GIST-Seoul National University, Imitating the Structure of Cat Eyes with Good Night Vision Developing a High-Sensitivity Artificial Vision System That Can Distinguish Objects and Backgrounds Well

- High-sensitivity video capture in various lighting environments, bright or dark, by mimicking the ‘vertical pupil’ and ‘reflector’ structures of cat eyes... Object detection and recognition without the need for software post-processing
- Joint research by Professor Young Min Song’s team from the School of Electrical Engineering and Computer Science at GIST and Professor Dae-Hyeong Kim’s team from the School of Chemical and Biological Engineering at Seoul National University... “Expected to be applied to autonomous vehicles, drones, surveillance robots, etc.”, selected as the cover paper for the international academic journal《Science Advances》

▲ (From top left) Professor Young Min Song of GIST, Professor Dae-Hyeong Kim of Seoul National University, Professor Gil Ju Lee of Pusan National University (From bottom left) Researcher Min Su Kim of Seoul National University, Dr. Min Seok Kim of GIST, Dr. Mincheol Lee of Korea Electrotechnology Research Institute

Recently, innovative robot vision systems that allow robots to recognize and explore their surroundings have been widely utilized, but they have the disadvantage that pixels become saturated in bright environments and the photocurrent is low in dark environments, making it difficult to distinguish between objects and the background.

A biomimetic camera with improved performance in detecting and recognizing objects in various lighting environments, both bright and dark, has been developed by a domestic research team by implementing ‘camouflage removal*’ inspired by the structure of animals’ eyes.

It is expected that it can be applied to self-driving cars, drones, surveillance robots, etc. by complementing the limitations of the aperture system of existing cameras.

* camouflage removal: A technique to separate an object from its surroundings by clarifying the boundary between the object and the background.

The Gwangju Institute of Science and Technology (GIST, President Kichul Lim) announced that a research team led by Professor Young Min Song of the School of

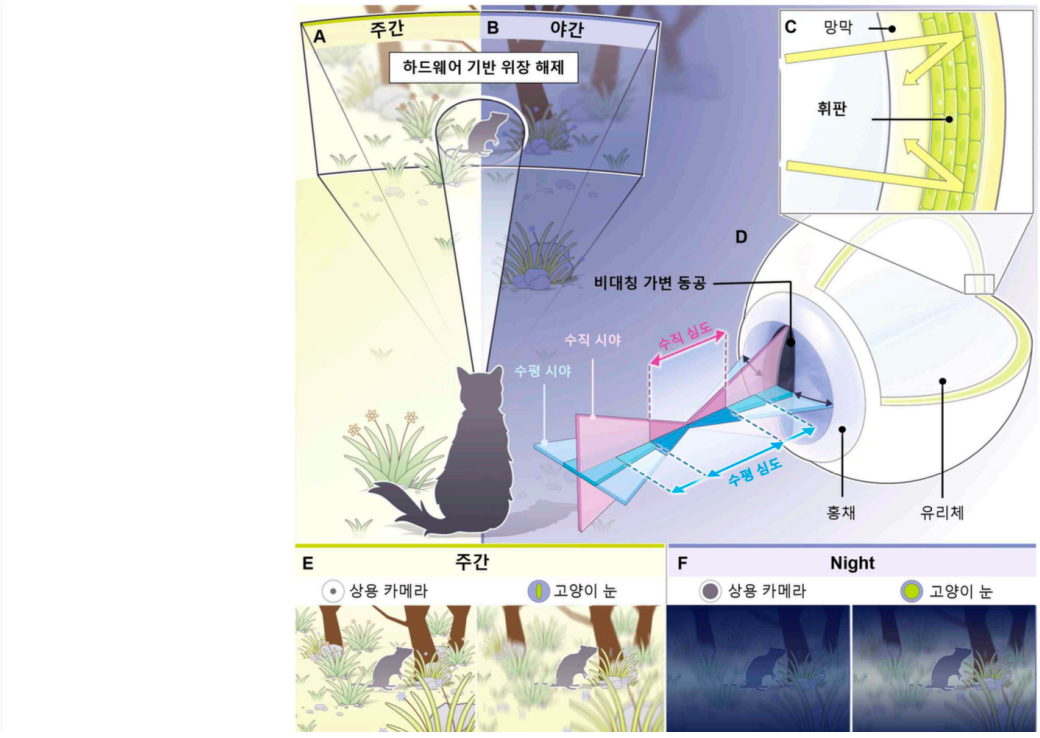
Electrical Engineering and Computer Science, in collaboration with Professor Dae-Hyeong of the School of Chemical and Biological Engineering at Seoul National University, developed a spherical camera that mimics the structure of a cat's eye by combining a vertical variable aperture and an imaging optics system and fabricating a hemispherical image sensor array with unit pixels composed of a single photodiode and a silver film*.

