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Bio-Inspired Mechanical Spoon Concept: Resonance Avoidance, Structural, and Thermal Analysis

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ABSTRACT

Hand tremors make simple tasks such as eating a significant problem for the people suffering from essential tremors and Parkinson's disease trying to manage their everyday activities. Electronic stabilising spoons are available for commercial purchase, however they tend to be expensive and inconvenient to use and requires constant charging. This paper presents a mechanical bio-inspired spoon as one of the solutions to this problem, with data from Finite Elements Analysis (FEA) to validate. We incorporated biomimetic features in the design. The bowl of the spoon is designed with a protective layer to reduce the effects of tremors, that mimics a silkworm cocoon, while the handle implements bamboo-like segmented joints for greater durability. Additionally, the neck area uses an orthogonal spring structure that is inspired by the shock-absorbing hyoid bone in a woodpecker's skull. The design was modelled in SolidWorks 2026 student edition and was analyzed for static structural, modal frequency, and thermal analysis. The simulation results show that the first natural frequency is 58.52 Hz, which is far above the usual frequency range of hand tremor (4 to 12 Hz). This large gap means that the spoon is kept away from resonance, so the tremor cannot be amplified. A separate analytical calculation was done where it is shown that, because the natural frequency sits so far above the tremor band, the spoon behaves like a rigid body and follows the hand, and it does not actually isolate the tremor on its own. The maximum stress of 13.8 MPa under a 1 N load is much lower than the yield strength of AISI 304 stainless steel (207 MPa) and the factor of safety is calculated as approximately 15. The thermal study shows that there is a good heat isolation between the bowl and the handle. The final design weighs 87.89 grams, which is within a comfortable weight limit.

Keywords
Engineering, Biomedical Engineering, biomimicry, assistive eating utensil, resonance avoidance, finite element analysis

1. INTRODUCTION

Essential tremors have been found to be common pathological type of tremor seen in adults, with a prevalence of around 0.9% in the general population (1). Hand tremors usually occur at frequencies in the range of 4 to 12 Hz with amplitudes from a few millimetres to several centimetres (2). People suffering from these problems find it quite difficult to eat due to the uncontrolled shaking which prevents them from picking up food from a plate and putting it in their mouth without spilling. This situation leads to embarrassment and social alienation.

Weighted utensils, swivel spoons, and electronic stabilising gadgets, such as Liftware Steady, are currently used to help with tremors when eating. They consist of electronic sensors and motors which can sense hand tremors and move the tool in the opposite direction, achieving about 70% tremor dampening. Nevertheless, the problem with electronic instruments is their high cost and the need to recharge them. Moreover, some people might be unable to use electronic utensils because of their price in their countries of origin.

Research has shown that simply weighting utensils does not help in decreasing tremors and may even cause muscle exhaustion (3). Thus, a more advanced approach is needed. In this research project, we try out the idea of designing a utensil using mechanical principles inspired by nature, and we study how an orthogonal spring structure at the neck behaves when the hand shakes, without using any electronics.

Nature has created many effective methods for absorbing shocks and damping vibration. Woodpeckers beat tree surfaces with decelerations higher than 1200g, and yet they do not get any brain damage, hitting it with their beaks up to 18 to 22 times a second (4).

Their hyoid bone, which wraps around the skull in a spring-like configuration, plays a key role in this shock absorption. Similarly, bamboo's nodal structure provides an exceptional strength-to-weight ratio through its hierarchical fibre reinforcement schemes (5). The silkworm cocoon has developed a layered structure that gives good protection from environmental hazards despite its light weight (6).

This research focuses on developing a purely mechanical spoon concept based on the biological inspiration of nature's designs. The research intends to achieve four major objectives, which include: (1) design a spoon based on bio-mimicry principles, (2) generate an advanced computer-aided design (CAD) in SolidWorks software, (3) analyse the design using finite element simulations in terms of static, frequency, and thermal aspects, and (4) check the design for practicality and safety.

2. HAND TREMORS AND EXISTING SOLUTIONS

Tremors are described by the International Parkinson and Movement Disorder Society as involuntary rhythmic oscillations of a body segment. The primary causes of tremors in the hands are essential tremor and Parkinson's disease. Studies have shown that the frequencies of essential tremor fall within the range of 4 to 12 Hz, whereas voluntary actions of the hand take place at less than 3 Hz (7).

