Computation of Corresponding Force in Jaw Muscles using Frugal Biomechanics

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Introduction

A rough prototype of a Gnathometer is being developed in this project using a force sensor to compute the muscle force generated during jaw activity. Although elementary, the model is presented as a low-cost and non-invasive alternative, making it a practical tool for preliminary diagnostics and research on bite force variability among individuals. Wide-ranging applications in dentistry, orthodontics, prosthodontics, maxillofacial surgery, and sports science are enabled by an improved understanding of the forces exerted by jaw muscles.

The human masticatory system is understood to be a result of both mechanical leverage and muscular coordination. Jaw movements and biting actions are primarily powered by the masseter, temporalis, and pterygoid muscles, which function around the temporomandibular joint (TMJ) in conjunction with the dental structure. The resultant force produced during biting or clenching is considered a cumulative effect of muscle strength, skeletal geometry, and occlusion alignment. [1] In this project, the muscle forces involved in the generation of bite force by the incisors are computed using inverse dynamics.

Aim

To develop a basic, sensor-based system for the experimental measurement and analysis of jaw muscle forces using a gnathometer-like prototype.

Objectives

- Designing CAD model of gnathometer and 3D printing it.
- Constructing the electric circuit for the gnathometer.
- Forming a relation between bite force and muscle force (using literature).
- Coding the relation to compute the muscle force with input bite force.
- Experimentally testing the gnathometer on our teammates to increase its accuracy and precision.
- Taking readings for bite force applied by our teammates.

- Computing muscle force using the input bite force data.
- Training a model for bite force and muscle force datasets to increase its accuracy

Experimentally Measured Parameter: Bite Force exerted by incisors
Computationally Estimated Parameter: Muscle Force in jaw muscles

Methods

Mechanical Design

A 3D frame was designed and modeled in CAD as illustrated and then printed using PLA as the construction material. Accommodating the force sensor and providing space for wiring were identified as the two principal design considerations. An infill density of 10% was maintained to ensure that sufficient elasticity was achieved and that the frame would not fracture during biting.

Electrical Assembly

The electrical assembly was composed of the following components:

1. SPARKFUN ESP32 Thing microcontroller
2. FlexiForce A301 Force sensor
3. 3.7V LiPo Battery
4. 10 k ohm and 2.2 k ohm Resistors and jumper wires

The implementation of the electrical unit was rendered straightforward: upon the application of force, the resistance of the sensor is decreased, this change is measured and read by the ESP32 chipset, and the resulting values are displayed on a computer. Calibration of the sensor is then performed using known weights. [2]

Computations

- The individual muscle forces during incisal biting are estimated by treating the mandible as a rigid body with the temporomandibular joint (TMJ) serving as the pivot.
- A hierarchy of muscle forces for incisal biting is established as follows:

$$F_{masseter} > F_{temp} > F_{pterygoid} \tag{1}$$

- The following variables are known:
  - The masseter is oriented 12° anteriorly and 4° laterally.
  - The temporalis is oriented primarily in the vertical direction.
- For the pterygoid (with only its superior and anterior components considered), orientations of approximately 60° to the X-axis, 75° to the Y-axis, and 40° to the Z-axis are used (the medial component is neglected due to symmetry).

- Effective moment arms are given as: masseter, 25–30 mm; temporalis, 10–15 mm; pterygoid, 15–18 mm.
- Only two equilibrium equations (torque balance about the TMJ and vertical force balance) are formed for three unknown muscle forces.
- Unique solutions are obtained by one of the following methods:
  1. The temporalis force is assumed to be a fixed ratio of the masseter force based on their cross-sectional areas.
  2. The total muscle force is minimized via optimization – minimize $(F_m^2+F_t^2+F_p^2)$.
  3. The pterygoid force is neglected—due to its comparatively low magnitude—for a simplified static analysis.

Results

Weight	**Voltage**	**Force**
50 g	0.89 V	15 N
90 g	1.3 V	24 N
250 g	1.8 V	36 N
900 g	2.9 V	60 N
1 kg	3.3 V	70 N

Table 1: Measurement results from the gnathometer prototype

Discussions

Interpretation: The maximum bite force cannot currently be measured by the force sensors in use.

Summary: Scaling of the force sensors is required.

Comparison: In order to measure the maximum force, the resistances employed in the paper should be increased.

Limitations: The maximum bite force may not be measurable with the existing sensors.

Future Scope: Tests are being performed on different individuals to enhance accuracy.

Conclusions

- Scaling of the resistances needs to be performed on the existing force sensor circuit.
- Testing needs to be conducted on different individuals.

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Contributions

- **Agrajah Bhobe, Vikash Verma, Anushka Dubey:** Computation Data and Parameters
- **Srushti Rajwade:** CAD model
- **Tanush Khairnar:** 3D printing
- **Asmi Rangnekar:** Circuit connections
- **Devpal Meena:** Code and testing

References

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