* tapetum lucidum: A layer of tissue present in the retina, a biological reflective system commonly found in the eyes of vertebrates. The phenomenon in which animals' eyes reflect and shine in the dark is caused by this tapetum.

Professor Young Min Song is an optical device expert who has developed various camera technologies through the visual structures of various creatures existing in the natural world, such as fish, crabs, and squid.

Animals in nature have developed unique visual systems optimized for complex environments through long-term evolution, which potentially holds solutions to overcome the limitations of artificial visual systems.

The eyes of felines have a vertically elongated pupil and a characteristic structure called the tapetum lucidum, which gives them the ability to disguise themselves in a variety of lighting conditions. The vertical pupil allows for asymmetrical depth of field* and high-resolution focus on objects, while the tapetum lucidum acts as a biological light reflector, enhancing visual sensitivity even in low-light environments.



▲ Structural and functional features of cat eyes

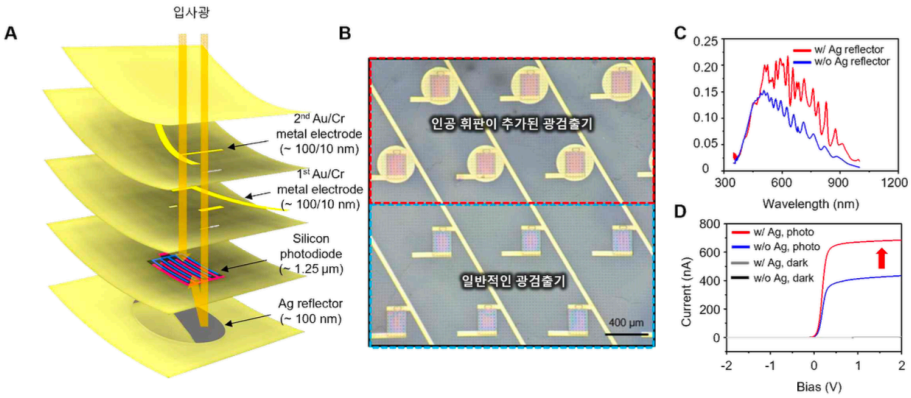
(A and B) Schematic showing the camouflage-detecting ability of a cat under various lighting conditions. (C) Magnified schematic of the tapetum lucidum within the retina. (D) Anatomy and optical properties of the cat eye. (E and F) Optical visual properties of a cat eye compared to a commercial camera (mimicking a human) during daytime (E) and nighttime (F).

Existing camera systems use a circular aperture that mimics the pupil to focus on both the background and the object by using an aperture with a small aperture ratio when there is a lot of light. However, there are limitations in separating the object and the background in various lighting environments, and there is a

disadvantage in that post-processing is required through image sensor sensitivity adjustment or complex artificial intelligence calculations.

* depth of field: Depth of field refers to the range in front and behind the area that appears sharp in an image, and represents the depth of the area that is in focus in a photo or video. When the depth of field is shallow, only the area in focus is sharp, and the other areas are expressed blurry, and when the depth of field is deep, the entire image appears sharp.