A number of gadgets have been designed for feeding problems. Weighted utensils attempt to use inertia to resist tremor-induced movements. However, Meshack and Norman found no significant improvement with static weight addition; in fact, tremor was often worse with weight due to increased muscle fatigue (8). Rocon and others developed a wearable orthosis applying viscosity and inertia to the arm, achieving 40% power reduction through mechanical loading (9). This study showed that changing the impedance characteristics of the limb directly affects tremor.

Electronic solutions like the Liftware Steady use Active Cancellation of Tremor technology, detecting the direction of the tremor and moving the utensil attachment in the opposite direction. Clinical trials showed a 71% to 76% tremor reduction across eating tasks (2). However, the relatively high cost and maintenance requirements limit the accessibility of these technologies to the general public. This creates a gap in the market for an affordable and accessible solution to this problem, motivating the exploration of purely mechanical alternatives.

3. BIO-INSPIRED DESIGN PRINCIPLES

Biomimicry has become a promising new source of inspiration for engineering design, as many natural phenomena offer efficient solutions to mechanical problems. For example. the capability of the woodpecker's beak to withstand repeated high-impact forces has inspired many designs; using X-ray computed tomography to analyse the head structures of golden-fronted woodpeckers, Yoon and Park developed bio-inspired shock-absorbing system with a failure rate of only 0.7% at 60,000g compared to 26.4% for conventional methods (4). A key feature of the woodpecker's anatomy which allows this is the hyoid bone, which extends around the skull and aids in force distribution while also functioning as an energy absorber.

Similarly, the mechanical properties of bamboo have attracted significant scholarly interest. Chen et al. identified three hierarchical fibre reinforcement schemes in bamboo nodes: spatially tightened interlocking, triaxial interconnected scaffolding, and isotropic intertwining (5). Together, these structural features enhance load distribution and stability. The nodes also serve as natural regions of stress dispersal, improving the lateral strength. Furthermore, the tensile strength-to-specific weight ratio of bamboo is approximately six times greater than that of steel (5).

Silkworm cocoons are another great example of biological armour. According to Zhang and others, the wild silk cocoon shows an exceptionally good capacity for toughness, heat buffering, one-directional moisture transport, and UV stability (6). The multi-layered nonwoven armour has evolved to offer effective protection without much weight. This formed the basis for the development of the spoon bowl in the current study.

4. METHODS

4.1 Design Principles

The design approach used five key principles identified through the literature review: (1) Resonance avoidance through frequency separation, keeping the spoon's natural frequencies well above the tremor frequency range; (2) a flexible spring element at the neck between the handle and the bowl, intended to add some compliance; (3) optimisation of the mass distribution to keep the centre of gravity low; (4) ergonomics for a comfortable grip; and (5) bio-mimicry aesthetics to reduce stigma.

The limits put on the design process were a weight of less than 150 grams (130 grams, as per the literature review, is ideal for the elderly population), a length of less than 250 millimetres, a food-grade material, and feasibility of manufacture.

4.2 Bio-Inspired Design Elements

Three aspects of nature have been built into this particular spoon design.

Cocoon-Inspired Bowl: The bowl is similar in form to the protective nature of silkworm cocoons. With its deeper curvature, the bowl design lowers the risk of spillage even under tilted positions. Its multi-layer construction gives it strength, while the inner surface allows easy release of food from the spoon. It takes advantage of the protective abilities of the cocoon, which evolved over time to protect what is inside with a light-weight construction.

Bamboo-Inspired Handle: The extruded rings on the handle take inspiration from the nodes of a bamboo, which help guide the fingers for superior grip and replicate the stress-mitigation abilities of bamboo. The nodes work like reinforcements, keeping the handle stable, while the hollow centre helps minimise weight.

Woodpecker-Inspired Orthogonal Spring: The orthogonal spring connecting the bowl and the handle uses a mechanism incr

