Reptiles Inspired Biomimetic Materials and Their Novel Applications

Kishor Kalauni and K. M. Gupta
Department of Applied Mechanics, Motilal Nehru National Institute of Technology, Allahabad -211004, India
Email: kishor.kalauni@gmail.com, kmgupta@mnnit.ac.in

Isha Bharti
Teaching-cum-Research Fellow, Department of Applied Physics, Delhi Technological University, Delhi-110042, India

***Abstract*—For all nature's sophistication, many of its clever devices are made from simple materials like keratin, calcium carbonate, and silica which nature manipulates into structures of fantastic complexity, strength, and toughness. In the past few decades, materials scientists have shown increasing interest in studying the whole variety of biological materials including hard and soft tissues, and to use discovered concepts to engineer new materials with unique combinations of properties. This paper aims at elaborating the development of such biomimetic materials by compiling the ongoing researches. In this regard, the research developments of some newer materials by other investigators have been presented here. Brief details of the development of Gecko feet inspired sticky-bot, Mini-viper model robot, Clothes that change colour, Snakes imitating robot, Robot scorpion are discussed. In these elaborations, it is shown that these biomimetic materials can be effectively used in a large variety of application in near future.**

***Index Terms*—gecko feet inspired sticky-bot, mini-viper model robot, clothes that change colour, snakes imitating robot, robot scorpion**

I. Introduction

Biomimetics is the word most frequently used in scientific and engineering literature that is meant to indicate the process of understanding and applying (to human designs) biological principles that underlie the function of biological entities at all levels of organization. Among the many fields of study of biomimetic, one area is the Mobile Robot. Biomimetics and bio-mimicry are both aimed at solving problems by first examining, and then imitating or drawing inspiration from models in nature. Biomimetics is the term used to describe the substances, equipment, mechanisms and systems by which humans imitate natural systems and designs, especially in the fields of defence, nanotechnology, robot technology, and artificial intelligence. Designs in nature ensure the greatest productivity for the least amount of materials and energy. They are able to repair themselves, are environmentally friendly and wholly recyclable. They operate silently, are pleasing in aesthetic appearance, and offer long lives and durability. Biomimetic materials inspired by biology from molecules to materials and from materials to machines. Some of mimicking of natures are adhesives that mimic gecko fingers, heat-sensing system that mimic viper, colour-changing clothes that mimic chameleons and constant state of balance inspired by snake. They are presented as examples of next generation bio-inspired materials. Biomimetic articulated robots are robots that imitate living creatures and have many modules. Various forms of bio-inspiration and related examples are listed below for a ready reference.

TABLE I. Various Forms of Bio-Inspiration and Related Examples

Biological example	Type of analogy	Biomimetic Materials
Gecko	Adhesion	Dry adhesives
Snakes	Sensing system, and Balancing system	Shape memory alloys (SMAs), Piezoelectric materials, and Electro-active polymers.
Chameleons	Colour changing	Choleric liquid crystals (CLCs)
Scorpion	Behavioural	Central pattern generators

II. Gecko Feet Inspired Biomimetic Products and Materials

Small lizards are able to run very fast up the walls and walk around clinging to the ceiling, very comfortably. Until recently, we could not understand as to how it could be possible for any vertebrate animal to climb up walls like the cartoon and film hero Spiderman. Now, years of research have finally uncovered the secret of their extraordinary ability. Little steps by the gecko have led to enormous discoveries with tremendous implications, particularly for robot designers. A few of them can be summarized as follows:

- Researchers in California believe that the lizard's "sticky" toes can help in developing a dry and self-cleaning adhesive.
- Geckos' feet (Fig. 1a) generate an adhesive force 600 times greater than that of friction. Gecko-like

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robots could climb up the walls of burning buildings to rescue those inside.

- Dry adhesives could be of great benefits in smaller devices, such as in medical applications and computer architecture.
- Their legs act like springs, responding automatically when they touch a surface. This is a particularly appropriate feature for robots, which have no brain. Geckos' feet never lose their effectiveness, no matter how much they are used; they are self-cleaning and they also work in a vacuum or underwater.
- A dry adhesive could help hold slick body parts in place during Nano surgery.
- Such an adhesive could keep car tires stuck to the road.
- Gecko-like robots could be used to repair cracks in ships, bridges and piers, and in the regular maintenance of satellites.
- Robots modelled after the geckos' feet could be used to wash windows, clean floors, and ceilings. Not only will they be able to climb up flat vertical surfaces, but overcome any obstacles they meet on the way.

