm the overall functionality and form of the charging tray and system, focusing on essential aspects like portability, ease of assembly, and compatibility with physiological sensors.
3. **Sketching & Rough Prototypes:** Rough sketches will be made to visualize the tray and charging system's layout and port placement. These drawings will be used to ensure the selected materials would align with both structural and functional needs.
4. **Feedback & Refinement:** The rough designs and material choices will be reviewed and gather feedback, and be adjusted before proceeding with the CAD model.
5. **Design**: CAD software will be used to create detailed digital models of the charging tray.
6. **Printing**: The designs will be printed using 3D printers or molded through injection molding (for HDPE).
7. **Charging System Circuit Development :** Design the circuit for the gang charging system. This involved creating a layout that could efficiently distribute power to multiple physiological sensors simultaneously. Prototype will be done on a breadboard and conduct multiple tests to confirm that the sensors were charging properly and safely.
8. **Assembly**: Components will be assembled and tested to ensure proper fit and functionality.

Final Prototype

The goal for this semester is to make a hard-shell cased gang charging system that is able to transport, charge, and recuperate 40-50 sensors simultaneously without overheating, with a charge level indicator and UV disinfection mechanism. It should be simple and intuitive, and easy to remove and insert sensors. The prototype will be robust and have a reasonable level of UV resistance enough to withstand daily use in a military environment.

Testing and Results

Testing

*All test will be performed in future

Test 1 *- Drop Test*

1. The tray will be dropped on a hard surface that is kept constant throughout all trials.
2. It will be dropped from three heights: 1 meter, 1.5 meters, and 2 meters. These are meant to simulate the range of heights the tray may be dropped from when in use.
3. It will be dropped in three different orientations at each height: flat(bottom-down), edge(side-down), and on a corner. This ensures locating any weak points in the design.
4. After each drop, the tray will be checked for cracks, dents, loss of structural integrity or other damage, and this information will be documented
5. This makes a total of nine drops per trial, and after each trial, the tray will be evaluated on overall damage resistance from a scale of 1-10, with 10 being undamaged.
6. Repeat this trial two more times for a total of three trials while printing and using a new, undamaged tray for each trial
7. (If pelican case is obtained) - Repeat three more trials of the same steps where the tray is installed in the pelican case, and repeat the observations as above. In this instance, after each drop, open the pelican case and examine the tray for damages.

Test 2 *- Device Containment and Protection Test*

* This test will hinge upon if the client provides a device to work with. If not, an object will be found or created that is similar in size and weight to perform the test.

1. The device(or device replica) will be placed in the tray design. Depending on how many devices or device replicas are available will determine how many tray slots are used.
2. A drop test will then be performed from 1 meter, 1.5 meters, and 2 meters and in all three orientations as above in test 1. This is subject to change once further details on the tray, pelican case, and device access are known.
3. After each drop, assess if the device is still in its original position and if it underwent any deformation, cracking, or any other damage. Note these observations in a data table.
4. Repeat these steps for three trials with a new tray for each trial.
5. (If pelican case is obtained) - Repeat three more trials of the same steps as above where now the tray is installed in the pelican case, and the device is placed in a tray slot within the pelican case. After each drop, open the case and make the necessary observations of the device.

Note - Future design may be charged magnetically which may affect these tests.

Test 3 *- Charging Functionality Test*

* This test also depends on getting the device from the client, but an alternative device that uses the same charging mechanism may be an option.

1. Note what percent of battery life the device has left. If this is not an option, use the device until it is dead so that it will be at 0 percent battery.
2. Place the device on the charger(whether it is in a tray slot or separate) and start a timer.
3. Wait until the device is at one hundred percent and stop the timer, recording the time.
4. Divide the percent that the device went up(if it started at zero, this would be 100) by the time to get the rate of charging in percent/time.
5. Perform this trial three times and obtain the average rate and determine if this an effective charging rate for the clients needs.
6. (Continuation if applicable)If multiple chargers are able to be wired together in a circuit, perform this same trial three times but with the number of chargers that are available all being used, and find the average rate of charging in this case. Then compare the results of just one device charging at a time. Record all data.