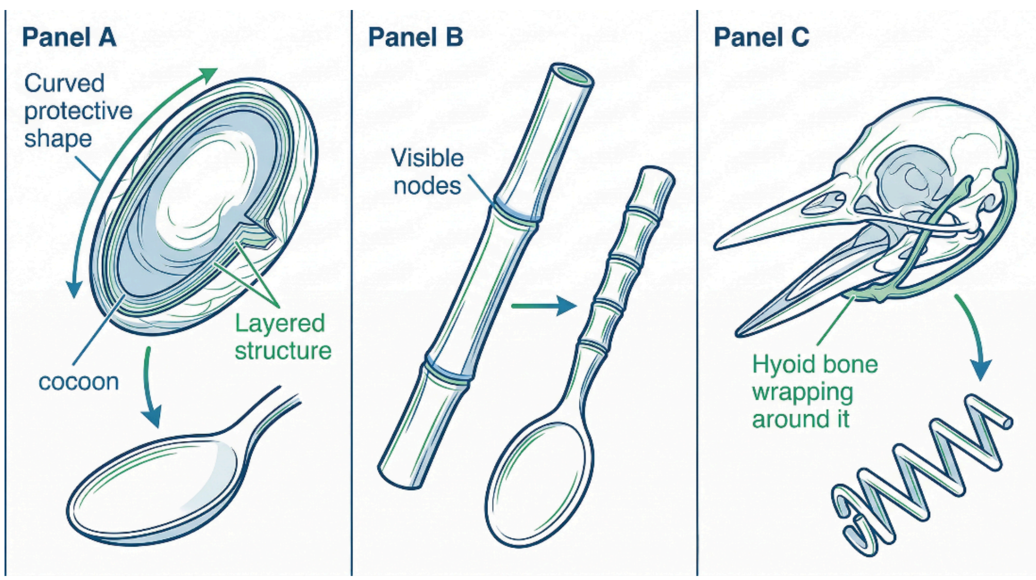

Figure 1. Biomimetic inspiration behind the three major design elements

4.3 CAD Modelling

The spoon was modelled using the SolidWorks Student Edition software. The dimensions of the spoon are as follows: the length of the spoon is 200mm, with a bowl width of 42mm and a handle diameter of

19mm near the grip end. The orthogonal spring, connecting the bowl and the handle, measures 52mm. AISI 304 was selected as the construction material due to its corrosion resistance, durability, and suitability for food-based applications. The material properties used were an elastic modulus of 190 GPa, a Poisson's ratio of 0.29, a yield strength of 207 MPa, and a density of 8000 kg/m³.

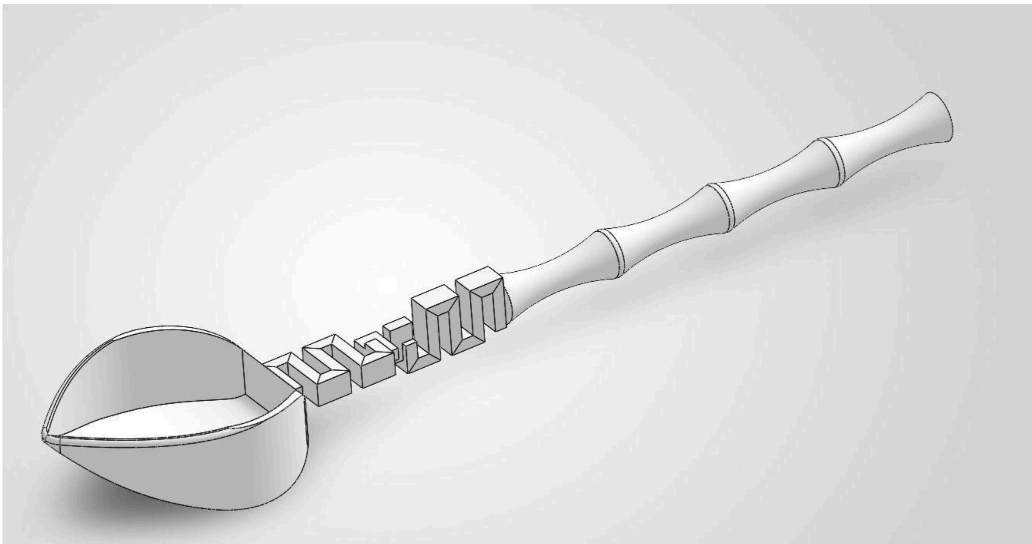

Figure 2. SolidWorks CAD model of the bio-inspired spoon.

The mass properties of the final design show that the total mass is 87.89 grams, the volume is 10,985 mm³, and the surface area is 11,570 mm². The centre of mass was calculated to be at X = -16.48 mm, placing it slightly closer to the bowl than the geometric centre of the spoon. While this may improve stability in some cases, it may not always be beneficial for tremor reduction as a mass placed farther from the user's hand can increase the lever arm of the tremor-induced motion. Therefore, the influence of this mass distribution on performance would need to be evaluated experimentally using a physical prototype.

