TECHNICAL DESIGN CONCEPT FOR A PROTECTIV SUIT INSPIRED BY BIOMIMETICS

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***ABSTRACT**: Stunt choreography frequently necessitates specialized protective attire due to its rigorous demands. While such clothing typically derives from equipment used in extreme sports, certain activities, given their distinctiveness, still present significant health risks to performers. Locomotion serves as a prime example. Exploring the potential of biomimetics, the concept of employing a suit modeled after snake skin was contemplated. Such a suit would offer enhanced protection, minimize friction, and boost performance efficiency.*

***Keywords:** protective clothing, locomotion, biomimetics, snakeskin, friction, stunt.*

TEHNIČKI PREDLOG ZA DIZAJN ZAŠTITNOG ODELA INSPIRISANOG BIOMIMIKRIJOM

***APSTRAKT:** Zahtevnost kaskaderskih koreografija nemalo puta iziskuje posebne vrste zaštitne odeće. Ta odeća je najčešće deo opreme za neki ekstremni sport, premda pojedine aktivnosti, zbog svoje unikatnosti, i dalje predstavljaju veliku pretnju za zdravlje izvođača. Lokomocija je jedan od primera. Koristeći se biomimikrijom, razmotrena je mogućnost zaštite pomoću odela konstrusanog prema uzoru na zmijsku kožu, čime bi se obezbedila bolja zaštita, smanjilo trenje i povećala učinkovitost performansa.*

***Ključne reči:** zaštitna odeća, lokomocija, biomimikrija, zmijska koža, trenje, kaskada.*

1. INTRODUCTION

The film costume emerges from the collaborative efforts of two distinct industries: film and textile. It serves as an essential element on every film set while also functioning as a textile product. Its creation involves two main stages: the artistic phase, which encompasses conceptualization and sketching, and the technical phase, focused on actualizing these designs. Mastery of both artistry and technical craftsmanship is essential in this process.

However, costume is not the only segment of the clothing industry on the film.The safety of performers on set demands protective gear for scenes involving risky stunts, vital for safeguarding their health. In the past year alone, US theaters showcased films with a staggering 5,903 stunt credits. Each performance necessitated some form of protective clothing, tailored to the specific choreography and requirements. Given the lack of a dedicated industry for stuntmen's protective wear, much of the gear is repurposed from extreme sports such as mountaineering or motorcycling. While serving its primary function to a large extent, it falls short of being considered ideal. The issue discussed in the paper underwent analysis in collaboration with the Serbian Stunt Association.
One reason these garments fail to offer optimal protection is because many stunt demands aren't typical for any extreme sport. This paper will address the challenge of safeguarding performers during the horizontal pulling of a contractor on a specific surface. We sought a solution to this issue by turning to nature. Employing biomimicry, we endeavored to create a suit inspired by the texture of snakeskin. By utilizing the same materials found in existing protective gear but innovatively redesigning its segments into a suit, we aimed not only to enhance protection but also to enhance the effectiveness of the performance itself.

2. BIOMIMICRY AS INITIAL INSPIRATION

Biomimetics or biomimicry is the emulation of the models, systems, and elements of nature for the purpose of solving complex human problems [1]. Biomimetics holds promise for application across numerous fields. Given the diversity and intricacy of biological systems, there exists a vast array of features ripe for imitation. Biomimetic applications span various stages of development, ranging from emerging technologies with potential for commercial viability to prototype stages. The term 'biomimetics,' coined by Schmitt [3], originates from the Greek words 'bios,' meaning life, and 'mimesis,' meaning to imitate [4]. This emerging science is grounded in the notion that nature tends to pursue the path of least resistance, often employing readily available materials to achieve its objectives with minimal energy expenditure. Ideally, biomimetics should involve integrating principles that echo nature's sustainability practices, encompassing everything from raw material utilization to recyclability, mirroring nature's lifecycle from inception to reuse.
Camouflage fabric stands as one of the earliest iterations of such materials. Now widely adopted by military forces globally, its origins trace back to 1850, when English troops deployed it during India's colonization. These fabrics aim to diminish the visibility of individuals by mimicking their surroundings. One of the most notable examples is the emulation of the lotus plant. This plant boasts a natural self-cleaning mechanism attributed to its surface morphology, featuring numerous tiny warts covered in hair-like structures akin to wax crystals. This blend of micro and nanostructures significantly minimizes molecular contact with the water surface, giving rise to the renowned "lotus effect".

2.1. Structure of snake skin

The snake skin is comprised of two primary layers: the "dermis" and the "epidermis." The dermis, situated deeper of the two, consists of connective tissue abundant with blood vessels and nerves. Meanwhile, the epidermis is made up of layers called "strata," densely

packed with cells. These strata encompass seven layers, forming a protective outer coating of the body.
At the base of the epidermis lies the "stratum germinativum," housing cells capable of rapid division. Subsequently, six additional layers form each "epidermal generation," representing both the old and new skin layers. These layers include the clear layer and the lacunar layer, which mature in the old skin layer as new skin grows beneath it. [6, 7].

