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Research paper

Bioinspired Robotics: Mimicking Nature for Enhanced Automation and Efficiency

Dr. M. R. Ebenezar Jebarani [1] *, Honganur Raju Manjunath [2], Sahil Suri [3], Dr. Naresh Kaushik [4], Dr. Ravikant Kushwaha [5], Dr. Shaktijeet Mohapatra [6], Shikhar Gupta [7]

[1] *Professor, Department of Electronics and Communication Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India*
[2] *Associate Professor, Department of Physics, Faculty of Engineering and Technology, JAIN (Deemed-to-be University), Ramnagar District, Karnataka, India*
[3] *Centre of Research Impact and Outcome, Chitkara University, Rajpura, Punjab, India*
[4] *Assistant Professor, uGDX, ATLAS SkillTech University, Mumbai, India*
[5] *Associate Professor, Maharishi School of Pharmaceutical Sciences, Maharishi University of Information Technology, Lucknow, India*
[6] *Assistant Professor, Centre for Internet of Things, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, Odisha, India*
[7] *Chitkara Centre for Research and Development, Chitkara University, Himachal Pradesh, India*
**Corresponding author E-mail: ebenezarjebarani.ece@sathyabama.ac.in*

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Abstract

Biomimetics (BM) is the multidisciplinary collaboration between the sciences and technologies that provides remedies to real-time challenges by examining natural structures and applying their concepts to various usages. The present research examined BM advancements, encompassing Bio-Inspired Robots (BIR) and swarming robots designed for multiple applications, such as fruit picking, control of pests, and managing crops. The study showcased readily accessible BM solutions, such as Arugga Farming's robot honeybees and the Robotriks Traction Unit (RTU) agricultural precision apparatus. BIRs have reduced risks associated with surface bruising, rupture, crushing damage of plant cells, and deformation due to plastic during the gathering of soft-skinned fruits. Despite the potential of innovative agricultural methods designed to emulate natural systems to mitigate climate change and promote growth in agriculture, there are apprehensions regarding their long-term environmental consequences, financial implications, and inadequacy in supporting organic processes like pollination. The marketplace for BIR technology with prospective uses in agriculture aimed at modernizing farming and addressing the issues above has surged enormously. Future study and development should focus on creating economical Finite Element Analysis (FEA) robots and FEA-tendon-driven gripping devices for agricultural harvests. In summary, BIR and robotic swarms possess significant potential in farming.

Keywords: *Robotics; Bioinspired Robotics; Nature; Automation; Biomimetics; Mitigate.*

1. Introduction

Biomimetic (BM) for farming refers to the capacity to integrate artificial and biological systems while preserving the functions and environments of wild varieties by imitating natures [1]. It is accomplished by employing a multidisciplinary strategy in creating devices, systems, and materials influenced by biological procedures for scientific, technical, and medicinal purposes. Although research and advances in biomimicry are relatively recent, their origins are linked to Leonardo da Vinci's device, which was inspired by avian anatomy [4]. These influences resulted in creating the inaugural airliner, bionic vehicle designs, BM robots, and building methods influenced by nature [11]. The current BM manufacturing of biomaterials for farming exemplifies one of the most significant uses of BMs in this field. Biomaterials provide several potential uses, including hydrogels for water retention, carbon sequestration, substances that degrade for greenhouses, antimicrobial packaging for produce, and sustainable agricultural practices. This paper examines Bio-Inspired Robots (BIR) and swarm robots, which provide significant potential in harvesting, plant care, and sowing. The focus on automation and robotic-animal objects is anticipated to yield a refined comprehension of the advantages, obstacles, and future possibilities [3] [2]. This data would facilitate decision-making for both smallholder and large industrial growers. Demand from consumers would serve as a spur for industrial study and development.

BM technologies offer significant potential in ecological system planning for the smart reduction of soil deterioration, the preservation of ecosystems, and the development of agricultural technology [12]. Innovative farming methods have demonstrated the capacity to lower production costs and enhance yields by intelligently regulating humidity, water supply, snow, greenhouse microclimate, and pesticides and fertilizers [5]. In addition to manufacturing, BMs have applications in gadgets, sustainable packaging, and the cultivation of flesh, utilizing nanostructures that emulate the light-reflective properties of the wings of butterflies. The list is not comprehensive, as new BM uses continually appear with scientific advancements.