Further testing can be designed to combine charging and drop testing to ensure charging connection is secure through adverse carrying conditions that could come from pelican case movement.

Results

*Specific results and data will be available once testing is complete

Test 1 *- Drop Test*

Test 1 will effectively evaluate if the tray design is able to remain intact and in usable form after several drops and in different orientations. This will ensure the product is up to client standards as it has to withstand extensive travel and also will be used in sites where transport will not be the most careful. Ideally, there will be little to no damage to the trays dropping from these heights, as the chosen material ABS and design, durability has been a large consideration.

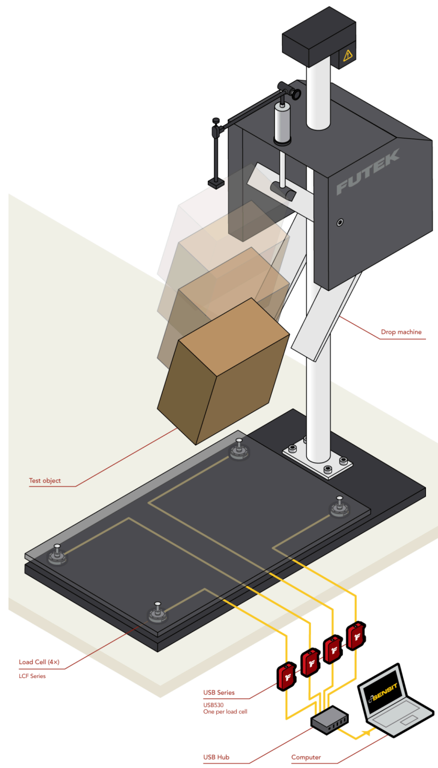


Figure 8: *Shows an example of conducting a drop test. [20]*

Test 2 *- Device Containment and Protection Test*

Test 2 serves to ensure that when in the tray, the device will not be at risk of becoming detached whether in the pelican case or not. This is important as there will be many devices in the tray, and if they are falling out it will create a mess in the case. Staying in the tray will also protect the device from other damages while being transported. Further down the line, when the electrical component of the design is in place, it will also be key to maintain a solid connection between the device and the tray so that charging occurs. The results of this test will show if these tasks are accomplished.

Test 3 *- Charging Functionality Test*

Test 3 will validate if the designed charging system is functional and works at an efficient enough rate to effectively charge the device. This is vital to the client as constant charging while in the tray is an important requirement. This test will evaluate if the tray will accomplish that goal, and also show if charge can be extended to multiple devices at the same time

Discussion

The expected outcomes of our testing hold interesting implications especially regarding the deployment of the gang charging system in demanding environments requested from our client. For example, passing the drop test from 1, 1.5, and 2 meters respectively with little to no damage would prove that the durability demonstrated by the ABS tray would suggest that it can reliably withstand the rigors of daily use in high risk settings. The ruggedness of this design is particularly noteworthy when compared to consumer-grade options such as MSTJRY USB and the Masimo Corp changing stations which lack the necessary durability and capacity.

Ethical considerations were a priority to our research and development process. Ensuring the safety of users was critical, leading us to select materials like ABS that are non-toxic in their final form and suitable for prolonged human interaction. The inclusion of UV disinfection also addresses hygiene concerns, mitigating the risk of disease transmission among users, a critical feature in shared equipment scenarios common in military or industrial settings. By facilitating real-time physiological monitoring, the device also contributes to the well-being and safety of workers, aligning with ethical imperatives to protect human health in hazardous environments.

The evaluation process identified a few notable areas for improvement. The upcoming outcome of the device containment and protection test will reveal whether or not the tray will secure sensors efficiently. However, under most conditions, higher-impact scenarios can lead to device dislodgement. To combat this issue a plan to integrate additional securing mechanisms, such as adjustable clamps or elastic bands into the tray design will be put in place. Enhancements to the tray's structural integrity are also planned, including increasing material thickness at important points and applying UV-resistant coatings to extend the devices operational lifespan in conditions.

The team recognized has potential sources of error that could affect our results. For example, the use of simulated devices may not have perfectly replicated the weight distribution and physical characteristics of the actual sensors, potentially affecting the accuracy of the containment tests. Furthermore, Inconsistencies in the manner of dropping the trays could have led to variable impact forces, influencing the observed damage. Additionally, the testing will likely be conducted in an under controlled room like environment where environmental factors such as extreme temperatures, humidity, or exposure to chemicals all of which could affect the tray's performance that will not be tested for. These factors highlight the need for testing under varied conditions to fully validate the device's reliability.

Conclusions

This project aimed to develop a gang charging system capable of transporting, charging, and maintaining 40-50 wearable physiological sensors intended for high-risk occupational environments like those encountered by the US Marine Corps. The final design features a durable tray made from Acrylonitrile Butadiene Styrene (ABS), which is located within a Pelican Case. This tray system incorporates wireless inductive charging along with UV disinfection capabilities. This solution addresses the critical need for real-time monitoring devices that are easy to transport, study, and efficient.

Through testing, the team hopes to observe that the ABS tray offers commendable durability, successfully withstanding drops from heights up to 1.5 meters with minimal damage. While the preliminary tray design aims to effectively secure the sensors under most conditions, additional research on securing mechanisms will be done to enhance device retention during higher-impact events. The final prototype idea has thus far, effectively balanced cost-effectiveness with manufacturability, making the system both practical and economically viable for widespread deployment.

Furthermore, the inclusion of UV disinfection and charge level indicators adds value by enhancing hygiene and allowing users to monitor device readiness easily. The design balances cost-effectiveness with manufacturability, ensuring that the system is not only practical but also economically viable for widespread implementation. Overall, the project aims to deliver a comprehensive solution that enhances safety and operational efficiency in dynamic environments.

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Appendix

Appendix I - Product Design Specification (PDS)

Function

A new wearable device for physiological monitoring, specifically designed for occupational safety in environments like heat stress and confined spaces, is currently being developed. The design contains a hard-shelled carrying case which provides protection but lacks trays that can connect physiological sensing devices with charging cables. Thus, the team is tasked to design and fabricate a gang-charging system to help solve this problem effectively and efficiently. Overall, the design should be able to transport, charge, and recuperate 40-50 sensors. The charging system ideally should indicate charge and UV levels. The final design should balance cost, durability, and manufacturability.

Client requirements

- The client primarily requests a tray to be fabricated that is able to charge the devices.
- The client requests ease of removal and insertion of sensors out of the tray.
- The client requests there is a charge indicator on the device.
- The client requests a mechanism for UV disinfection within the device
- The client requests the device is simple and intuitive, easily operated by a person without an engineering background.
- The client requests the device has internal backup power.

Design requirements

1. **Physical and Operational Characteristics**
    a. **Performance requirements**
        i. It is expected that the tray can hold 40-50 sensors of unspecified dimensions and allow easy removal and insertion of these sensors.
        ii. The tray must allow constant connection between the sensors and the charging system.
        iii. A UV disinfection system is preferred within the Pelican Case and should be activated when the case is closed.
        iv. The model should withstand extensive travel.

v. The device will be exposed to high temperatures, low temperatures, dust, and humidity.
vi. The device should be functional when used at Marine training sites, construction sites, and athletic training facilities.
vii. The device should be simple enough to be operated by someone without an engineering background.

b. Safety

i. Voltage flow and current are concerns in the event of a short circuit, overload, or ground fault in the wiring system.
ii. Charging system must follow Intrinsic Safety Standards. [1]
iii. In the event of using UV-curable resins, the user must wear chemical-resistant gloves that are not made of latex. Nitrile and neoprene gloves are best suited for handling. Parts should also be washed after being cured using the solvent that is compatible with the chosen resin. [2]
iv. Trays should not contain sharp edges or protruding pieces that are sharp enough to penetrate the user's skin.
v. There will be no materials that will require labeling as toxic or harmful material.
vi. All corners must be rounded or filed down to prevent shearing and/or slicing injuries to handlers.
vii. Tray must clamp and attach to the Pelican Case tightly without counteracted bending moments.

c. Accuracy and Reliability

i. Charging cables must be functional for 24 hours at a time.
ii. The UV disinfection system must prevent contagion between multiple users and disinfect devices.
iii. Client requires the charge display must have a $\pm 5\%$ error from true charge values.
iv. The tray device must remain accurate when exposed to high temperatures, low temperatures, dust, and humidity.

d. Life in Service

i. The device should be able to operate for 24 hours at a time.
ii. The sensors must remain in contact with the charging system at all times during usage.
iii. The tray should have a life span of approximately 10 years.

1. The tray should be easily repaired.
2. The tray should remain functional after 100s of uses.

iv. The UV light within the disinfection system should have a lifespan of approximately 8,670 - 1,400 hours. [3]

e. **Shelf Life**

i. The storage facility where the device will be kept has a temperature range from 68°-75° Fahrenheit.

ii. The device will be stored in a facility with a relative humidity level of 55-40.[4]

f. **Operating Environmen**t

i. The gang charging device should ideally operate in many different environments. The device will mainly be used on Marines training sites, construction sites, and athletic training sites.

ii. The device must withstand very high temperatures of over 100° Fahrenheit.

iii. The device should be able to withstand very low temperatures. There are US military bases in very remote areas that reach temperatures as low as -25° Fahrenheit [5]. The device must remain operable after being exposed to such a temperature.

iv. The case must be rugged enough to withstand other environmental factors including sand, wind, and dust.

v. The case must be able to withstand heavy and long transportation times. During this process, the device has to remain intact and not break the internal devices.

g. **Ergonomics**

i. Many people will be tasked to operate the device, including engineers, trainers, military personnel, etc.

ii. The device should be easy enough to be operated by a person in any occupation.

iii. The process of using the device should be very simple allowing it to be operated by only one person.

h. **Size**

i. The smallest pelican case that can be used to fit 40-50 devices is a 13 in x 11 in x 6 in case with an interior dimension of at least 12 in x 9 in x 5 in. The small size of this case allows the operator to carry and move the device.

ii. The largest pelican case recommended is a 33 in x 18 in x 11 case with an interior dimension no larger than 30 in x 16 in x 10 in. This case has wheels and a handle allowing the user to transport the device.

i. Weight

i. The client prefers that the device is under 30 pounds.

j. Materials

i. Body materials need to be shock-resistant, sturdy, elastic, and durable like high-performance resin.

ii. It needs foam that can protect the device while charging: polyester foam will be ideal.

iii. Pin and latches of the pelican box shouldn't be rusted easily, so it would be ideal to use materials like Stainless Steel.

iv. Light charging ports are needed.

k. Aesthetics, Appearance, and Finish

i. The client prefers the color of the final product is black or US Navy colors (Navy Blue and Gold).

ii. Hard and rough texture that can absorb shock.

iii. Cube shape that is stable and resistant to tipping or shaking.

2. Production Characteristics

a. Quantity

i. A single successful working prototype is the goal of the project

ii. It would be ideal if the design is easy to repeat and implement into other pelican cases so it can be effectively used on a large scale for the Marine Corps

b. Target Product Cost

i. The initial budget for the project is $300, and this will be the target cost. Additional funds will be offered by the client if necessary.

ii. The pelican case will cost either $120 or $406 depending on the size chosen, but the client will provide this and will not be factored into the budget.

3. Miscellaneous

a. Standards and Specifications

i. The National Electrical Code(NEC) is a set of standards for safe electrical design and installation. Much of the NEC is focused on 600V or less, which will be relevant for this design as wall outlets use around 120V [6].

ii. Some of the more applicable codes include Article 250.52, which prevents electrical shocks and hazards due to faulty or wet wiring via proper grounding. This must be factored into the design as the devices may be wet when placed into the case [6].

iii. Article 300 details the minimum allowed wire coverings for buried wires to ensure no moisture exposure [6].

iv. Article 210 specifies minimum wire size and ampacity for varying circuits[6]

v. Many further standards in the NEC can be examined for certain scenarios.

vi. In the case that UV is used in the design, there are several UV standards to be adhered to. ASTM(American Society for Testing and Materials) E2297-23 details proper sensitivity range and calibration for UV use[7]. ASTM G154-23 details the standard practice for operating UV lamps and exposure of materials, which has important implications for what material is chosen[8].

b. Customer

i. Understanding the customer's preferences is vital in ensuring that the ChargeForge Gang Charging System is both functional and appealing.

ii. The primary customer is the U.S. Marine Corps, represented by the client, Isabel Erickson. The system must meet their operational needs, which involves functioning in extreme environments like marine training sites and construction fields.

iii. The Marines require a durable device capable of withstanding rough handling, varied temperatures, and dust. Additionally, the device must be simple to use, intuitive for personnel, and integrate easily into their current workflow.

iv. Color preferences have also been noted, with a strong preference for a black or Navy Blue and Gold design, aligning with Marine Corps branding. Meeting these aesthetic and functional expectations is essential for customer satisfaction.

c. Patient-related concerns

i. Although this device is primarily aimed at occupational safety rather than direct patient care, certain patient-related concerns remain relevant.

ii. An example of important patient-related concerns is the gang charging system must ensure that the sensors, used to monitor physiological conditions, are properly disinfected between uses to prevent cross-contamination.

iii. Incorporating UV light for this purpose offers an efficient, low-maintenance method for disinfection, ensuring compliance with hygiene standards, especially when multiple users share the same sensors.

iv. Additionally, the storage of personal data may be a concern, as physiological sensors might gather sensitive health data. Therefore, the device should comply with data privacy regulations, ensuring that any data stored is confidential.

d. Competition

i. After analyzing the competition for gang-charging systems, few are tailored specifically for tough, military-grade environments that require both charging and disinfection capabilities.

ii. Competing products usually focus on either charging or storage but lack the UV disinfection and extreme durability that this system offers.

iii. This system differentiates itself by integrating durability, ease of use, and UV disinfection in a compact, portable form, meeting the specific needs of Marines operating in challenging conditions.

iv. For example, Masimo Corp filed a patent on a physiological device charging station. This design includes a multiple-level system that holds the trays for the devices. The design has a charging port that protrudes from the bottom of the station to provide charge to the devices. However, this design is very large and not made for easy transportation [9]. One of the main requirements for the design is that it is very easy to transport.

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Appendix II - Material Costs and Analysis

Predicted Expense Sheet

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Tray										
ABS Filament	Use an ABS Filament on the Ultimaker 3D printer			Makerspace			100(	$0.05	$50.00	ABS Materia
									$0.00	
Charging System										
									$0.00	
									$0.00	
								TOTAL:	**$50.00**	

Expense Sheet

Appendix III - Tray Material Design Matrix

Criteria Descriptions:

Durability: The material must withstand handling and multiple trials without breaking apart. The material must withstand changes in temperature - between 241.48 K and 310.3 K. According to the PDS criteria, the client expects a lifespan of approximately 10 years.

Manufacturability: The design will be scored on the difficulty of manufacturing the tray and the charging system. This includes access to and effects of software necessity, machine accessibility, skill level requirements, and outside resource necessity.

Weight: The material should be lightweight enough to ensure the tray design is less than 6.8 kg.

Safety: The design will be scored on how likely the chosen material and charging system will produce any hazards during the construction process and during use afterward.

Cost: The cost of the design must fall within the budget of $300. The likelihood of excess material must be taken into account to reduce wasteful spending.

UV Resistance: The material must be able to withstand UV disinfection between uses. The effective dose for disinfection ranges from 5 to 10 mJ/cm^2 [4], but some systems can exceed 30 mJ/cm^2 for faster disinfection. The material should be fully functional after 100+ rounds of disinfection.

Ranking Analysis:

ABS:

Durability: Acrylonitrile butadiene styrene (ABS) is a sturdy thermoplastic with excellent durability. It has a Young's Modulus between 1.9 and 2.5 gigapascals (GPa) [5] and a tensile strength of 45 MPa [6], making it an excellent shock and vibration absorber while resisting cracking and fracturing under loading. These properties make it a popular choice in protective cases for electronics[5]. ABS has approximately 12.6 kJ/m^2 of impact resistance [7] and a melting point of 473.15 - 513.15 K [8], which fulfills the intended objective. As ABS exceeds the required durability goals, it scored a 5.

Manufacturability: ABS is commonly used in 3D printing and is available in the Makerspace. This allows for easy manufacturability as a design can be drawn on design software to exact measurements and specifications and then printed out. It can also be printed relatively quickly at 60 mm/s [9], which ensures there will be no warping or other imperfections during printing. As the Makerspace is easily accessible and 3D printing is relatively simple, ABS scored a 5 for manufacturability.

Weight: ABS is considered a lightweight material with a low density of 1050 kg/m^3 [6]. The density of ABS is slightly higher than HDPE and lower than PETG so it scored a 4.

Cost: ABS is a relatively inexpensive material, as it is comparable in pricing to the other materials at $15-20 per kilogram[10]. This price aligns with the project's budget, as the tray design will not exceed 1-2 kilograms. Thus, it scored a 4 for cost.

Safety: ABS is a non-toxic material and there have been no known adverse health effects reported due to long-term exposure[11]. One drawback of ABS is that it has low fire resistance and can be harmful when burned, but this would not ideally need to be considered for this project. As ABS has low fire resistance, it scored a 3 for safety.

UV Resistance: ABS exhibits moderate UV resistance with its thermal expansion of 90E-6 in/in*K [6] with a maximum working temperature of 343K [6]. Some special chemicals and coatings can be applied to enhance UV stabilization which helps to prevent color from fading and surface degradation[5]. Thus, it scored a 4.

HDPE:

Durability: HDPE is highly durable, with excellent impact resistance and the ability to withstand tough environmental conditions such as temperature fluctuations, humidity, and mechanical stress. The Young's modulus, which measures a material's stiffness and how easily it can deform or stretch for (HDPE) can range from 600 to 1500 MPa. [12] HDPE has a tensile strength of approximately 35 - 40 MPa [13]. This makes it ideal for military use where the device will be transported frequently and exposed to harsh environments. HDPE has a melting point of 390 - 410 K [13], well above the desired goal. With all these criteria in mind, HDPE scored a 4 on durability as it falls within the target temperature resistance and strength but could be more durable.

Manufacturability: HDPE is easy to mold because of its low melting point of 390 - 410 K [13] which makes it easy to manufacture in bulk through processes such as injection molding, extrusion, and thermoforming. For this reason, HDPE can be constructed in any shape that is needed for the gang charging system tray. The HDPE tray would be manufactured in the Engineering Centers Building which is easily accessible yet time consuming so it scores a 4 for manufacturability.

Weight: HDPE is very lightweight because of its linear molecular structure with few side branches, making it vital for a portable charging system. The density of HDPE is 930 to 970 kg/m^3. [14] As the lightest weight option, HDPE scored a 5.

Safety: HDPE is non-toxic, non-conductive, and chemically resistant, making it very safe for use in environments where it might be exposed to chemicals, moisture, or extreme conditions. However, HDPE is slightly flammable so it poses a risk if the charging mechanism overheats. With this possibility in mind HDPE scored a 3 for safety.

Cost: HDPE is cost-effective and similarly priced to other plastic filaments with HDPE, ABS, and PETG all costing around $15-$20/kg [10]. Its affordability, combined with its strength, makes HDPE a great option for large-scale manufacturing and for keeping the project within budget. Since there will be no additional 3D printing costs with HDPE, it scores a 5 for cost.

