Digestive Tract Trainer

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Introduction

The human digestive system is a system of connected organs that plays a vital role in breaking down food, absorbing nutrients, and maintaining homeostasis. Within this system, the physiological processes of peristalsis and segmentation are essential for the movement and mechanical digestion of food. However, these complex motions can be difficult to convey using static anatomical models and traditional classroom methods. To address this gap, a dynamic digestive tract trainer was developed to demonstrate both peristalsis and segmentation in a visually accurate and interactive way [1].

Peristalsis: Occurs in the alimentary canal organs of the digestive system, such as the esophagus, and is defined as the alternating motion of contraction and relaxation [2-3].

Segmentation: Occurs in the intestines and is defined as the mixing and churning of food, where non-adjacent segments contract and move to break down food [2-3].

The team designed and manufactured a functional and transportable trainer through a comprehensive engineering process involving CAD modeling, electrical design, molding, and iterative testing. The trainer provides an innovative, one-of-a-kind, and durable educational tool for classroom use.

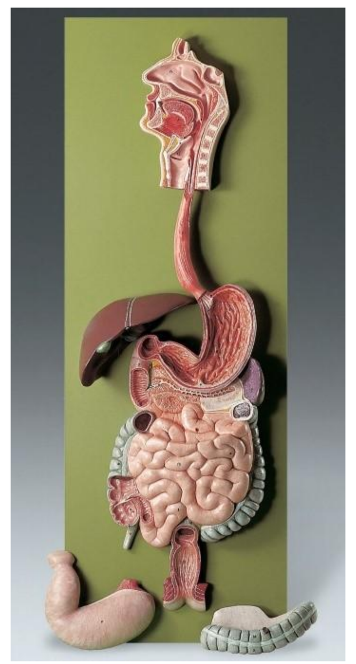

Figure 1. Original Model

Customer Expectations

Dr. Angela Bojrab requested for a dynamic human digestive model to help provide a visual demonstration to anatomy and physiology students on Trine's campus. Segmentation and peristalsis, the primary digestive movements, are difficult concepts to grasp, whereas a dynamic model could enhance student understanding of these concepts.

- Demonstrate Segmentation & Peristalsis
- Represent Digestive Track
- Fit on a Tabletop
- Distinguishable components
- Incorporates Different Materials and Mediums

Table 1. Technical Specifications

Tasks	Target Value
Flat Backplate Fits on Tabletop	≤ 60 x 24 in
Gastrointestinal (GI) Tract is Anatomically Accurate	Yes/No
Segmentation is Demonstrated	Yes/No
Peristalsis is Demonstrated	Yes/No
Movement through GI Tract is Demonstrated	Yes/No
Model is Lightweight	≤ 20 lb.
Model is Scaled Proportionally	Yes/No
Mixed Ecoflex is Flexible	OO-31 Shore Hardness
Mixed Ecoflex is Tear Resistance	Max. Tensile Strength > 0.025072 MPa

Validation

The Digestive Tract Trainer was validated by the team to verify both anatomical accuracy and proper electronic configuration. To ensure **anatomical accuracy**, the placement and features of all organs were verified using a visual inspection test method. To validate the **electronic components**, the circuitry was thoroughly tested using an inspection test method to verify that all movements and LEDs worked as intended, and demonstrated digestion as intended. The validation ultimately resulted in a working model that visually and functionally represents the movement of food through the digestive system.

Design Components

3D Modeling

Anatomical Organs: SolidWorks™ was used to design all anatomical organs within the system. Once the individual organs were modeled, they were assembled to ensure feature compatibility and correct anatomical placement on the backboard. The printed and molded organs were controlled to a ±.01" tolerance per the capability of the Prusa MK3S+ & MK4 printers.

Designing to Imitate: Designing the dynamic organs required specific features within the models to enable movement that simulates peristalsis and segmentation. The stomach, along with the large and small intestines, were designed with a hollow cavity to allow inward movement when subjected to the force exerted by the servos. The esophagus features a cavity along its pathway, allowing the bolus to stretch the silicone as it passes through.

Backplate Design: The design of the backplate and stand was completed in SolidWorks™. The critical dimensions shown in Figure 3 were controlled with a ±.10" tolerance during cutting and assembly. The model features a rectangular box with a two-hinge system that enables the model to be placed upright.