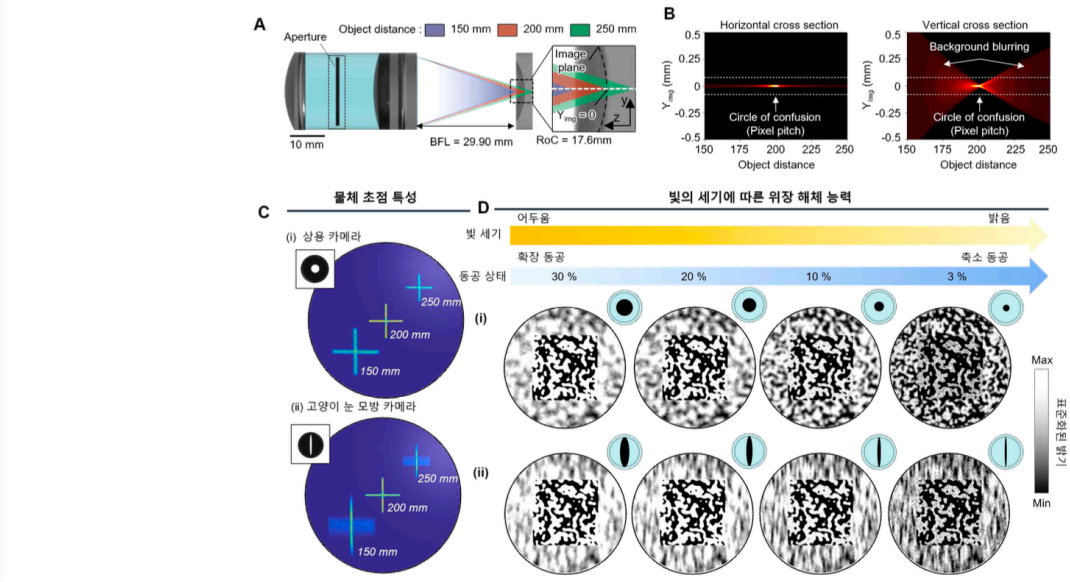
The research team effectively blocked strong light using a vertical variable aperture to prevent overexposure of the photodiode, and improved light absorption efficiency by 52% through a circular pupil and silver plate that allow sufficient light to be received in dark environments.



▲ Structure and optical characteristics of silicon photodiode devices

(A) Schematic of a silicon photodiode array with an artificial lamella (HPA-AgR). (B) Optical micrographs of a conventional photodetector and a photodetector with an artificial lamella added. (C) Simulation of light absorption of silicon without a lamella and with a lamella in the visible region. (D) Photocurrent measurements of silicon photodiodes with and without a lamella.

Furthermore, through optical simulations and experiments, they verified the system's high-sensitivity target imaging performance and camouflage-detection capability in various lighting environments and theoretically and experimentally demonstrated that a system with a vertical pupil can more effectively distinguish between the background and the target object than a system with a small circular pupil.



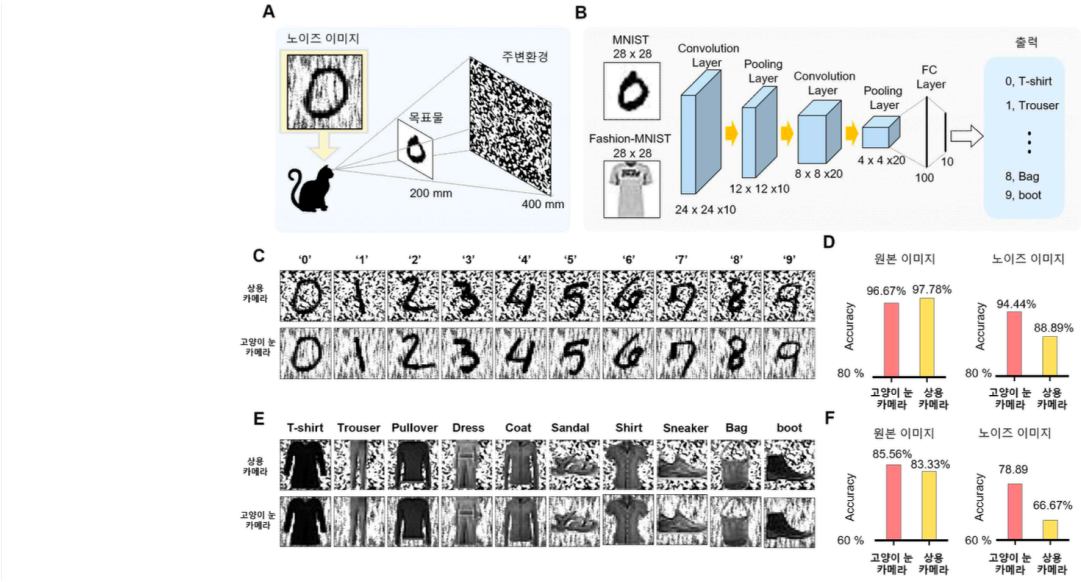
▲ Optical simulation of the characteristics of the cat eye-mimicking visual system

(A) Optical schematic diagram of a cat-eye-mimicking visual system. (B) Optical simulation results of cross-sectional focal positions at different object distances. (C) Comparison of ray-tracing

simulation results at different object distances using a commercial camera aperture (i) and a cat-eye-mimicking vertical aperture (ii). (D) Comparison of ray-tracing simulation results for camouflage debunking using a commercial camera aperture (i) and a cat-eye-mimicking vertical aperture (ii).

