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Design of 3D-Printed Prosthetics for Disabled Pets

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Abstract: Pets play a vital role in human lives, yet approximately 10% of pets in the EU and USA are disabled, facing challenges with traditional prosthetics due to high costs and surgical risks. This study explores the application of 3D printing technology to develop customizable and affordable prosthetics for disabled pets, focusing on dogs. By leveraging advancements in material science, biomechanics, and veterinary medicine, the research designs a multidisciplinary framework for creating prosthetics that are more accessible and comfortable. Preliminary findings indicate that 3D printing significantly reduces production costs and time while enhancing functionality and aesthetics. This study aims to improve the quality of life for disabled pets and contribute to the broader field of assistive technologies.

Keywords: Ergonomics, 3D Printing, Dog Prosthetics, Biomechanics, Pet Mobility, Animal Welfare.

1. Introduction

Pets are a part of many families. About 88 million households in the European Union have a pet, with rates of household pet-ownership ranging from 38% to 68% in the European Union and the U.S.A. But it's time to face the uncomfortable truth, Platero et al. (2022) and Vos et al. (2021) pointed out that approximately 10% of these pets are disabled. There are noticeable differences and significant variations in bone shape and size between breeds of pets, particularly dogs. Osseointegration technology, which involves surgically connecting prosthetics with specifications directly to an animal's bones, is used in traditional pet prosthetics. The complexity of this process, combined with the substantial resources and manpower it requires, contributes to the high costs associated with such prostheses. In addition, incorrect implant insertion carries the risk of fracturing the distal portion of the bone, which may lead to bone deformity, changes in natural movement posture, and infection. Furthermore, the high costs, inaccessibility, and aesthetic issues associated with pet prostheses increase the risk of disabled pets' being abandoned, potentially posing a social problem.

This research is currently in its early stages and has already gained technical references from the design of human 3D printed prostheses, and initial research feedback has been positive. This research is a multidisciplinary, comprehensive study involving veterinary medicine, biomechanics, and material science to design and develop 3D printed prostheses for disabled dogs. By combining expertise in these fields, we hope to provide more affordable, customizable, and accessible pet prosthetic solutions to improve the quality of life of disabled pets.

2. Research Background

3D-printing technology is used in the development of human prosthetics (McAlpine et al., 2020). Relative to traditional embedded prosthetics, 3D-printed human prostheses have achieved significant improvements in shape, characteristics, functions, and intelligent expansion and optimisation. These extensive advancements in 3D-printed prosthetics for humans can provide a head start for the design of pet prostheses.

2.1. Pet Prostheses Development

2.1.1. Osseointegration Technology

Traditional pet prostheses are usually made with osseointegration technology, which is expensive; furthermore, the incorrect insertion of a prosthesis can lead to problems such as infection and restricted movement. Osseointegration technology refers to the surgical fixation of prostheses of specific specifications directly to the bones of animals (Figure 1). Differences in animal size make it difficult for many animals to receive effective help. The complexity of osseointegration and the substantial resources and manpower it requires contribute to the high costs associated with such prostheses (Walfield et al., 2017).

Figure 1. Example of a Thoracic Limb Prosthetic Device for a Patient with a Mid-radius Amputation

2.1.2. Common Materials in Traditional Pet Prosthetics

The materials used in traditional pet prosthetics production are subject to size constraints, because they must rely on moulds. Mould customisation is associated with higher prices and difficulty in acquisition. One of the most used materials in prosthetics is thermoplastic, which requires mould customisation and particular processes, as well as multiple attempts on the pet to take shape. Other common pet prosthetic materials are aluminium and titanium. They are typically used with a die-casting method that involves dissolving metal into a liquid and then shaping it with a mould; this production process is generally considered to be more complex and expensive than that of thermoplastic materials (Walfield et al., 2017).

2.1.3. Assistive Devices

While some assistive devices for pets do not necessitate bone implants, these options are typically more suitable for addressing limb deformities than for partial amputations. These pet assistive devices often use silicone to provide cushioning and reduce friction. Due to the limited hardness range of silicone, it cannot meet all prosthetic needs. Moreover, while the hanger and ground interface parts of this type of device do not require special ordering, the materials on the market are mainly thermoplastics. These materials are generally considered to have poor elasticity and are easy to wear, and it is difficult to find sizes appropriate for small dogs (Walfield et al., 2017).

