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Review

Understanding the Concept of Biomimetics for Geoinformatics Technology and its Utilization for Nature-based Solutions

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ABSTRACT
This study aims to introduce a wide range of readers to some of animals' exceptional remote sensing and navigation abilities. A comparison of remote sensors employed by animals and those built by humans is presented in this research. Thermal infrared sensors used by snakes, echolocation used by bats and dolphins, and navigation systems used by birds are all part of the research and comparison. Prey countermeasures to prevent capture are also taken into account. Remote sensing and navigation capabilities of certain animals are far superior to those provided by the human body or devised by humans. The use of the biometric method in creating novel sensors may be promoted. The paper contributes to a better understanding of animal behavior, particularly their unique abilities to perceive, echolocate, and travel over long distances with great accuracy. Studying animal sensors within a biomimetic framework can help remote sensor designers improve their designs for the purpose of border management, forest fire control (for example, the photo mechanic infrared receptor for detecting forest fires in the beetle), jamming the signal from the tiger moth which clogs bat sonar, integration of visual and infrared information in bimodal neurons in the rattlesnake optic tectum, and biomimetic sonar that locates and recognizes objects.

Key Words: Remote sensing, Sensors, Electromagnetic Radiation, Sonar, Animals, Reptiles.

INTRODUCTION

Nature is the greatest engineer, and humans have absorbed all of nature's notions in every facet of existence. Furthermore, the majority of breakthroughs and discoveries have been made due to monitoring and obtaining information from nature. Every living organism on this planet has a unique trait that allows them to live in nature. As a result, it is clear in the past and now that nature inspires scientists to build or discover new things that are available in our surroundings. Our sensing organs, such as eyes, ears, and brains, also motivate remote sensing instruments and systems. Electromagnetic radiation (EMR) allows our eyes to see a distant object. The waves allow our ears to hear the sound. All living animals on the planet have the same EMR. However, various animals employ different frequencies. Many animals, such as snakes and owls, can see through the infrared region of the EMR, whereas the human eye can only see in the visible range of the EMR. Bats can produce ultrasonic sound at frequencies between 10 and 150 kHz, which our ears can bear up to 20 kHz (vibration per second). Biomimetics is the term for the process of inventing gadgets that are inspired by or imitated from nature. In other words, biomimetics is the process of creating new technologies by distilling concepts and techniques gained from biological systems. Biomimetics can be used in sensor design in various ways, including replicating the shape of natural sensing organs, emulating function, such as human senses, emulating behavioral features, and repurposing naturally occurring biological components (Bogue 2009, Victor 2013).

The goal of biomimetic design is to create or design small devices that are inspired or copied by the biological system's innovative concepts and processes. The goal of this research is to consider the direction of sensor design utilizing the biomimetic approach. This new approach can be employed for an advanced surveillance system for border management, signal jamming, underwater surveillance, and forest fire control, as per our organization's requirements and also for national security. There are numerous more aspects to the biomimetic notion, however, we focus on aerial surviellance for this review.

Remote sensing has traditionally been understood to mean that the sensor and target are separated by a great distance, with Electro-Magnetic Radiation acting as a link between them. The electromagnetic spectrum is a collection of electromagnetic waves organized by wavelength and frequency. The electromagnetic spectrum spans shorter wavelengths (gamma rays and x-rays) to longer wavelengths (ultraviolet and visible light) (microwave and radio waves). Remote sensors are divided into two categories: wavelength and application. Imagers (mappers), radiometers, spectrometers, and distance rangers are examples. Imagers create a two-dimensional representation of the features being observed. Film or digital cameras, multi-spectral scanners, and radar mappers are among them. Radiometers, such as thermal infrared radiometers, enable extremely accurate signal strength measurements in a few spectral bands. Range detectors, such as LIDAR's and radar altimeters, assess bathymetry and ground/sea elevation, while spectrometers measure the spectrum distribution of a signal (Jensen 2007; Klemas 2009, Martin 2004, Victor 2013). Cameras that image solar reflected light or thermal infrared sensors that map the temperature of heat-emitting landscapes are examples of passive sensors. Radar, LIDAR, and acoustic echo-locators are among the active sensors. They send out power pulses that reverberate off of targeted targets. Remote sensing is the process of obtaining information about an object without physically touching it in its most basic form. Sight, hearing, smell, taste, and touch are the first three of our five senses, and they can be thought of as remote sensors. The sun's light lights the target things throughout the day, allowing our eyes to view the distant object and delivering information to our brain to detect it.