The research team compared and analyzed a vertical aperture system and a small circular aperture system for experimental verification along with theoretical verification through optical simulation.

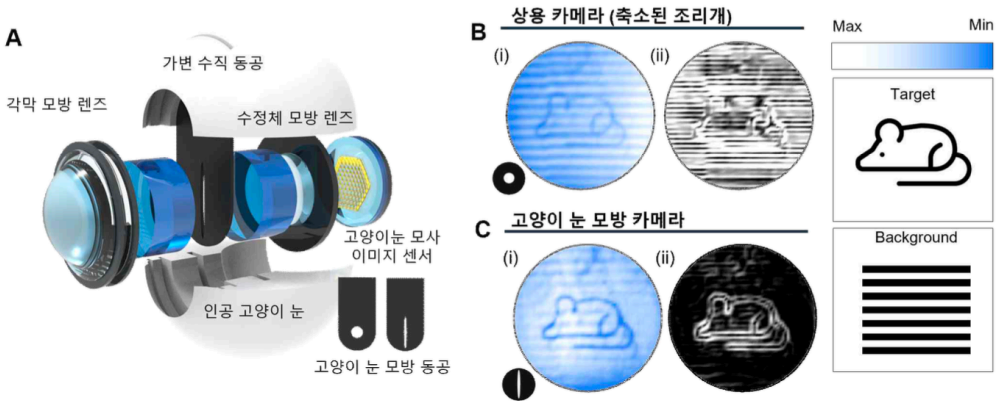
As a result, the vertical aperture system was able to clearly capture objects at a specific distance away, while effectively blurring the background at a different distance. In addition, in an AI-based object recognition experiment conducted to evaluate practicality, it was proven that the vertical aperture system significantly contributed to improving the object recognition rate.



▲ Object recognition in noisy backgrounds in a visual system inspired by cat eyes

(A) Cat vision system with improved decamouflage capability via background blurring. (B) Convolutional neural network (CNN) diagram for MNIST and Fashion-MNIST datasets. (C) Optical simulation results for MNIST dataset using commercial cameras and cat-eye cameras. (D) MNIST test accuracy with and without noise. (E) Optical simulation results for Fashion-MNIST dataset using commercial cameras and cat-eye cameras. (F) Fashion-MNIST test accuracy with and without noise.

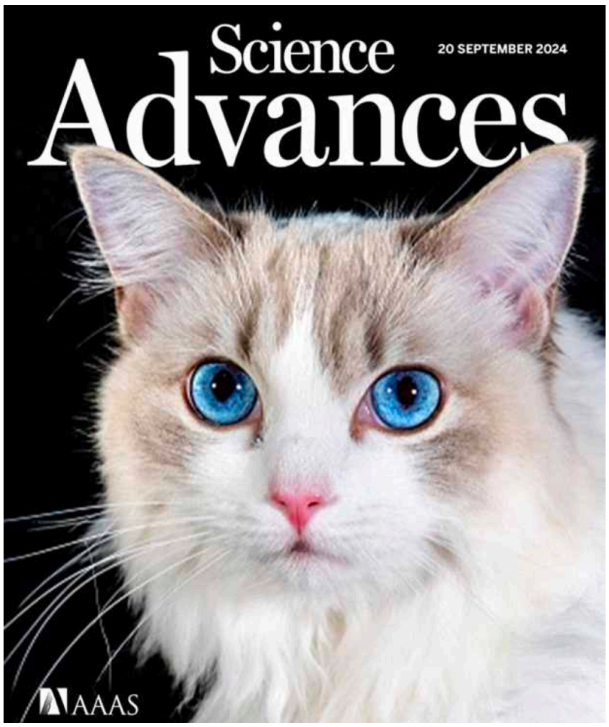
Professor Young Min Song said, "Through this research achievement, we developed a high-sensitivity artificial visual system by simulating the vertical pupil and retina structure of a cat, and successfully demonstrated monocular camouflage removal ability*. It is expected that it can be applied to various fields such as autonomous vehicles, drones, and surveillance robots, as it can improve object recognition ability with hardware itself without software post-processing even in various lighting environments."



▲ Imaging demo of a visual system inspired by cat eyes

(A) