ChargeForge: gang charging system for newly developed physiological monitoring device

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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.

Brief Status Update

The team has been designing and printing CAD designs in the MakerSpace. The team is beginning to design the electrical components of the system as well as begin testing of the tray design..

Summary of Weekly Team Member Design Accomplishments

- Team:
    - Set up a client meeting with Aptima
    - 3D Printed first prototype
    - Presented at Show and Tell

- Allison Rausch
  - Printed on CAD designs
  - Continued researching testing specs
  - Started Progress Report 9
- Jake Maisel
  - Printed CAD designs
  - Researched testing protocols
  - Set up show and tell meeting with our client
- Yeanne Hwang
  - Create an 2nd prototype CAD file by applying the modifications
  - Investigate structures for multi-charging connectors
- Kenan Sirlioglu
  - Researched Standards for USB
  - Went to Makerspace to check 3-D printer materials and dimensions
  - Looked into possible testing protocols
- Luke Blaska
  - Began formulating ideas for how to attach tray inside of pelican case
  - Discussed ideas with client and advisor about testing protocols like wear and tear testing as well as tolerance testing
  - Continued electrical research

Weekly/Ongoing Difficulties

The team continues to print updated designs. The team may experience difficulties when fitting the pogo pins into the unit as well as soldering USB wires properly. The team also anticipates issues when navigating the testing of the charging system.

Upcoming Team and Individual Goals

- Team:
  - Test Prototype
  - Finalize testing protocols
  - Update final report
  - Order USB and Pelican Case
- Allison Rausch
  - Finalize mechcanical testing protocols
  - CAD design modified prototype
  - Submit orders through the client
- Jake Maisel
  - Finalize tray design and print
  - Order all the materials for the electrical
  - Continue to research testing protocols

- Yeanne Hwang
    - Order new materials from client
    - Create design for Unit Cell Lab Archives
- Kenan Sirlioglu
    - Complete testing protocols
    - Propose tests and conduct them
- Luke Blaska
    - Finalize individual slot design that will effectively hold device considering all requirements
    - Research interior of specific pelican case that we will work with and see how we can attach the tray within it
    - Begin testing of what we have so far to see if it could be a viable solution

Project Timeline

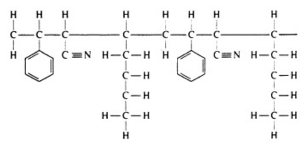
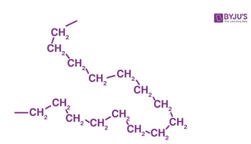
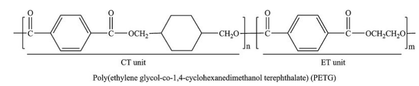
Project Goal	Deadline	Team Assigned	Progress	Completed
Product Design Specification (PDS)	September 19, 2024	All	100%	9/18/24
Design Matrix	September 26, 2023	All	100%	9/25/24
Preliminary Presentations	October 4, 2024	All	100%	10/3/24
Preliminary Deliverables	October 9, 2024	All	100%	10/9/24
Show and Tell	November 1, 2024	All	100%	10/30/24
Poster Presentations	December 6, 2024	All	0%	

Final Deliverables	December 11, 2024	All	0%	

→ Arrows indicated dependencies

Charging Tray Material Design Matrix

Table 1: *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 Filament won.*

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

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 our 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 our 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 Makerapace 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 our desired goal. With all these criteria in mind, HDPE scored a 4 on durability as it falls within our 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 for 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 reduce 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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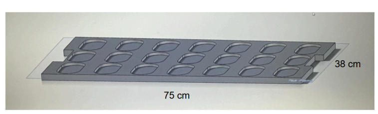
Tray Design Matrix

Figure 2*: 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 the Design Blank 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

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 our 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.

References

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