4.4 Finite Element Analysis Setup

Three studies were conducted using SolidWorks Simulation: static structural, modal frequency, and thermal analyses. The model was meshed using a high-quality solid mesh consisting of parabolic tetrahedral elements. A global element size of 1.5 mm was applied throughout the model, while a finer mesh of 0.5 mm was used around the radii of the orthogonal spring where the highest stress was expected. Mesh consistency was assessed by comparing the peak von Mises stress from a 1.5 mm mesh with that of a 2.0 mm mesh. The difference between the two values was less than 1.8%, suggesting that further refining the mesh would be redundant. The bowl, the spring, and the handle were modelled as one single bonded body. This matches a part made by 3D printing or investment casting in AISI 304 stainless steel. The Direct Sparse solver was used for all studies. The modal frequency study was setup as an undamped frequency extraction and therefore it gives the natural frequencies of the structure but does not include any damping. Therefore, a separate damped calculation was done, as shown in Section 5.2, which was used to look at how the tremor is transmitted.

5. RESULTS

5.1 Frequency Analysis

The modal analysis technique was used to obtain the natural frequencies and mode shapes of the spoon. The handle was held fixed on one side as the boundary condition, as if the spoon is being held by the user's hand. The natural frequencies obtained for modes 1 to 5 are: Mode 1, 58.52 Hz; Mode 2, 64.16 Hz; Mode 3, 291.95 Hz; Mode 4, 497.21 Hz; and Mode 5, 583.97 Hz.

The first mode frequency, 58.52 Hz, is much higher than the 4 to 12 Hz frequency range of hand tremor. Keeping these two values far apart matters, because it stops the spoon from resonating with the tremor. According to vibration theory, when the frequency of the excitation force is much lower than the natural frequency of the vibrating object, the object behaves like a rigid body. The frequency ratio (tremor frequency divided by natural frequency), taking the tremor as at most 12 Hz, is about 0.2. What this rigid-body behaviour means for the tremor is looked at more closely in Section 5.2.

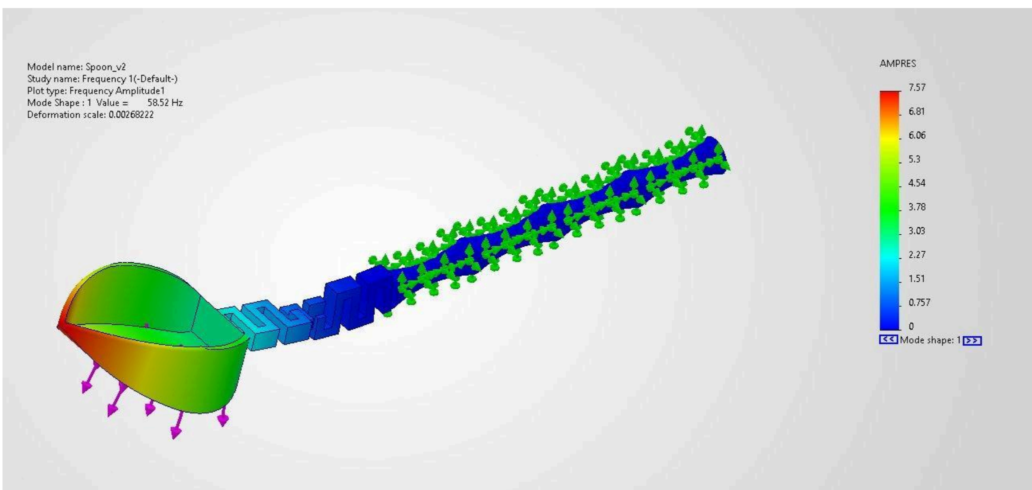

Figure 3. Mode shape 1 at 58.52 Hz showing bending deformation.