Figure 2. Final Model CAD Assembly

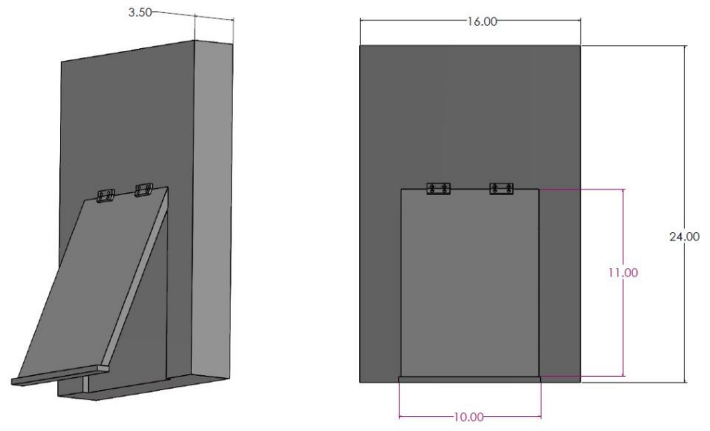

Figure 3. Final Backboard CAD Assembly

Electrical System

The digestive tract trainer uses an Arduino-base control system to operate multiple servos and LEDs that simulate realistic digestive motion. Each servo is connected to a nylon string attached to a metal rod inset within the soft silicone organ. As the servo rotates, it pulls the string, causing the rod to compress the organ and replicate natural contractions like peristalsis and segmentation.

Power is supplied by a 12V battery and stepped down to 5V using a buck transformer to run the Arduino and components safely. A voltage meter monitors battery levels, with a main on/off switch and a separate start button to trigger the motion sequence. The Arduino code directs each servo to rotate to an initial angle, return to zero, then move to a second angle before resetting again, allowing adjustable and repeatable movements to closely simulate realistic digestive rhythms. The complete electrical layout and component placement are shown in Figure 4-7.