2.1.4. 3D-Printed Pet Prosthetics

With the rapid growth of three-dimensional (3D) printing technology, the production and design of pets' prostheses have become less expensive. This method also yields non-toxic, comfortable devices. A defined measurement process allows pet owners to collect the data required for 3D printing by themselves. However, the main purpose of the relevant research has been to meet the demand for pet prostheses costing less than US$200, which has negatively affected the functionality, expandability, and appearance of the prostheses (Walfield et al., 2017).

2.1.5. Conclusion

In general, traditional osseointegration technology is associated with high costs, high surgical risks, a long production process, and difficulty in producing a variety of sizes. Furthermore, the resulting wearable pet assistive devices are not suitable for pets with partial amputations, and the trial scope is limited. In comparison, the development time of 3D-printed pet prostheses is shorter, and the main direction of the relevant research has been to reduce the cost of pet prostheses. Although surgical and customisation challenges can be overcome, current market demands are not fully met in terms of functionality and appearance.

2.2. 3D Printing in the Design of Pets' Prostheses

2.2.1. Reducing Production Time and Optimising the Installation Process

3D printing technology has been used in prosthetics for humans and animals and is generally considered to have advantages in terms of rapid customisation, a wide choice of materials, and flexibility in redesign. One study (Gupta & Goil, 2020) showed that compared with traditional production, the production time of artificial jaws produced using 3D printing was reduced by approximately 33%, and the overall surgical time was reduced by 31%. Another study (Walfield et al., 2017) pointed out that 3D-printed pet prostheses can be produced in combination with pre-existing parts available on the market, providing options for users who do not want to 3D print full prostheses.

3D printing is a trending technology applied to animal prostheses because of the speed of printing and assembly and the flexibility of redesign, allowing the shape to be easily modified to adapt to an animal as its body changes. 3D-printed products can be quickly customised, overcoming the difficulties posed by high mould costs and great differences in individual pet sizes. There is an increasing interest in exploiting state-of-the-art 3D-printing technology for clinical problem-solving; the 3D-printed prostheses production process results in significant time savings (Belinha et al., 2019; Stelt et al., 2020).

2.2.2. 3D Printed Lattice Structure to Optimise Prosthetic Limb Elasticity

3D-printing technology allows for the modification of an object's structure. For example, the 3D printed lattice structure can optimise the elasticity of a prosthesis through its various basic lens shapes (Gao et al., 2023). Figure 2 shows a mechanical model of a 3D-printed lattice. In 3D printing, the lattice structure can improve resilience and optimisation without increasing friction., thereby optimising the silicone material used in traditional pet prostheses. The 3D-printed lattice structure can also enhance the texture and aesthetics of the product.