(a) (b)

Figure 1. (a) Gecko feet, and (b) Sticky-bot: Gecko inspired wall climbing robot [1]

The water's spreading out incredibly fast as drops fell on to the lizard's back and vanished. Its skin is far more hydrophobic. There may be hidden capillaries, channelling the water into the mouth. A subsequent examination of the thorny lizard's skin with an instrument called a micro-CT scanner confirmed, revealing tiny capillaries between the scales evidently designed to guide water towards the lizard's mouth. With this in mind, Cutkosky [2] endowed his robot with seven-segmented toes that drag and release just like the lizard's, and a gecko-like stride that snugs it to the wall. He also crafted Sticky-bot's legs and feet with a process, which combines a range of metals, polymers, and fabrics to create the same smooth gradation from stiff to flexible that is present in the lizard's limbs and absent in most man-made materials. Stickybot (Fig. 1b) is a four-legged robot capable of climbing smooth surfaces. He subsequently embedded a branching polyester cloth "tendon" in his robot's limbs to distribute its load in the same way evenly across the entire surface of its toes. Sticky-bot now walks up vertical surfaces of glass, plastic, and glazed ceramic tile, though it will be some time before it can keep up with a gecko. For the moment it can walk only on smooth surfaces, at a mere four centimetres per second, a fraction of the speed of its biological role model. The dry adhesive on Sticky-bot's toes isn't self-cleaning like the lizard's either, so it rapidly clogs with dirt. "There are a lot of things about the gecko that we simply had to ignore".

III. Viper as a Model in Its Defense

Dr. John Pearce, of the University of Texas Electrical and Computer Engineering Department, has studied Crotalines [3], better known as pit vipers. His research focused on the pit organs of these snakes. In front of the snake's eye (Fig. 2a) is a tiny nerve-rich depression, called the pit, which is used in locating warm-blooded prey. It contains a sophisticated heat-sensing system—so sensitive, that the snake can detect a mouse several meters away in pitch darkness. The researchers stated that when they unravel the secrets of the pit viper's search-and-destroy mechanism, the methods the snake employs can be adapted more widely to protect the country from enemy missiles.

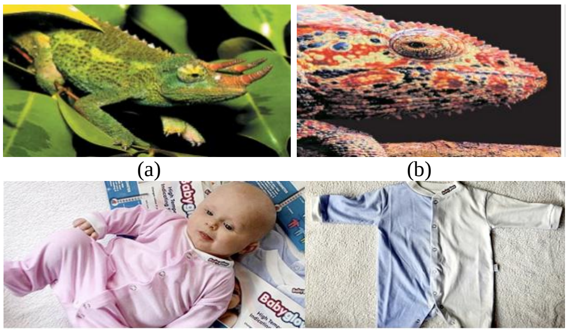
The snake's pit is a thin membrane rich in blood vessels and nerve bundles. The membrane is so sensitive, and the variations in responses so minute that, to catch and study these signals has proved exceedingly difficult. To understand the functioning of the pit organ, it is necessary to work with delicate measurements and photomicrographs. The Mini-VIPER model robot in (Fig. 2b) weighs around 3.5 kilograms and is equipped with an array of sensors. Most of these conventional sensors, are strain sensors, thermal sensors, and optical sensors. More advanced actuation concepts are typically employed using active materials such as Shape memory alloys (SMAs), piezoelectric materials, and electroactive polymers. Small enough to move through tunnels and narrow alleys, it can be thrown into a building through a window and automatically begins scanning its environment. The robot is designed to protect infantry soldiers from explosives, booby traps and hostile forces lying in ambush.

(a) (b)

Figure 2. (a) Snake, and (b) the mini-viper model [4] photo: Elbit

IV. Chameleons Inspired Colour Changing Clothes

The impressive ability that chameleons (Fig. 3a-Fig. 3b) have to change colours to match their surroundings is both astonishing and aesthetically pleasing. The chameleon can camouflage itself at a speed that quite amazes people. With great expertise, the chameleon uses its cells called chromatophores which contain basic yellow and red pigments, the reflective layer reflecting blue and white light, and the melanophores containing the black to dark brown pigment melanin, which darkens its colour. The technology in colour-changing clothes (Fig. 3c) and the chameleon's ability to change colour may appear similar, but are in fact very different. Even if this technology can change colour, still it entirely lacks the chameleon's camouflage ability that lets it match its surroundings in moments. For instance, place a chameleon into a bright yellow environment, and it quickly turns yellow. In addition, the chameleon can match not only one single colour, but a mixture of hues.