RESEARCH METHODOLOGY

A relevant set of published articles that address Biomimetics in the range of electromagnetic spectrum were selected for synthesis of literature search. To establish a database, we searched the ISI Web of Science (http://webofknowledge.com) and Google Scholar (https://scholar.google.com/) for peer-reviewed journals. This downloaded articles were systematically arranged to extract information on how biomimetic can aid in nature-based solution, and their contribution to innovation technology and how nature can act as model for technical sensors. We selected all published articles that appeared in the database during the past 40 years (1980-2020) for developing this review. We used the keywords like "Boimimetic", "Biomimicry", "Biosensors" for collecting literature from various database such as Google Scholars, Web of Science, PubMed, Scopus, ProGuest. All literatures were screened following PLASMA guidelines (Fig. 1).

RESULTS AND DISCUSSION

Thermal infrared capability

With the use of their sensory organs such as their upper jaws, limbless reptiles such as rattlesnakes and pit vipers are better able to distinguish and sense thermal infrared radiation between the ranges of 5 and 30 meters. They can detect heat from a candle flame from a distance of 10 meters. The snake sees a heat image created by their warm-blooded food, such as rodents and birds, which emit heat in the form of thermal infrared EM waves. Rattlesnakes employ heat sensors to locate cool areas to hide from the searing desert sun (Bakken et al. 2003; Krochmal and Bakken 2012, Victor 2013). Rattlesnakes may detect temperature variations as tiny as 0.2^0C over short distances. A temperature-sensitive membrane is suspended near the back of the pit organ, which functions as a pinhole infrared camera. The membrane has around 40 x 40 sensory cells and a field of vision of about 100 degrees, implying that input to the organ might be represented in the brain with a resolution of roughly 2.5 degrees. The aperture of the infrared organ is broad, around 1 mm, and comparable to the organ depth, because the radiation

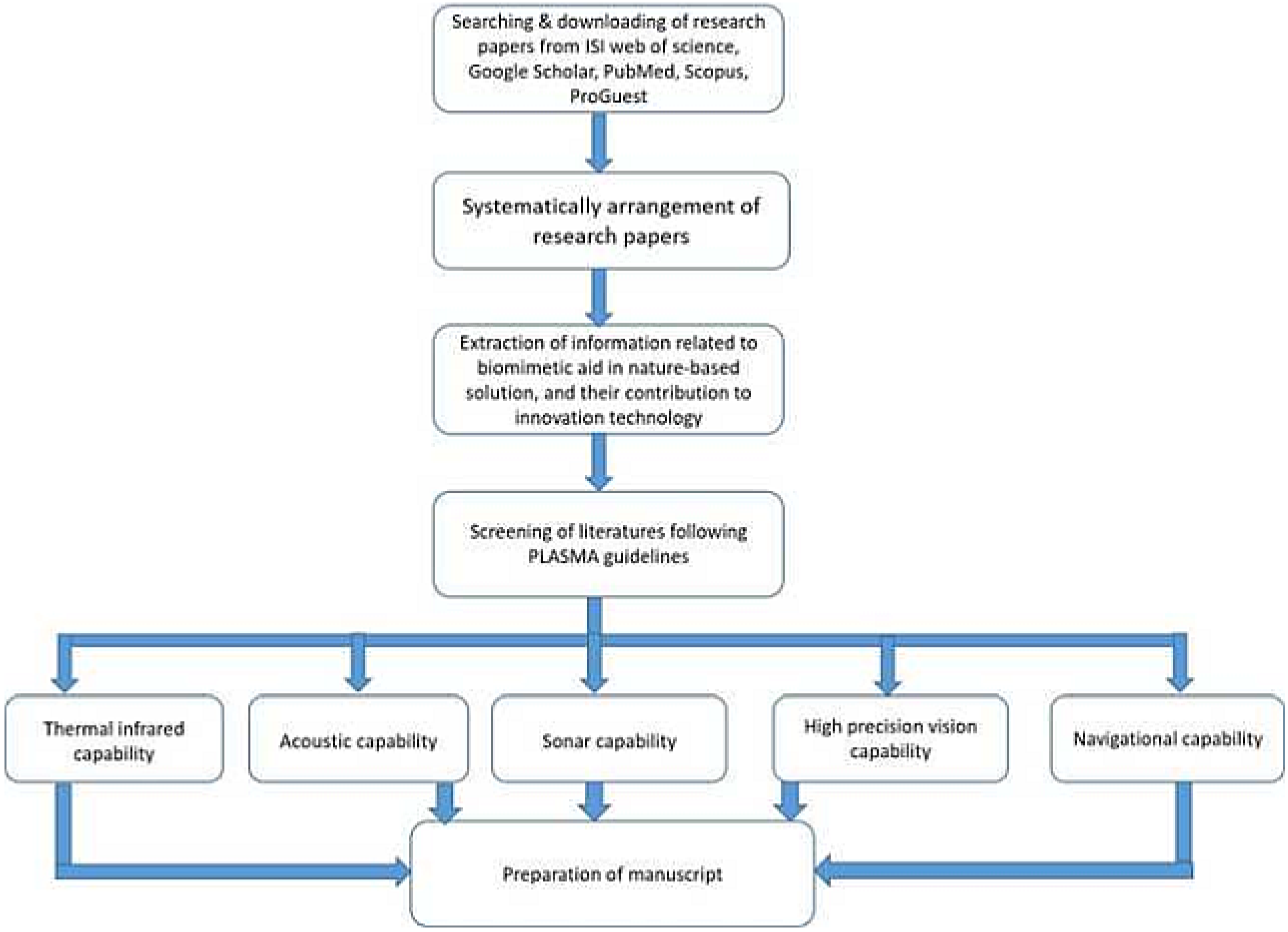

Figure 1. Flow chart showing methodology followed

flux entering the organ must be large enough to detect moving prey swiftly. As a result, instead of striking a point-like section of the membrane, as in an ideal pin-hole camera, incoming radiation from a point source strikes a broad disc-shaped region, resulting in distended and hazy images on the membrane (Fang 2010; Sichert et al. 2006). Infrared remote sensing is also used by other creatures, such as vampire bats and insects. Forest fire beetles, for example, use their infrared senses to detect forest fires from tens of kilometres away (Schmitz and Bleckman 1998; Schmitz et al. 2000). Pit vipers, according to an intriguing study, detect thermal contrast rather than absolute temperature. The IR system is essentially a 'brightness constancy' computation, similar to how visual systems compare the luminance of a target to that of the background. Optical and heat transfer analyses indicate that IR images on the pit membrane are likely quite blurry, though the central nervous system may sharpen and enhance neural images. The infrared sensory system's neuronal response is phasic, meaning it is more sensitive to the rate of change of a signal than to its absolute level (Schraft et al. 2019). Numerous small animals, including shrews, the majority of rodents, and some marsupials, have fur composed of at least four distinct and complex hair types. A common and unexplained feature is periodic internal banding with spacing of 6–12 m, which suggests an underlying infrared function. Guard hair, a bristle-like form, has the appropriate shape and internal periodic patterns to function as an infrared antenna. Optical analysis of guard hair from a variety of species reveals precise tuning to the thermal imaging wavelength (Baker 2021).

Acoustic capability

Bats have evolved an auditory distant sensing system that surpasses any constructed by man over millions of years to travel and hunt for insects in full darkness. They are so advanced that they can fly at night at high speeds while avoiding any obstructions in their way, and they can detect and track microscopic insects from several meters away. The bat's larynx produces ultrasonic sound with frequencies ranging from 10 to 150 kHz . Sound frequencies of 20 kHz, on the other hand, are barely audible. The sound is produced in the form of pulses through the vocal tract and open mouth or nose at a rate of 20-30 pulses per second. The forms, locations, and distances of the bat's sonar pulses are determined by their reflections of surrounding objects (Altringham 1996, Neuweiler 2000).

The bat's brain is more complex than previously thought in its processing of sonar echoes. The bat's target returns a wide range of reflected echoes depending on its size. This spectrum is used by the bat to acquire fine time resolution. One set of brain-based reactions evaluates distance to a target by measuring the timing of returning echoes. The other set of brain responses assesses the echoes' spectrum in order to create a three-dimensional image of the object. As a result, bats have developed a way for obtaining synthetic aperture sonar while flying, which not only identifies the distance and direction of all objects in a scene, but also reconstructs the shape of a specific object (Horiuchi 2005, Jones 2005, Simmons 1979, Thomas et al. 2004, Dror et al. 1996, Ferragamo and Moss 1998, Horiuchi 2005, Jones 2005, Simmons 1979, Thomas et al. 2004). There have been several attempts to replicate the bat's sonar using microchips, tiny devices, and biomimetic techniques (Hesselberg 2009, Kuc 1997, Waters 2007, Wu et al. 2003). The researchers are looking into how a bat's physical shape, flight behavior, sonar pulse selection, and repetition rate all contribute to the bat's extraordinary sensory performance (Horiuchi 2005, Victor 2013). The discovery of ultrasonic bat echolocation sparked a worldwide search for additional animal biosonar systems, which resulted in the discovery of two avian groups, among others. The South American Oilbird (*Steatornis caripensis*: Caprimulgiformes), for instance, is nocturnal and feeds on fruit. The other is a collection of diurnal, insect-eating swiftlets (genera *Aerodramus* and *Collocalia*: Apodidae) from the Indo-Pacific region. Two groups of birds use their syrinx to create clicking sounds that enable them to navigate in the dark using echolocation. Although swiftlets and oilbirds lead very different lives, their sonar enables them to nest in relatively safe dark caves. Swiftlets are diurnal insectivores that spend their days flying and catching insects that they visually locate. Oilbirds are nocturnal frugivores with superior vision at night (Brinkløv et al. 2013). In an exciting study, Vietnamese pygmy dormouse *Typhlomys chapensis* is an intriguing semi-fossorial semi-arboreal mouse that is little known. The validity of research on ocular structure demonstrates that *Typhlomys* is incapable of object vision. As a result, *Typhlomys* has no other means of rapidly orienting itself among tree branches besides echolocation. At frequencies between 50 and 100 kHz, ultrasonic vocalisation is represented by bursts of up to seven more or less evenly spaced and uniform frequency-modulated sweep-like pulses in rapid succession. These sweeps are structurally comparable to some bat species' frequency-modulated ultrasonic echolocation calls, but they are too faint to be detected by a conventional bat detector (Panyutina et al. 2017). Another example is the aye-aye (*Daubentonia madagascariensis*), which is well recognised for its distinctive acoustic foraging activity known as 'tap-scanning' or 'percussive foraging. Tap-scanning is a remarkable activity that enables aye-aye to detect and extract wood-boring larvae from small crevices beneath tree bark. Tap-scanning demands an outstanding acoustic near-field sensitivity in the animal auditory system (Nemati and Dehghan-Niri 2020).

Sonar capability

Whales and dolphins rely on sounds and hearing to enable echolocation and long-distance communication, even when underwater visibility is poor (Au 1993, Purves and Pilleri 1983). Using very low frequency noises, large whales can communicate over hundreds of kilometers in the ocean. Sonar is used by around 65 toothed whale species. Regarding the echolocation and sonar ability of whales give surge to the specific study of this astonishing sea creature called as whale ecology. Whale ecology includes the usage of home ranges, breeding and feeding grounds, migration corridors, and movement patterns among them (Burnham 2017). Also, the use of sound by cetaceans to communicate, navigate and forage, as well as how they interpret the sounds-cape, is a key consideration for future endeavours (Burnham 2020). Whales make two types of noises: one that sounds like whistling (high-pitched sounds) and the other that sounds like a rattle or clicking. Whistles are usually employed for communication, while clicks are utilized for echolocation, which is used for navigation and object detection. Killer whales, for example, use echolocation for hunting and navigation, while humpback and blue whales make a succession of noises that sound like songs and could be used for communication. Whale songs can last up to 10 minutes and consist of a series of grunts, moans, and high-pitched squeals (AG/DEH 2006, Klemas 2012, Norris and Harvey 1974, Purves and Pilleri, 1983).