UV Resistance: HDPE does have some limitations when it comes to UV exposure. As a material, HDPE is not naturally UV resistant, meaning prolonged exposure to UV light, including UV-C light used for sterilization, can lead to degradation over time.A quantification of UV exposure for disinfecting the monitoring devices is 5 to 10 mJ/cm^2 [15] at 200-280 nm wavelength. Unmodified HDPE can degrade significantly after exposure to UV-C light for around 100–500 hours. Thus, HDPE scores a 2 on UV resistance.

PETG:

Durability: PETG has a high tensile strength of 31.3 Mpa and a Young's modulus of 2.01-2.11 GPa [16]. This allows PETG to sustain repeated impacts while keeping its overall shape and function. This is important because it will be subjected to harsh conditions that are found on military bases. The melting point of PETG is 538.5 K [17]. This is a very high melting point that makes the material ideal for sustained heat of the outdoors. Although PETG has a high melting point and a similar Youngs Modulus to the other options, it has a lower tensile strength than ABS so PETG scored a 4 for durability.

Manufacturability: PETG is a very easy material to manufacture because PETG is a 3D printable material. This allows the material to be shaped into any design concept for the charging tray. However, PETG prints at around 40-60 mm/s which can be slightly slower than the other materials.[18] As access to 3D printers is readily available, PETG scored a 5 on manufacturability.

Weight: This material is denser than some of the other materials that are being considered. PETG has a density of 1,260 - 1,280 kg/m^3 [19]. So it scored a 3.

Safety: PETG is a very safe and nontoxic material. This material does not pose a risk to the customer. The fumes that are emitted are nontoxic making it a safer material than ABS[]. Thus, PETG scores a 5 for safety.

Cost: PETG is cost-effective and has the same price as other plastic filaments with HDPE and ABS all costing around $15-$20/kg.[20] These are all very cost-effective materials. As a cost is associated with 3D printing, PETG scored a 4 on cost.

UV Resistance: PETG is a UV-resistant material, however, prolonged exposure to UV causes wear on the material. This degradation of the material can lead to a reduced mechanical properties by 30% [21]. This is very important because the tray will be exposed to UV. This could lead to rupture of the material due to photolysis. Thus, PETG scored a 3 for UV resistance.

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Appendix IV - Predicted Tray Design Matrix

Criteria Descriptions:

Accuracy of Connection: The design must provide accurate and reliable connectivity between the sensors and their respective chargers.

Ease of Use: The design must be simple enough that people who lack an engineering background can operate it properly without explanation. The design should also allow easy removal and insertion of the sensors as the design will be utilized in a fast paced environment.

Durability: The tray design must withstand handling and multiple trials without breaking apart. The design must be able to withstand frequent use, of uses per day, and extensive handling. According to the PDS criteria, the client expects a lifespan of approximately 20 years.

Manufacturability: The design will be scored on the difficulty of manufacturing the tray and the charging system. This includes access to and effects of software necessity, machine accessibility, skill level requirements, and outside resource necessity.

Cost: The cost of the design must fall within the budget of $300. The likelihood of excess material must be taken into account to reduce wasteful spending.

Safety: The design will be scored on how likely the chosen material and charging system will produce any hazards during the construction process and during use afterward.

Ranking Analysis:

Design 1:

Accuracy of Connection: Design 1 employs a magnetic mechanism, holding chargers into the divots, to ensure a secure and reliable connection between the sensors and their charging points. The flat, hollow tray design allows seamless integration of inductive charging technology, enabling efficient energy transfer to the sensors. The strength and precision of the magnetic fields could be supported by studies on magnetic coupling in wireless power transfer systems [X]. Due to the consistency and reliability of this connection, Design 1 received a rating of 5 in terms of accuracy of connection.

Ease of Use: Design 1 is very simple to operate. The user only needs to place the sensors onto the tray, allowing for an intuitive and frictionless process. With no physical barriers to remove the sensors, they can be retrieved effortlessly. Thus, Design 1 scored a 5 for ease of use.

Durability: While the thickness of Design 1 has not been finalized, the balance between durability and weight remains a concern. A thinner design might be less resistant to wear and tear, impacting long-term durability. As a result, Design 1 scored a 3 for durability, pending further testing and optimization.