Recent assessments indicated that the BM farming industry is poised for significant growth and will enhance global economic growth. BM technologies are projected to contribute at least $1.8 trillion worldwide Gross Domestic Product (GDP) [13]. The former contribution would diminish the impact on communities, as the BM revolution emulates and learns from nature, unlike 19th-century industrialization, which plundered natural resources. Fig. 1 illustrates the unique benefits of BMs to farming.

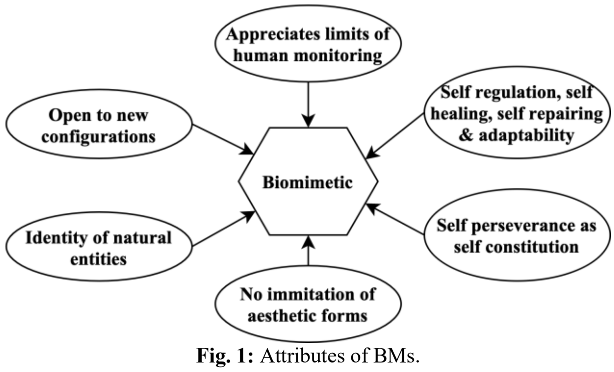

Fig. 1: Attributes of BMs.

Pragmatic interventions encompass Agriculture 4.0, the Internet of Things (IoT), and BM farming [7]. This evaluation emphasizes the latter's possibilities, while the former has been well examined. The connection between international food safety and BM science is based on advancements achieved through BM methods to tackle water scarcity, utilizing cost-effective and adaptable Warka and water cone technologies to extract water from the surrounding environment. BM methodologies have created BM phosphorus scavengers by quantum chemistry investigations of phosphate ions on diminutive, inherently disordered proteins [14]. The study indicated that worldwide food safety might be enhanced by using phosphate hunters while mitigating phosphate molecules' adverse environmental impact. The developments related to BMs represented only a subset of the numerous advancements capable of revolutionizing the future of farming.

The present study concentrates on two interconnected BM BIR structures: swarm robots and soft robotics. Soft robotics was developed for specific tasks, like picking delicate veggies and fruits, planting, and managing crops [9] [8]. Conversely, swarming intelligence refers to the collected characteristics of decentralized, self-organized natural structures. Swarming robotics refers to applying swarm concepts to robots, enabling them to emulate natural groups, such as animals, to create an adaptable and resilient method [15] [10]. Flocking can be seen as a category capable of adapting to environmental changes and exhibiting distinct behaviors, including goal fulfillment, aggregate or dispersal, communication, and memory retention. Likewise, swarm robots demonstrate autonomy, collaboration, and cooperation, which are essential for sustained usage.

2. Methods

The BIR Systems for Adapted Lattice Creation (BIRS-ALC) utilizes nature-inspired automated systems to fabricate high-strength lattice frames [6]. Through the meticulous integration of BM design principles, modern robotics, and the study of materials, it is feasible to construct structures exhibiting qualities superior to those of artificially created counterparts. BIRS-ALC comprises three primary components: a synthetic robotic model, a bio-inspired lattice optimization technique, and a thorough assessment unit. The BM model draws from the construction techniques of natural constructors like wasps and termite infestations with limbs, advanced grips, and soft actuators for enhanced accuracy. A universal framework and a coordination system are essential for the robots to move around and effectively in their surroundings, particularly beyond the current work zone or materials reservoir.

Positional data is essential for appropriate action selection during resource rivalry, such as with another robot. Possessing an international coordinate system and standardized reference framework facilitates the planning of robotic actions, obstacle avoidance, and the coordination of several robotics in an environment. The bio-inspired optimization technique for lattice construction is based on computational developing concepts and utilizes natural models recognized for durability and effectiveness.

The BIR dynamically adjusts its strategy throughout the structure and maneuvers inside the project environment, responding quickly to evolving conditions. The durability evaluation module assesses the finished lattice frames and offers insights into their performance in practical uses, encompassing tension, stress, shear, and resistance to impacts. Data is gathered at each process phase, from pre-construction to post-construction evaluation, utilizing various sensors and testing apparatus. The BM Adapted Fiber Assembly (BAFA) represents a novel approach to BM technology, using techniques derived from nature's most proficient constructors.

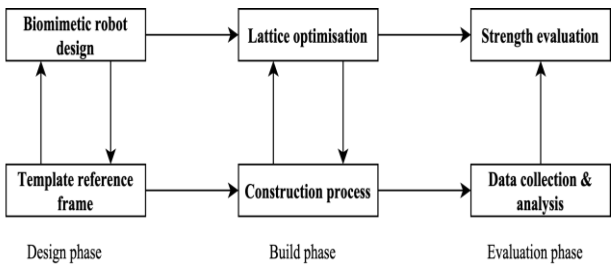

Fig. 2: System Architecture.

BIRS-ALC is designed to generate intricate lattice models with unparalleled accuracy and versatility. The fundamental model components in Fig. 2 comprise bio-inspired modular appendages facilitating multidirectional movement, precise tampering and shape configuration, and gripping devices modeled after the intricate yet robust grips of diverse insects. Fig. 3 depicts these fundamental design principles derived from a natural architect.

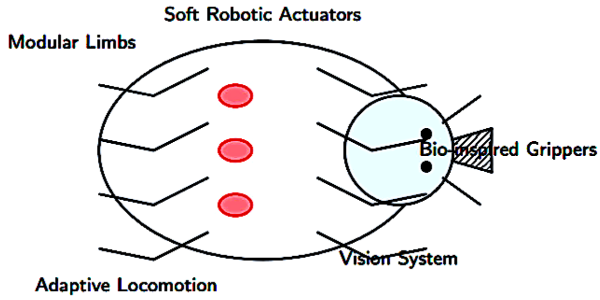

Fig. 3: Soft Robotic Actuators.

BIRS-ALC's functionalities are enhanced by incorporating soft robotic motors, which provide it with more excellent biological-like maneuverability and flexibility, facilitating its movement and operation under diverse environmental situations. Should the operations, conditions, or building model alter, the BIR autonomously modifies its motions to accommodate the issues and navigate the obstacles.
BIRS-ALC's resilient global navigational system employs a template reference framework that coordinates the model. It aids robotics in preserving precise spatial data, that is essential to achieving recursive autonomous path planning, avoiding obstacles, and effective communication among several robotics.
These synthetic modules are integrated to form a model of robots that not only emulates the free-forming building abilities of premier constructors but surpasses them in scaling and accuracy. The BIRS-ALC's aesthetic is founded on flexibility and effectiveness, enabling it to tackle building lattice structures from the ground up by utilizing innovative, highly optimized construction methods. Incorporating these bio-inspired elements allows BIRS-ALC to tackle the building of lattice design via an innovative robotic model, facilitating the manufacturing of lattice frameworks with optimal strength and utility.

3. Results

BIRS-ALC technology has higher characteristics than production approaches. The final compressive force of the BIRS-ALC structures (185 10 MPa) exceeds that of the Selected laser-melted (SLM) lattices by 23%. It surpasses Fused Deposition Modelling (FDM) with fiber reinforcement by 54%. They Surpass Stereolithography (SLA) metal lattice structures. The noticeable enhancement stems from the synthetic concepts integrated into BIRS-ALC, facilitating a more effective load distribution. Fig. 4 illustrates the stress-strain characteristics of BIRS-ALC structures compared to alternative methodologies. The final durability and surface beneath the curve of BIRS-ALC structures are more excellent, indicating superior ultimate power and energy absorption capacity. These qualities are crucial for aeronautical and automotive uses, necessitating lightweight yet robust materials.

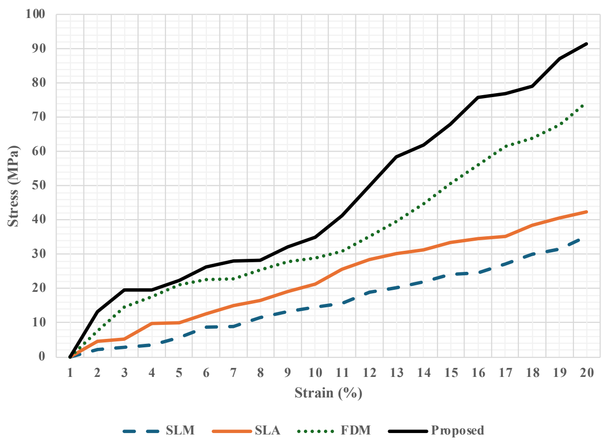

Fig. 4: Stress-Strain Analysis.