Dolphins have a characteristic whistle that is distinguished from other dolphin whistles by its particular contour, or frequency variation over time. To communicate, dolphins use whistle signals, and to locate and detect prey, they use brief broadband echolocation clicks. The center frequencies of high-intensity signals are frequently 100 kHz or more, whereas the center frequencies of low-intensity signals are 30-60 kHz. The clicks are broad-band pulses with a frequency of up to 150 kHz, a cycle count of four to eight, and a length of 40-70 microseconds (Thomas et al. 2004, Victor 2013). Humans cannot echolocate as well as dolphins can. Bottlenose dolphins have a time resolution of roughly 14 microseconds. The bottlenose dolphin's biosonar is a highly sophisticated, high-performance system that consistently outperforms any artificial system in its operating regime. This is accomplished through the use of a variety of techniques that have not been fully exploited outside of the biological realm. While it is believed that all members of Cetacea (whales and dolphins) possess some form of echolocation, the bottlenose appears to have the most optimised system (Fulton 2007). Dolphins, whales, bats, and other species' sonar techniques have been investigated in biomimetic attempts to duplicate their effectiveness and efficiency (Olivieri 2002, Toko 2000). Engineers created radio-controlled, multi-link, free-swimming biomimetic robot fish with three-dimensional motion control (Polverino et al. 2012, Yu and Wang 2005).

High precision vision capability

Birds have sharper vision than humans and can see in spectral ranges that humans cannot, such as ultraviolet (UV). Many songbirds have UV-reflecting feathers that communicate species, gender, and social status. They also employ UV to locate food, as many fruits, flowers, seeds, and insects contrast more strongly in UV than in human-visible wavelengths (Bristol University 2007). Photoreceptive "cones" in the retina at the rear of the eye allow us to see colour light in both birds and humans. The human eye has 10,000 cones per square millimeter. Songbirds, on the other hand, have up to 12 times as many cones per square mm, or 120,000 cones per square mm. There are three types of cones in humans. Trichromatic colour vision is achieved by each cone being sensitive to blue, green, or red light. For quadromatic colour vision, birds have an additional cone that extends their visible light spectrum into the UV area (Withgott 2000, Victor 2013). Both humans and birds rely on photoreceptive "cell rods" in the retina in low-light situations. The human eye has 200,000 cell rods per square mm, although other species, such as owls, have up to a million. Furthermore, unlike humans, birds have no blood veins in their retinas. As a result, light scattering is reduced, giving birds' better visual acuity than humans.

Peregrine falcons, red-tailed hawks, and golden eagles, for example, make extensive use of their exceptional vision to become masters of the sky. The retina of most raptors functions as a telephoto lens, providing stereo vision and UV light sensing. Raptors are nature's ultimate hunters, with razor-sharp talons, powerful beaks, and cunning hunting methods supported by their excellent vision. The anatomy of the peregrine falcon is so advanced that if it were the same size as the F-22 fighter jet, it would outmaneuver it in a dogfight (Brown and Amadon 1969; Cresswell 1996, Kenward 1999, Ratcliffe 2005).

Navigational capability

Birds move large distances from their summer homes to their wintering grounds in search of regions with abundant food and better breeding opportunities. A small satellite transmitter hidden amid the feathers on the bird's back allows for continuous tracking. This latest type of telemetry, which includes transmitters and data loggers as well as position data from the global positioning system (GPS), allows scientists to monitor individual birds throughout the year, which is impossible with traditional bands. It is now possible to trace the travels of a single bird across thousands of kilometers and over many years thanks to these ever-smaller and more powerful tracking devices (Weidensaul 2012, Victor 2013). Birds and monarch butterflies employ incredible navigation techniques to guide them along their migration routes. To navigate, you'll need to know three things: your current location, your goal, and the route you'll take to get from your current place to your destination. Birds, fish, and some animals can fly vast distances and navigate with remarkable accuracy utilizing environmental data. The majority of research on how birds make migratory flights has focused on environmental cues that birds employ to maintain a specific flight path. Landmarks on the Earth's surface, magnetic lines of flux that longitudinally ring the Earth, the Sun, the Stars, and possibly even wind directions and scents are all examples of these cues (Nelson 2012; USGS 2006). To understand the remote sensing techniques used by such species, their cognition behaviour needs to be studied extensively. Cognition, defined as the processes involved in the acquisition, retention, and use of information, underpins animals' abilities to navigate their immediate environment, embark on long-distance seasonal migrations, and socially acquire movement-related information. Thus, in order to fully comprehend and predict animal movement, researchers must first understand the cognitive mechanisms that underpin it. According to research on a few model systems, most animals exhibit superior spatial learning and memory abilities, which means they can acquire and later recall information about the distances and directions between relevant objects (Kashetsky et al. 2021).