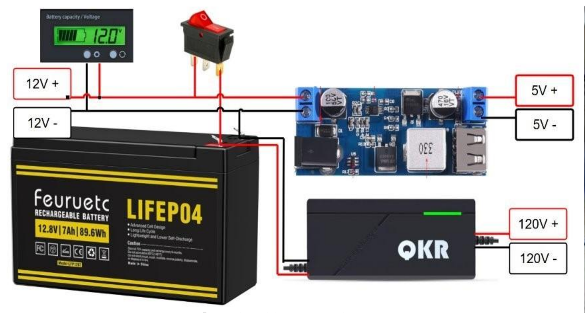

Figure 4. Battery Diagram

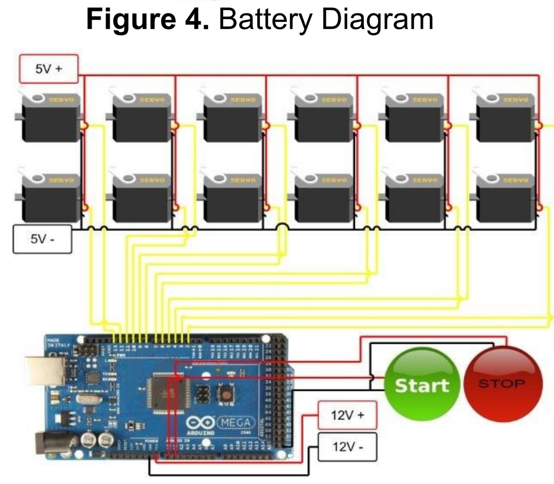

Figure 5. Servo Diagram

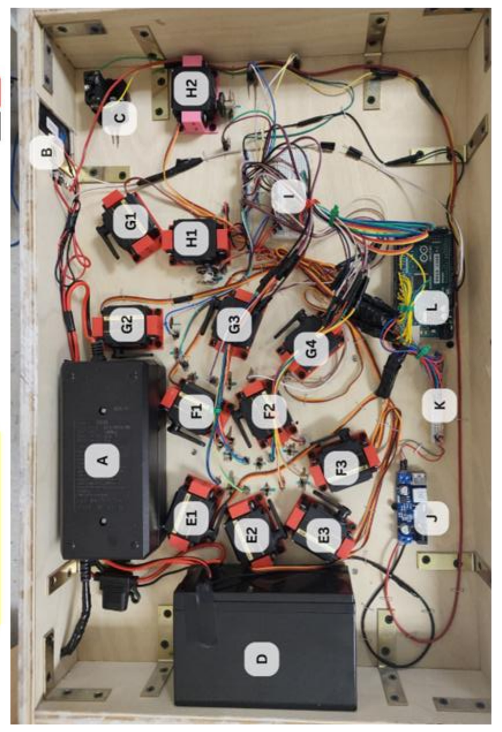

Figure 6. Internal Electrical Component Layout

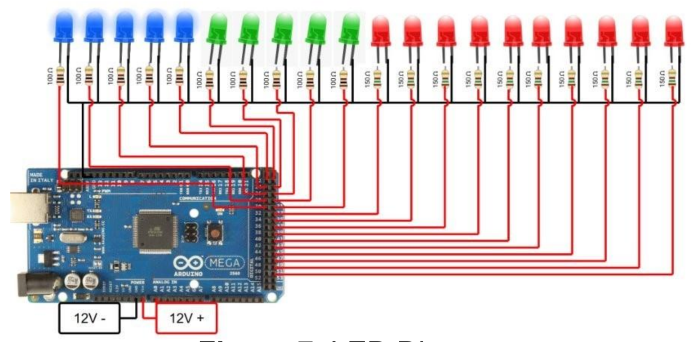

Figure 7. LED Diagram

Organ Manufacturing

The digestive organs were manufactured using separate methods depending on functionality of the organs. The manufacturing process was separated via the following categories:

Rigid Organs

- 3D-printed using Prusa MK3S+ & MK4
- Sliced via PrusaSlicer
- PLA filament
- 15-20% Infill

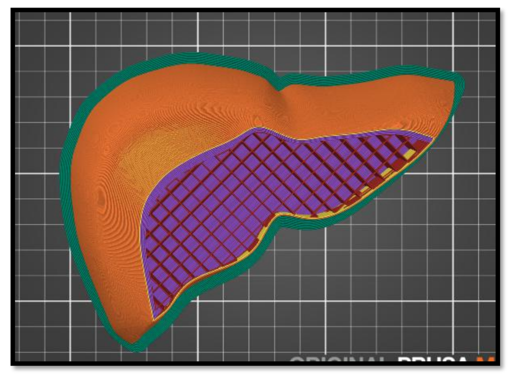

Figure 8. Sliced G-code

Flexible Organs

Silicone molded via Ecoflex OO-31 Near Clear

- 1:1 ratio of Part A and Part B mixed together with added pigment (Silc Pig™)
- Poured into 3D-printed organ molds
- Cured for 4 Hours

Servo attachment

- In-laid attachment inserted into organ
- Glued into place
- Reinforced with brushed on layer of silicone

Testing

Radial Tensile Testing

Purpose: Determine Ecoflex OO-31's ability to endure the radially applied forces to determine if the silicone components can withstand repeated actuation.

Standards:

- ASTM D1414-22 Standard Test Methods for Rubber O-rings [4].
- ASTM D412-16 Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension [5].

Methods: 10 O-rings specimens with a diameter of 0.08 inches, the smallest thickness of any silicone component, underwent a tensile test via an Instron Machine loaded with a 150 kN load cell until the specimens reached fracture point.

Results: All silicone components are expected to withstand applied forces without breaking.

- Mean maximum tensile strength of O-rings: 1.15 MPa
- Applied forces on silicone components: ≥ 0.0250 MPa

Figure 9. Tensile Testing

Shore Hardness Testing

Purpose: Determine the resistance of Ecoflex OO-31 to indentation and determine its shore hardness classification, a critical parameter in assessing the mechanical properties and performance suitability of silicone molds for various applications.

Standards:

- ASTM D2240-15 Standard Method for durometer hardness [6].

Methods: A molded specimen with a diameter of 6 inches and a thickness of ⅓ inches underwent a hardness test via a Shore OO durometer, with 30 samples taken.

Results: All silicone components are expected to have a shore hardness value of 31, which will enable the dynamic portions to perform as intended.

- Mean hardness value of specimen: 31.09

Conclusion

Completion of Customer Requirements

The Digestive Tract Trainer includes:

- Backboard box containing electrical components weighing 20 lb.
- Stand to prop up the model
- 3D printed rigid/stagnant components
- Dynamic movements of organs
- Proportionally scaled model
- Silicone molded dynamic components
- Pathway of digestion displayed by LEDs
- Flexible and tear resistant Ecoflex

Project Recommendations

- Improving digestive movement code to improve demonstration of peristalsis and segmentation
- Providing an easier method to carry and store the trainer, such as adding handles and a dust cover

References

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