(a) (b)

(c)

Figure 3. (a-b) Chameleon's body with a system that lets it change colour to match its surroundings, and (c) Baby clothes that change colour with temperature [5].

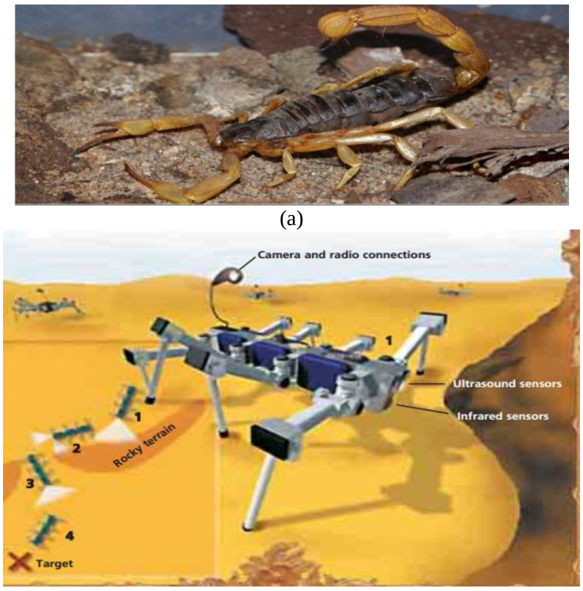
The secret behind this lies in the way pigment-containing cells under the camouflage's skin expand or contract to match their surroundings. God has created the chameleon's body with a system that lets it change colour to match its surroundings, endowing it with a considerable advantage. Chameleons inspired for making clothes, bags and shoes that are able to change colours the same way as the chameleon does. Researchers envision clothing made from the newly developed fibre, which can reflect all the light that hits it, and equipped with a tiny battery pack. This technology will allow the clothing to change colours and patterns in seconds by means of a switch on the pack. Yet this technology is still very expensive. Scientists have designed choleric liquid crystals (CLCs) to alter the visible colour of an object to create the thermal and visual camouflage in fabrics. The colour of CLCs can be changed with temperature sensitive thermocouples [6]. The heating-cooling ability of thermocouples can be used to adjust the colour of the liquid crystals to match the object's background colour, providing camouflage or adaptive concealment.

V. Snakes Imitating Robot to Overcome the Problem of Balance

For those engaged in robotics, one of the problems they encounter most frequently is of maintaining equilibrium. Even robots equipped with latest technology can lose their balance when walking. Robot experts attempt to build a balance-establishing learning that the snake (Fig. 4a) never loses its balance. Unlike other vertebrates, snakes lack a hard spine and limbs, and have been created in such a way as to enter cracks and crevices. They can expand and contract the diameter of their bodies, can cling to branches and glide over rocks. Snakes' properties inspired for a new robotic, interplanetary probe developed by NASA's Ames Research Centre which they called the "snake-bot" (Fig. 4b). This robot thus was designed to be in a constant state of balance, without ever getting caught up by obstacles.

(a) (b)

Figure 4. (a) Snake, and (b) Snake-bot [3]



(a)

(b)

Figure 5. (a) Scorpion, and (b) Scorpion Robot [3]

VI. A Robot Scorpion Can Work in Harsh Desert Conditions

Sand or other abrasive particles have a way of eroding anything they encounter. Scorpions (Fig. 5a) have been able to survive harsh desert conditions ever since their creation. They live their entire lives subjected to blowing sand, yet they never appear to well, to erode. As a result, items such as helicopter rotor blades, airplane propellers, rocket motor nozzles and pipes regularly wear out and need to be replaced. A group of scientists recently set out to discover their secret, so it could be applied to man-made materials. In the United States, Defence Advanced Research Projects Agency (DARPA) is working to develop a robot scorpion (Fig. 5b) [3]. The reason the project selected a scorpion as its model is that the robot was to operate in the desert. The scientists subsequently applied what they observed in the scorpions' exoskeletons to man-made surfaces. They determined that the effects of erosion on steel surfaces could be significantly reduced, if that steel contained a series of small grooves set at a 30-degree angle to the flow of abrasive particles [7]. But another reason why DARPA selected a scorpion was that along with being able to move over tough terrain very easily, its reflexes are much simpler than those of mammals and can be imitated.