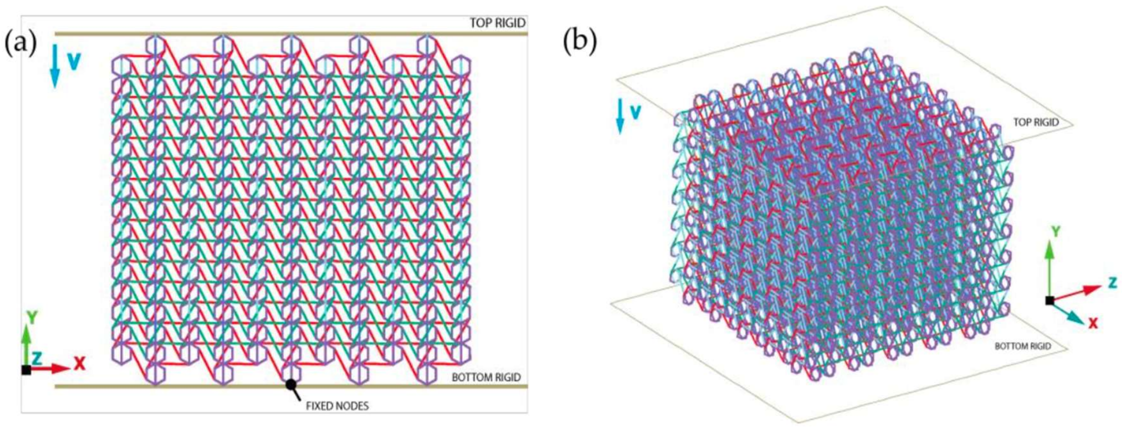

Figure 2. Stress Simulation Model of the 3D Lattice Structure

Polylactic acid (PLA) is combined with 3D printing technology and is used in various fields due to its excellent biodegradability. PLA 3D research has suggested that in addition to providing internal structural support, the surface of a 3D-printed product can be aligned with its internal structure using techniques such as polishing. This helps reduce surface roughness and enhances mechanical properties such as stretch strength. In a study by Ray Tahir Mushtaq et al. (2023), laser polishing reduced surface roughness by more than 88.8% (from 7.8 μm to 0.87 μm), while the tensile strength of the specimen increased by 14.03% (from 39.2 MPa to 44.7 MPa). The 3D elastic cord structure in this pet prosthetic offers practical solutions for designing and treating surface materials. The special lattice structure design can provide a special textural effect in the final product.

2.2.3. Combining 3D-Printing Materials to Simulate Native Limbs

A variety of materials can be used in 3D printing, and materials of different hardness levels can simulate native animal limbs. For example, animals' knee joints are generally harder than their calf bones; 3D-printing materials of various levels of hardness can simulate this difference. For example, Stereolithography (SLA), a vat-photopolymerization technique, that uses a laser beam, is known for its ability to fabricate complex 3D structures ranging from micron-size needles to life-size organs, because of its high resolution, precision, accuracy, and speed. (Lakkala et al., 2023) SLA 3D printing has various applications, including prototyping, jewellery making, and dental modelling. One interesting application of printing is the production of mechanical metamaterials for use in robotic grippers, providing flexibility and strength in their design (Solomon & Yerazunis, 2021). Similarly, the combination of various materials and 3D printing can be used to simulate the original limb structure in 3D-printed animal prostheses.

2.2.4. Expanded High-Tech Possibilities for 3D-Printed Pet Prosthetics

Compared with traditional, moulded prostheses, 3D printed prostheses can be more compatible with other devices to achieve functional expansion, such as implanting optical heart rate sensors to detect animals' movement posture and thus assess the fit of pet prostheses, and implanting oximeters and chips to otherwise expand the functions of pet prosthetics.

2.2.5. Reducing the Need for Prosthetic Surgeries

As Marcellin-Little et al. (2015) pointed out, 3D printed pet prostheses can be customised through 3D scanning. 3D printed pet prostheses are more accurate than prostheses made from traditional moulds, so there is no need to embed the prostheses into the animal bones. This reduces the difficulty and time of prosthetic limb acquisition.

2.2.6. Combining 3D Printing and Traditional Pet Prosthetics

3D-printing technology, in the context of pet prosthetics, can be used for a specific parts or parts to be combined with traditional materials during the production process, to reduce the cost. In this production method, 3D printed parts are used to connect to the missing parts of the pet's body, thereby reducing the pet's pain during surgery while retaining compatibility with existing accessories on the market.

2.2.7. Conclusion

Overall, 3D-printing technology brings many advantages to the manufacture of animal prostheses. Specifically, it speeds up and simplifies the production process and provides the possibility of personalisation for pets of various sizes. In addition, through the use of point-like body structures and multiple material selections, 3D-printed prostheses are mechanically and structurally closer to animals' bones than are moulded prostheses, providing more ductility for the functions of pet prostheses. This technology thus provides innovative solutions for improving pets' recovery and quality of life.

3. Research Methodology

3.1. Literature Overview

The literature review will include journal articles, academic publications, patent searches, and relevant news sources and documentaries examining the background and development of 3D printing and pet prosthetics, the application of 3D printing in the pet market, and the 3D printing of human devices.

Specifically, the review areas will be:

- understanding disabled dogs
- studying various prosthetic types used by humans and animals
- exploring the design and materials of prosthetics currently available on the market
- investigating various 3D printing technologies for potentially useful for developing dog prosthetics
- studying 3D-printing materials, in conjunction with various 3D printing technologies, in terms of the materials' flexibility and durability
- studying lattice structures as a potential design element for innovative dog prosthetics

3.2. Research Gaps

To address relevant gaps in the literature, the proposed research will have the following goals.