Birds travel over cloud decks where landmarks are not visible, under gloomy skies where celestial cues are not apparent, and even within cloud layers when neither set of signals is available, according to radar research. Some birds, such as European robins, appear to navigate using the Earth's natural magnetic field. Also, in various research, homing pigeons use magnetic fields as part of their complex navigation system, especially during overcast conditions (Walcott 1996). Butterflies appear to navigate using the Earth's magnetic field as well. According to theories and tests, certain birds' neurological systems and sensory receptors are related to iron-containing magnetite crystals, whereas others' geomagnetic orientation is based on the response of visual pigments in the eye to EM energy (Johnsen and Lohmann 2008, Lohmann and Johnsen 2000. Ritz and Schulten 2000). Among numerous species, turtles and salmon possess the sensory capacities necessary to detect a coastal area's unique magnetic signature. Additionally, a link between population genetic structure and the magnetic fields seen on nesting beaches has been identified in turtles, supporting the theory that turtles distinguish their natal locations via magnetic cues. Salmon are expected to adopt a biphasic navigation technique in which magnetic signals guide them through the open sea and into the vicinity of their home river when chemical cues allow the spawning journey to be completed (Lohmann & Lohmann 2019). Biological navigation behaviour has been implemented in a significant number of robots (Franz and Mallot 2000, Victor 2013). Biomimetic systems have a substantial impact on a variety of fields of study. They allow for real-world testing of biological navigation models and the development of new navigation processes for technical applications, such as indoor robot navigation (Franz and Mallot 2000).

CONCLUSIONS

The wavelengths of electromagnetic or acoustic waves employed in remote sensing to detect, measure, or photograph features of interest include visible, infrared, microwaves, and acoustic waves. Remote sensors are divided into two categories: wavelength and application. Imagers (mappers), radiometers, spectrometers, and distance rangers are examples. Cameras that image solar reflected light or thermal infrared sensors that map the temperature of heat-emitting landscapes are examples of passive sensors. Radar, LIDAR, and acoustic echolocators are among the active sensors. They send out their own power pulses, which are reflected by specific targets. Many animals can "see" and "hear" using EM waves and acoustic waves better than humans. Some even have distant sensing capabilities that are more effective than human-developed procedures. As a result, it's no surprise that sensor designers are drawing inspiration from nature to create sensors that mimic many of the functions or structures found in animals (Bogue, 2009).

Various researches have provided vital insight into the remote sensing, echolocation, communication, and navigation processes employed by whales, dolphins, snakes, bats, and birds, among others. The findings of these investigations are driving engineers to use the biomimetic framework to create more efficient sensing devices. There are, nevertheless, numerous scientific questions that remain unanswered. How do migrating bird and butterfly progeny, for example, return to the same area year after year? Even in gloomy situations, how do birds navigate using the Earth's magnetic field and the stars? How can rattlesnakes use bimodal neurons to integrate "normal" vision and thermal infrared information to improve the resolution of their low-resolution infrared sensors? When whales communicate via sound waves, what information is transmitted between them? How can dolphins' brains use sonar data to create a precise three-dimensional image of their target and surroundings? How can bats interpret echo data to achieve extraordinarily high resolution and location accuracy with a limited sensor configuration when using echolocation? How do bats distinguish their own signal from background noise when it's a thousand times weaker? With only fractions of a second to reply, how are insects like moths and beetles able to jam the bat's sonar so effectively? When it comes to designing more effective sensors, the examples in this paper indicate that we can learn a lot from nature. Many animal senses are more efficient and sensitive than visual, infrared, radar, and acoustic sensors developed by humans, ounce for ounce and watt for watt. Many animals have evolved impressive remote sensing and navigation techniques over millions of years, long before man devised them (Victor 2013).

Researchers can learn from the above animals' unique abilities and develop new technologies for border management, forest fire control (for example, the photo mechanic infrared receptor for detecting forest fires in the beetle), jamming the signal from the tiger moth which jams bat sonar, integration of visual and infrared information in bimodal neurons in the rattlesnake optic tectum, and biomimetic sonar that locates and recognizes objects.

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