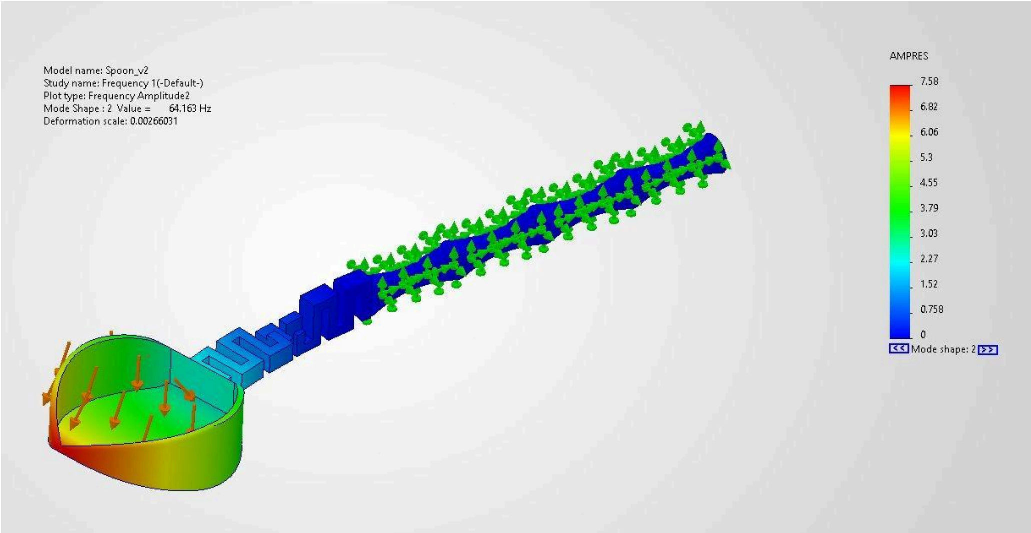

Figure 4. Mode shape 2 at 64.16 Hz showing torsional deformation.

The mode shape analysis shows that in modes 1 and 2 there is mostly bending and twisting of the bowl section relative to the handle. The orthogonal spring section shows the largest movement, which means it is the most flexible part of the structure. Modes 3, 4, and 5 show more deformation of the handle and spring sections.

5.2 Response to Tremor (Transmissibility)

Modal analysis enabled us to identify the natural frequencies of the spoon. However, it did not quantify how much tremor motion is transmitted to the bowl. To estimate this behaviour, a separate analytical calculation was done using a standard single-degree-of-freedom base-excitation model, treating the hand as the source of excitation and the bowl as the vibrating mass. The displacement transmissibility T, or the ratio between the bowl motion and hand motion, is given by:

$$T = \sqrt{\left[(1 + (2\zeta r)^2) / ((1 - r^2)^2 + (2\zeta r)^2) \right]}$$

where r is the frequency ratio (f/ f_n) and ζ is the damping ratio. A damping ratio of 0.05 was assumed for the stainless steel structure. As the excitation frequencies are much lower than the first natural frequency, the exact damping value only has a minor impact on the results.

At the bottom of the tremor band (4 Hz), $r = 4 / 58.52 = 0.068$, which gives $T \approx 1.005$. At the top of the band (12 Hz), $r = 12 / 58.52 = 0.205$, which gives $T \approx 1.044$. Across the entire tremor band, the transmissibility remains close to 1. This result is shown in Table 1 and Figure 5.

Tremor frequency (Hz)	Frequency ratio r	Transmissibility T
4	0.068	1.005
6	0.103	1.011

8	0.137	1.019
10	0.171	1.030
12	0.205	1.044

Table 1. Calculated transmissibility across the tremor band (assumed damping ratio 0.05).

The results indicate that the motion of the bowl is similar to the motion of the hand, with only a minimal reduction in transmitted motion. The frequency ratio r remains well below √2, indicating that that the system operates within the rigid-body region and not the vibration-isolation region. Although the design does not provide significant tremor isolation, it successfully avoids resonance. If the first natural frequency of the spoon had fallen with the 4-12 Hz range, substantially greater vibration amplitudes could have been generated. Therefore, despite the absence of active tremor reduction, the difference between the first natural frequency and typical tremor frequencies ensures that the system remains stable.