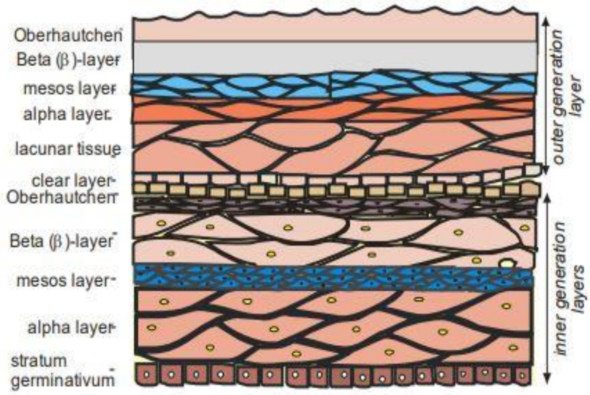

Figure 1: Cross section of reptile skin [6]

The alpha (α), mesos, and beta (β) layers consist of cells that undergo keratinization, producing two types of keratin (α and β keratin). This ongoing keratinization process gradually transforms these layers into a tough, protective outer layer. At the outermost level lies the "oberhautchen" layer, the toughest layer of keratinized dead skin cells. On the ventral side, this layer directly engages with the substratum during locomotion and features micro-ornamentation on both the dorsal and ventral surfaces [6, 7].
Snakes, like other reptiles, possess scales of various shapes and sizes covering their skin. These scales originate from the differentiation of the snake's underlying skin or epidermis, with each scale having an outer and inner surface. The number of scales remains fixed from birth, although they grow larger and may alter in shape during molting. In snakes, cell division in the "stratum germinativum" occurs periodically, leading to the replacement of upper layers above the division area. As a result, a second skin forms underneath the old one, which is then shed [6, 7].
Approximately two weeks before shedding, active growth begins in the stratum germinativum, leading to the gradual formation of a second set of layers beneath the old ones. During this process, the lowest layers of the old skin, including the clear and lacunar layers, undergo final maturation, culminating in the formation of a "shedding complex." Fluid is exuded, creating a thin liquid layer between the old and new skin layers. Enzymes present in this fluid break down the connections between the layers, causing the old skin to lift, which the reptile then actively removes [6, 7].

3. TECHNICAL DESIGN CONCEPT FOR A PROTECTIV SUIT

The absence of extremities in snakes has significant tribological implications, as their ventral body surface maintains almost constant contact with the substrate during locomotion. To facilitate movement, snake skin needs to exhibit low friction for sliding forward while simultaneously generating high friction for propulsive force along the substrate. The frictional properties between two materials in contact depend on several factors, including surface energy, material properties of both surfaces, and notably, the surface roughness of both bodies. Therefore, the specific roughness of the substrate on which the snake moves plays a crucial role in frictional force generation [11].
Moreover, the ventral surface of the snake is not smooth but comprises caudally-oriented scales covered with unique caudally-oriented nanostructures called microdermatoglifics. Previous studies have highlighted the significance of this specific ventral surface in generating anisotropic friction and facilitating snake locomotion. Atomic force microscopy and confocal laser scanning microscopy have revealed regular denticle-like nanostructures on ventral scales of most snake species. These structures, typically 2.46 ± 0.45 µm long and 0.60 ± 0.11 µm wide, are oriented in the caudal direction and parallel to the longitudinal body axis [11].
To address the locomotion requirements of stunt performers, protective gear is essential for the back, elbows, buttocks, intimate region, and knees. The concept revolves around a full-body suit featuring precisely arranged small scales, replacing the need for bulky partial shields. Namely, the concept is to improve multiple performances by textural alternation of already existing materials. The idea arose from the observation of snake skin, and the fabric itself would mimic the shape of the scales.
High-performance polyethylene fibers are an ideal choice for such products. Polyethylene (PE) is a polymer derived from the polymerization of ethylene. These fibers are synthesized through melt spinning. High-performance polyethylene encompasses a range of fibers modified from polyethylene, including high-density polyethylene (HDPE) and ultra-high molecular weight polyethylene (UHMWPE). The exceptional performance of these fibers is achieved by altering their structure, primarily by increasing chain length and crystallization.HDPE fibers, commercially known as Dyneema in Japan, have gained global recognition, although in the United States, they are marketed under the name Spectra [12-14].