Before developing their robot, the researchers spent a long time observing the movements of live scorpions using high-speed cameras, and analysed the video data. Later, the coordination and organization of the scorpion's legs were used as a starting point for the model's creation. The robot is controlled using a biomimetic approach of ambulation control. The approach is based on two biological control primitives, Central Pattern Generators and Reflexes. Using this approach, omni-directional walking and smooth gait transitions can be achieved. Additionally, the posture of the robot can be changed while walking. The robot was successfully tested in rough terrain with obstacles as high as the robot's body and in different terrains such as sand, grass, concrete and rock piles.

VII. Conclusions

From the above studies, the following conclusions have been drawn.

- Gecko feet inspires in developing a dry, and self-cleaning adhesive. A dry adhesive could help hold slick body parts in place during Nano surgery. Sticky-bot walks up vertical surfaces of glass, plastic, and glazed ceramic tile and also used repair cracks in ships, bridges and piers, and in the regular maintenance of satellites.
- After inspiring from viper a mini robot is designed to protect infantry soldiers from explosives, booby traps and hostile forces lying in ambush. Viper's search-and-destroy mechanism, the methods the snake employs can be adapted more widely to protect the country from enemy missiles.
- Smart and intelligent textiles are important developing area in science and technology because of their major commercial viability and public interest. Chameleons inspired for making clothes, bags and shoes able to change colours.
- Snakes' properties inspired for a new robotic interplanetary probe, which has a constant state of balance, without ever getting caught up by obstacles. The balancing problem can be overcome.
- By mimicking the scorpion, a robot is made for withstand harsh desert conditions. The robot can be asked to go to a specific region and, with a camera in its tail, send back to base images of the location

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Kishor kalauni is a postgraduate student of Material Science and Engineering discipline in the Department of Applied Mechanics of Motilal Nehru National Institute of Technology, Allahabad, India. He obtained Degree in Mechanical Engineering in 2010. He has authored 3 research papers in reputed International Conferences. His major fields of study are Bio-composites and Biomimetic Materials.

Dr. K.M. Gupta is a Professor in the Department of Applied Mechanics, Motilal Nehru National Institute of Technology, Allahabad, India. He has over 35 years of teaching, research and consultancy experience. He obtained Postgraduation (M.E. with Honours) in 1977, and completed his Doctorate (Ph.D.) degree from University of Allahabad.

He has authored 30 books and edited 2 books on Engineering subjects, and a chapter in Scrivener Wiley published 'Handbook of Bio-plastics and Bio-composites Engineering Applications'. He has also authored 106 research papers in reputed International and National journals to his credit. He has presented his research papers in 16 International conferences abroad has also chaired 7 International Conferences in China, Singapore, Dubai, Bangkok etc.

Professor K. M. Gupta has acted as Editor-in-Chief of The International Journal of Materials, Mechanics and Manufacturing (IJMMM), has edited many International Journals and International Conferences. He has worked as reviewer for various International and National Journals, and has acted as Member of several Editorial Board. In recognition to his academic contribution at International level, Marquis Publication (USA) has included him in the list of 'World Who's Who in Science and Engineering 2007' and 'Who's Who in the World 2008'. The International Biographical Centre, a leading research institute (Great Britain) has also selected him as one of the '2000 Outstanding Scientists 2009' from across the world; and Rifacimento International Publisher has included his biographical-note in 'Reference Asia: Asia's Who's Who of Men and Women of Achievement. Earlier, he has served as Dean of Research & Consultancy, Head of the Applied Mechanics Department at Motilal Nehru National Institute of Technology Allahabad. He has acted as Chairman of various Research Selection Committees, of Research Project Monitoring Committees and other Administrative Committees of his Institute and other Universities. He has also served as Chairperson, Community Development Cell (CDC) of MNNIT for several years. Presently, Dr. Gupta is teaching Materials Science, Engineering Mechanics, Thermodynamics of Materials, Electrical and Electronic Materials etc. His research interests are in the fields of Materials Science, Composite Materials, Stress Analysis, Solid Mechanics etc.

Isha Bharti is from New Delhi, India, currently working as Teaching-cum-Research Fellow in the department of Applied Physics, Delhi Technological University. She completed her Masters (M.Tech.) in Nanoscience and Technology with specialization in Nanobiotechnology from Delhi Technological University in 2011. Her major field of study is synthesis and fabrication of Nanobiotechnological materials, luminescent materials for novel biomedical applications and diagnostic therapies, etc.