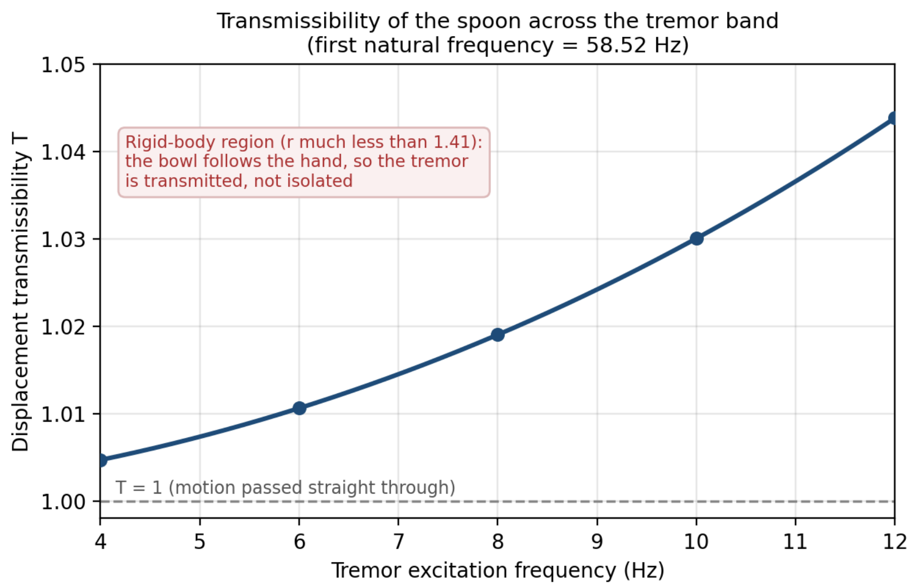

Figure 5. Analytical transmissibility of the spoon across the 4 to 12 Hz tremor band, based on the first natural frequency of 58.52 Hz.

5.3 Static Structural Analysis

A static load of 1N was applied to the upper surface of the bowl, representing the combined weight of the food and the forces typically experienced by a spoon during the eating process. The other end of the handle was marked as a fixed boundary condition.

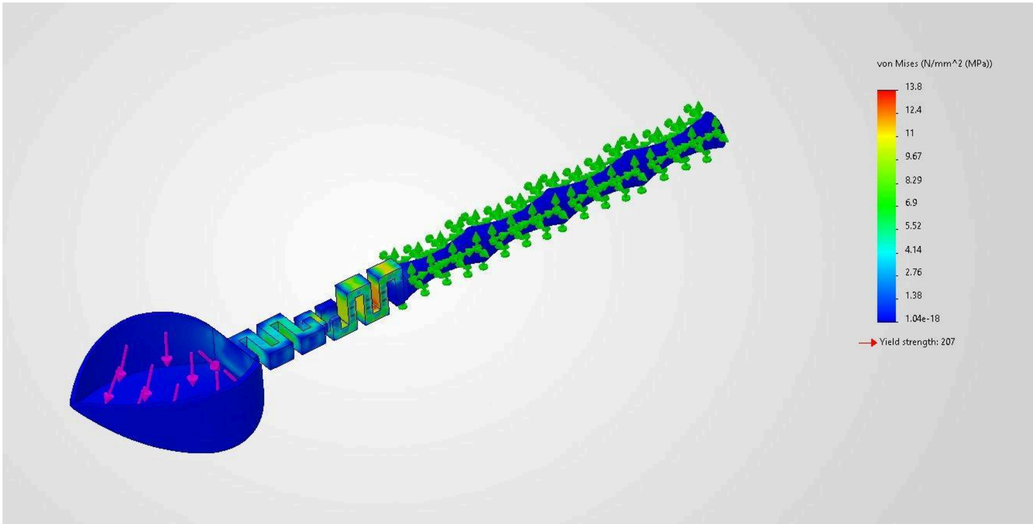

Figure 6. Von Mises stress distribution (maximum 13.8 MPa).