- understand the various factors that prevent some owners of pets with physical disabilities or deformities from obtaining adequate pet assistive devices, such as the owners' attitudes, economic conditions, difficulty in obtaining devices or the pets' own resistance to prostheses
- focus on the application of 3D printing in the field of pet prosthetics, determining which prosthetics designs have used 3D technology and whether there is room for optimisation of and innovation in these designs
- consider the problems that 3D printing materials may pose in their practical application in pet prosthetics, increase repeated debugging and trials, and increase the reliability of experimental feedback

3.3. Establishing a Design Process Model

Given the limited availability of information on the design process model for 3D-printed dog prosthetics in academic publications, one of the research objectives will be to establish a design process model to guide researchers and designers in formulating practical action plans. The design model will comprise the following steps:

- set service goals and analyse target cases to identify the problems faced by a disabled animal and the kind of help the product will be designed to provide
- refine the problem, classify the design direction, fully understand the help the pet needs, and analyse the demands of the pet owners. Decide on the appropriate materials, optimal appearance, etc.
- obtain theoretical support from pet groups or experts: Because pet-related design research may raise ethical issues, it is necessary to confirm that the design process is

standardised and reasonable and supervised by a third party.

- refer to industry standards regarding the impact of products on the environment, whether materials are toxic, and other potential issues

3.4. Interviewing Owners of Disabled Pets and Experts in Animal Prosthetics

Interviews will be conducted with owners of disabled pets (with the pets present), producers and designers of animal prosthetics, and service providers, with the following goals:

- ask pet owners/professionals about the psychological impact of pet disabilities on owners of disabled pets, inconveniences in the lives of disabled pets, etc.
- observe the gestures and movements of pets wearing prosthetics
- thoroughly explore the specific design requirements for the new prosthetics
- learn about the price of 3D-printed pet prosthetics on the market and other market factors through interviews

3.5. Exploring Design and Material Options for the New Prosthesis

Appropriate data collection and analysis are crucial to the successful development of 3D-printed pet prostheses, given their customised nature. Early data collection, with an emphasis on a targeted approach for multifaceted data acquisition, will be particularly important in the proposed research. Notably, there exist precedents in the pet market where 3D printing has been used. Applications such as Polycam enable users to generate high-quality photos of 3D models, while tools like the Kiri engine facilitate the collection of more precise data through multiple scans.

- 3D printing and prosthetics' aesthetic quality: 3D printing gives designers more flexibility in terms of product appearance. The aesthetics of pet prostheses will affect pet owners' attitudes towards disabled pets.
- Design and conduct model verification: One of the advantages of 3D-printed prostheses is that model data can be adjusted quickly and repeatedly. Repeated use and model verification are especially important for design. A fit test of the prototype sample will ensure that its size is appropriate and that the sample accurately fits the contours of the pet's skin. According to the respective habits of various pets, different 3D-printed lens structures will be used to adjust the elasticity of the pets' prosthetic limbs and to optimise the materials of the joints and accessories, and the 3D printed prosthetic limb prototype will be modified.

3.6. Evaluation of the New Products

- The product testing of the new 3D-printed animal prosthetic limb will follow the qualitative data collection, which requires that the data collection be repeated several times until the pet has fully adapted to the 3D printed prosthetic limb.
- Field testing and feedback: The printed prosthetics and devices will be applied to real pets, feedback data will be collected, and their comfort and usability will be evaluated.
- Participant observation: The use of new 3D-printed prosthetics by pets will be tracked, and their usage in various environments will be analysed.
- Analysis and interpretation of data: A survey will be created for pet owners, veterinarians, and other related professionals. Through the questionnaire, I will learn about their needs and the deficiencies in current pet prosthetics and assistive devices, as well as their opinions on the use of 3D-printed prosthetics.
- Design improvement: Based on the results of data analysis, necessary adjustments and improvements in the design and manufacturing processes will be made to optimise the product's comfort.

4. Conclusion and Outlook

The key findings of the study will be summarised, and the benefits of 3D printing, in terms of custom design and comfort, will be highlighted. This study will serve as a design reference or benchmark for researchers and designers in the further development of similar types of products. According to the description of the above literature, this study can draw on the support of 3D printing in many fields such as human prosthetic applications, animal behaviour research, and 3D printing material technology, and has the potential for implementation. In addition, traditional bone-embedded pet prostheses have a certain development history, which further verifies the feasibility of this study.

3D printing technology can significantly reduce the production time of pet prosthetics and provide support for customization in different sizes. 3D printing materials, such as PLA, can increase the elasticity of pet prosthetics, thereby improving the comfort of pets wearing prosthetics. These are important values brought by this study. In addition, future research will further explore the application of pet behaviour and more 3D printing materials and technologies in pet prosthetic design.

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