Fig. 5 illustrates the sound absorption value of BIRS-ALC across various sound wavelengths. The data indicates that the absorbing ratio of BIRS-ALC lattices at 1100 Hz attains 0.87%, 7%, and 23% greater than acoustic metamaterials and PCM-integrated structures. The acoustic properties of BIRS-ALC, characterized by superior acoustic absorption ratios and storage of energy capacity, render it a probable candidate for energy-efficient construction materials.

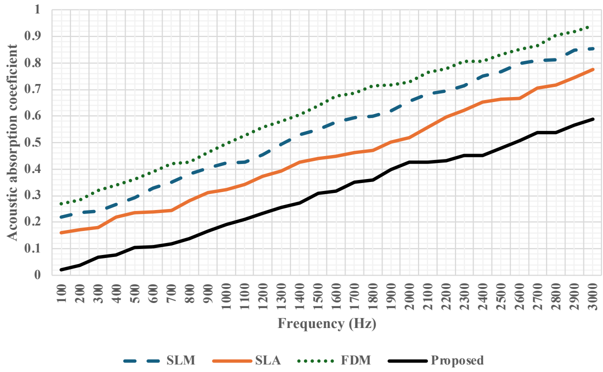

Fig. 5: Acoustic Absorption Coefficient Analysis.

The result demonstrates that BIRS-ALC lattices possess elevated absorption coefficients across an extensive frequency spectrum, particularly in the mid-to-high frequencies. BIRS-ALC lattices are pertinent for noise reduction and architectural acoustics due to their extensive acoustic effectiveness in sound absorption. The exceptional thermal and acoustic capabilities arise from their hierarchy and the ability to adjust the lattice shape over various length scales. This facilitates optical band gaps and phonon dispersion across all scales, enhancing sound quality and diminished heat transfer.

4. Conclusion

The proliferation of BM ideas has been driven by population expansion, labor deficits in agriculture, and the aspiration to mitigate adverse ecological effects on the environment. The anticipated global population increase will likely present new issues, such as food shortages, water deficiency, and elevated emissions. BM methods have been investigated to improve productivity in agriculture by emulating natural processes. Sustainable agriculture fulfills global food demands through a practical, welcoming, resilient economy. Incorporating bio-inspired technology allows huge farms to enhance productivity and effectiveness while reducing adverse ecological impacts, as evidenced by BIR for picking fruits and vegetables and swarming models. Initially, the models reduced the likelihood of physical harm, a prevalent issue associated with conventional harvesting machines and manual picking. Reducing mechanical harm (surface bruises, ruptures, crushing loss of vegetative tissues, and distortion) offers real-time advantages, as post-harvesting losses adversely impact revenue. Secondly, BIR devices could augment pollination by supplementing the seriously threatened native bee population. Alternatively, the group of bots could execute other vital tasks on farms, such as applying pesticides and assessing crop development. Current research indicates that farmers have not fully harnessed the promise of robots. The application of robots and tendon-based grips in gathering vegetables is insufficient.

Notwithstanding the apprehensions regarding robots, their significance in farming remains undeniable, particularly in light of the detrimental impacts of population increase and global warming on the sector. The studied literature confirmed that BM technologies are essential to climate-conscious farming, which aims to enhance food security while reducing greenhouse gas emissions. Scholars lack the unanimity to attain the objectives.

In contrast, pro-innovation scholars support creating and implementing BIR bees to augment wild bee populations in agriculture. Detractors contend that the robotic bees will adversely impact the environment, as they represent an invasive variety. The expense and feasibility of robotic bee initiatives endure uncertainty.

Notwithstanding the hurdles, the advancement of farming and the shift to Agriculture 4.0 will persist since it is essential for enhancing financial development and augmenting production. Substantial advancements have facilitated interoperation among artificial intelligence, robotics, and big data systems and utilized more environmentally friendly and durable materials. According to cautious forecasts and advancements by industry leaders, lightweight and swarm robotics will enhance current clever agricultural methods, resulting in environmentally friendly production. However, the apprehensions expressed by academics regarding the lifecycle of artificial apparatus in the real world must not be overlooked and addressed via studies and growth.

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