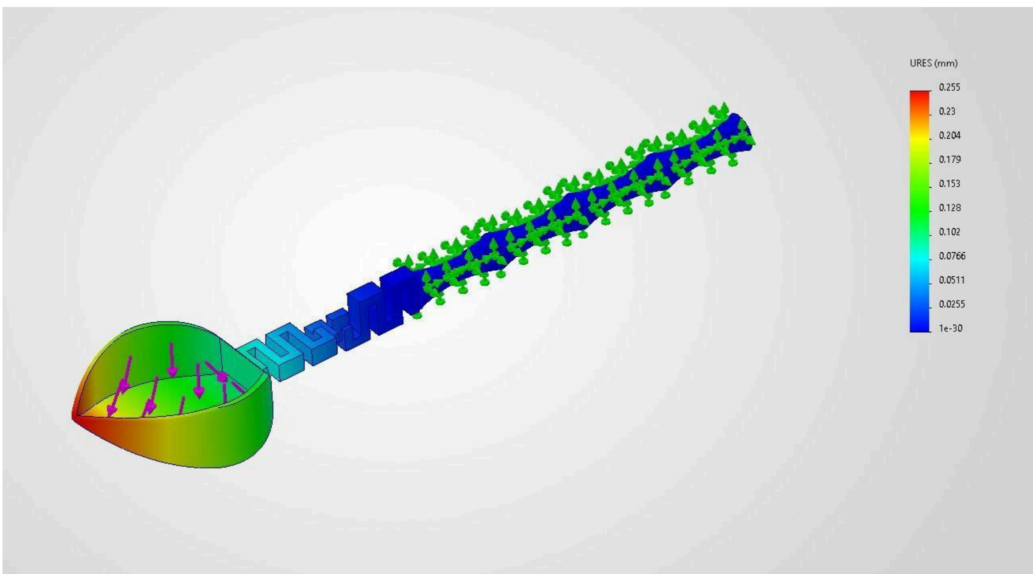

Figure 7. Displacement distribution (maximum 0.255 mm).

The orthogonal spring element has a peak von Mises stress of 13.8 MPa, since this element takes the largest strain. When comparing with the yield strength of AISI 304 stainless steel (207 MPa), a safety factor of about 15 was shown. This is very conservative design with a large margin for higher loads and fatigue. The peak displacement of 0.255 mm is found at the tip of the bowl which is small enough for practical purposes. This small displacement means the spoon keeps its shape well while serving food.

5.4 Thermal Analysis

The thermal analysis was carried out to mimic eating hot food. The spoon head was kept at 125 °C, with the handle held at room temperature (25 °C). This analysis was important to make sure the spoon is safe and comfortable while eating hot foods.

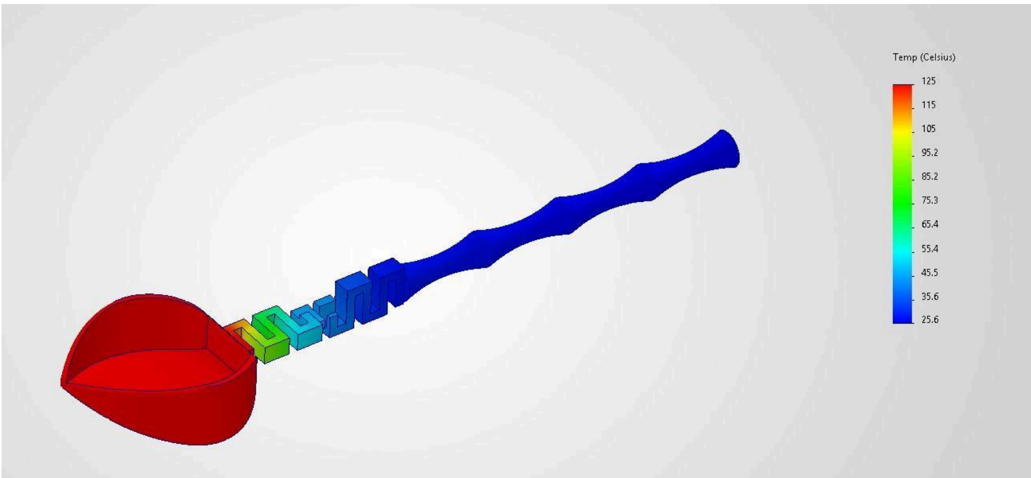

Figure 8. Temperature distribution showing thermal isolation between the bowl and the handle.

The simulation showed a steep temperature gradient across the orthogonal spring section. While the bowl remained at 125 °C, the handle temperature was shown to remain between approximately 30 and 35 °C. This reduced heat transfer might be due to length of the conduction path and the reduced cross-sectional area of the spring. In addition to these, the relatively low thermal conductivity of AISI 304 stainless steel (16 W/m·K) also enhances this effect. The simulation shows that the handle would remain in a comfortable temperature range for use even when the bowl contains hot food such as soup.

S. No.	Parameter	Value	Target / Limit	Status
1	Total mass	87.89 g	< 150 g	PASS
2	First natural frequency	58.52 Hz	Outside 4 to 12 Hz band	PASS
3	Max von Mises stress	13.8 MPa	< 207 MPa	PASS
4	Safety factor	15	> 2	PASS
5	Max displacement	0.255 mm	< 5 mm	PASS
6	Handle temperature	30 to 35 °C	< 45 °C	PASS

Table 2. Summary of simulation results.