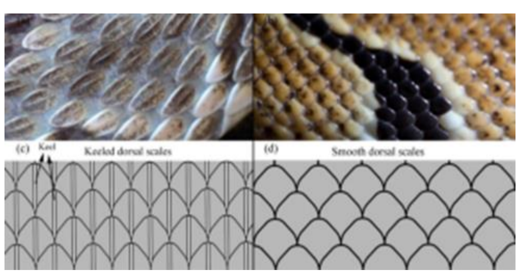

Figure 2: Example of the scales and how texture can mimic them [8]

Key characteristics of these fibers include[12-14]:

- Specific density less than 1, making them lighter than water
- Comparable strength to para-aramid fibers
- Excellent abrasion resistance, along with good electrical and chemical resistance
- High breaking strength even when wet
- Capable of bleaching and easy sterilization
- Low melting point
- Continuous operating temperature up to 250°F

Those familiar with the texture of snake skin will recognize that its scales align uniformly in one direction. These articulated scales serve to assist the snake in its forward movement while resisting backward motion. This implies that one of the basic parameters that needs to be investigated experimentally is precise angle of the scales. Some of the the basic characteristics that must be determined by research are:

1. Size of the scales
2. Scale density
3. Scale thickness
4. Overlap area

The primary traits of the material carrier should encompass exceptional elasticity and excellent air permeability. Implementing such texturing on the elastic material would enhance wearer comfort and significantly expand the range of motion.
Another crucial aspect of the concept is the stratification of materials. Essentially, the concept revolves around dividing the suit into three segments, each containing multiple layers of material. This layering primarily serves the purpose of mechanical protection, with the most layered sections strategically placed on the body's most vulnerable areas—whether they're in direct contact with surfaces or prone to injury. As mentioned earlier, the serration of snake epidermis has been proven to reduce overall friction, further justifying this design approach. Additionally, this design offers the added benefit of increased shock absorption by distributing force across the layers and by created air pockets between them. The layout scheme of materials with different layers is shown in Figure 3, where the thickest layer is shown in dark blue, light blue is of medium thickness and finally pink is the thinnest.

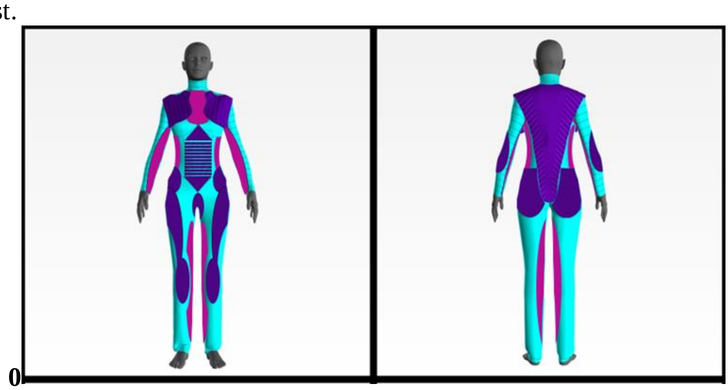

Figure 3: Technical drawing of the suit

In addition to the already mentioned performances, it should be noted that the operational period of such a product would be longer. In the aricle Wear Resistance Improvement of Keeled Structure and Overlapped Distribution of Snake Scales [8] revieled the study that investigates enhancing wear resistance by focusing on the keeled structure and the overlapped distribution of snake scales. Keeled and smooth snake scales were 3D printed and arranged in overlapped or parallel configurations on a substrate. Alongside these configurations, a reference sample with uniform thickness was included. Tribology testing revealed that samples with keeled structures exhibited higher groove counts compared to those with smooth surfaces, indicating a substantial enhancement in wear resistance, particularly vertically. However, surface morphology experimentation significantly influenced the tribology test results. Additionally, the keeled structure offers protection to the underside of snake scales, while overlapped distribution shields the central region, providing dual-layer protection for the snake's body. Overall, the keeled structure and overlapped distribution significantly bolster wear resistance in snake skin, offering valuable insights into reptile-mimicking surface structures and potentially benefiting the development of military uniforms for high-wear conditions [8].

4. CONCLUSION

Throughout history, humans have continuously sought to alter themselves through clothing. Initially, it served as an existential necessity, where animal furs replaced skin to survive harsh weather conditions. As human thought evolved, the significance of clothing shifted, transitioning to displaying status or adhering to beauty standards of the time. However, the fundamental purpose of protection remained unchanged. With advancements in the arms industry, the textile sector also flourished, producing specialized garments primarily for specific professions. Today, with widespread accessibility, such clothing has become commercialized.

While traditional clothing once defined individuals, recent decades have seen a new trend emerge: adapting clothing to fit individuals. Fueled by the demands of a fast-paced lifestyle that requires heightened productivity, there's a growing recognition that clothing should regulate and maintain physiological parameters to enhance work readiness.

In some industries, this type of clothing has become a necessity. Stunt choreography often requires specialized protective gear due to its demanding nature. Although such attire usually originates from equipment used in extreme sports, certain activities pose unique health risks to performers. Locomotion is a notable example. By delving into biomimetics, there's consideration for developing a suit modeled after snake skin.

It was determined that mimicking the texture of snake skin scales would offer superior mechanical protection, enhance comfort, facilitate greater flexibility, improve performance quality by reducing friction, enhance surface impact cushioning, thereby enhancing the physiological functionality of the entire suit and contributing to overall health protection.

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