Manufacturability: Design 1 is extremely simple to manufacture as the design itself is relatively simple and the team has easy access to 3D printers. Thus, Design 1 scored a 5 for manufacturability.

Cost: Design 1 will be cost effective as it will be made using 3D printers in the Makerspace. ABS plastic, the filament the team will use, is $15-20 per kilogram[X]. This price aligns with the project's budget, as the tray design will not exceed 1-2 kilograms. Thus, it scored a 5 for cost.

Safety: Design 1 is overall a safe design as it has no sharp edges and poses no health risks during 3D printing. In terms of sensor safety, the sensors could fall out of the tray depending on the depth of the divots. In terms of the charging system being housed within the tray, there is a risk of overheating. Even though this is not too large of a concern as ABS has a high melting point, Design 1 scored a 4 for safety.

Design 2:

Accuracy of Connection: Design 2 utilizes magnetic mechanisms within each slot to ensure a constant and reliable connection between the sensors and their respective charging points. The tray efficiently distributes power to each sensor port, ensuring constant charging. This design received a rating of 5 for accuracy of connection due to its dependable performance in power transmission.

Ease of Use: Although Design 2 allows for easy insertion of the sensors into their dedicated ports, the more intricate design of the slots makes sensor removal slightly more complex compared to Design 1. Despite this, it remains user-friendly, with the sliding mechanism providing a reliable docking experience. As a result, Design 2 offers a well-balanced user experience but falls short of the simplicity seen in Design 1 and thus it scores a 4 for ease of use.

Durability: Durability is a key strength of Design 2, as its thicker tray structure minimizes the risk of fractures or environmental wear. The charging mechanism, enclosed within the tray, adds to its protection from external factors. Given these factors, Design 2 scored a 5 for durability.

Manufacturability: The complexity of Design 2 presents more challenges in manufacturing compared to other options. The detailed CAD modeling and extended 3D printing time required for this design increase production effort. Consequently, Design 2 earned a score of 3 for manufacturability, acknowledging the additional time and effort needed to bring this design to fruition.

Cost: Design 2 will be relatively cost effective as it will be made using 3D printers in the Makerspace. ABS plastic, the filament the team will use, is $15-20 per kilogram[1]. This price aligns with the project's budget, as the tray design will not exceed 1-2 kilograms. However, design 2 has a larger volume than its competing designs so it will be slightly more costly. Thus, it scored a 4 for cost.

Safety: Safety is a primary focus of Design 2, as it features walls surrounding the sensors, ensuring they remain securely in place. This added protection reduces the risk of accidental dislodging, making the design inherently safer for users and the sensors alike. The secure housing of the sensors and lack of sharp edges highlight its commitment to safety. As a result, Design 2 scored a 5 for safety.

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Appendix V - Material Fabrication Protocols

ABS Plastic

1. **Process:** ABS is a thermoplastic filament that is melted and extruded through a heated nozzle onto a build platform. The layers of said filament soften and fuse together to create the final object [X]
2. **Temperature:** The ideal bed temperature for ABS is between 95–110°C. The extruder temperature is usually between 220–250°C, but can vary depending on the printer and brand. [X]
3. **Enclosure:** An enclosure or heated build chamber is recommended to maintain a consistent temperature and reduce warping. [X]
4. **Ventilation:** Use an open space with good ventilation.
5. **Build surface:** Kapton tape can be used as a build surface. To improve adhesion, you can also coat the print surface with ABS juice, which is a mixture of acetone and a small amount of ABS filament. Other options include glue stick or hairspray. [x]
6. **Warpage control:** Use brims and rafts to control warping.
7. **Fan:** Leave the fan off for the first layer, and set it to no more than 30% of its maximum speed for subsequent layers. [x]

8. **Smoothing:** To smooth ABS parts, you can brush liquid acetone onto the surface. Use a fine-tipped brush for small details and a flat brush for larger areas. After applying acetone, let the parts dry before use. [X]