6. DISCUSSION

The frequency analysis showed that the first natural frequency of the spoon (58.52 Hz) lies above the reported tremor range of 4-12 Hz. Therefore, this separation is beneficial as resonance with hand tremors and the subsequent amplification of vibrations becomes highly unlikely.

The transmissibility analysis also provides some insights into how the spoon behaves in dynamic conditions. The orthogonal spring might act as a flexible link between the bowl and the spoon; however the frequency ratio remains below the required threshold for vibration isolation. As a result, motion is transmitted almost directly from the hand to the bowl, with transmissibility values remaining close to 1 throughout the tremor range.

It is important to understand how meaningful tremor isolation could be achieved. For this to occur, the transmissibility has to drop below 1 and the frequency ratio r must exceed $\sqrt{2}$. In order to isolate the lowest tremor frequency of 4 Hz, a first natural frequency below approximately 2.8 Hz must be achieved. Assuming a combined bowl and food mass of 50g (0.05 kg), the spring stiffness would need to be:

$$k = (2\pi \times 2.8)^2 \times 0.05 \approx 15.5 \text{ N/m}$$

Under the same 1N load used in the static analysis, a deflection of 64 mm (0.064 m) would occur. A spoon that sags 64 mm when eating would be unusable, and the functionality of the spoon would be severely compromised. This trade-off between tremor isolation and structural rigidity, showing that a spring soft enough to isolate tremors would make the spoon impractical for use is important to note.

Even with these, the biomimetic features contribute to other aspects of the spoon's performance. The cocoon-inspired bowl might assist in reducing spillage because of its deeper profile, particularly for liquid food items like soup. The bamboo-inspired handle provides areas of enhanced grip for users and still maintaining a lightweight structure. The orthogonal spring region inspired by the hyoid bone of a woodpecker serves as the primary component for stress distribution and thermal isolation.

When the spoon is compared with existing solutions, the proposed biomimetic condition offers advantages; but these are not necessarily related to tremor suppression rather the general usability of the spoon. Unlike weighted utensils, which have increased muscle fatigue in users (8), the present design does not use additional masses. Moreover, unlike electronic devices such as the Liftware Steady, it requires no batteries, sensors (which are susceptible to latency issues), or charging infrastructure (2). While active stabilisation systems have shown tremor reductions of approximately 71-76% during eating tasks, the spoon developed in this study is not intended to achieve the same level of performance (2). Instead, its benefits lie in its simple construction, durability, and ease of use.

Several limitations of this study must also be acknowledged. The findings are based entirely on simulation and calculations, and require validation by developing and testing a physical prototype. Additionally, the damping effects were not included directly in the modal analysis; rather, they were considered only through a simplified transmissibility study. The slightly forward centre of mass may also influence the feel of the spoon in-hand, and must be investigated experimentally. Finally, user opinion of the appearance of the spoon was not considered, despite evidence that the appearance of such assistive devices has a significant impact on adoption and the stigma surrounding them (10).

Future studies should focus on testing with a fabricated prototype and experimentally validating the design. Studies involving patients with ET or Parkinson's disease would allow for a direct evaluation of features such as vibration transmission, food spillage, and user comfort. Further investigation using different spring geometries or alternative materials would also help improve the design.

7. CONCLUSION

This study explored the use of bio-inspired design principles in an assistive eating utensil for patients with hand tremors. Inspired by various biological features such as silkworm cocoons, bamboo nodes, and the woodpecker hyoid bone, a new spoon concept was designed and evaluated using FEA. The results show that the design avoids vibration amplification and resonance; it maintains a separation between its first natural frequency (58.52 Hz) and the typical hand tremor frequency range of 4-12 Hz. The spoon also showed good structural performance, with a safety factor of approximately 15 under a 1 N load. Thermal analysis predicted that the spoon would remain usable when come in contact at 125 °C, maintaining handle temperatures at 30-35 °C. The initial mass also remained within the comfortable range for use.

The transmissibility analysis shows that the spoon largely behaves as a rigid body and moves almost altogether with the hand. Therefore, tremors are not significantly reduced or suppressed. Further calculations also showed that a spring soft enough to provide sufficient tremor isolation would deflect too much in operating conditions, rendering it practically unusable. This suggests that the primary benefits of the design are resonance avoidance, structural integrity, and thermal isolation rather than tremor suppression.

Physical prototypes and user tests are still to be done to confirm the simulation predictions, but we claim that this concept is a useful step, and it points clearly to what a future design would have to overcome.

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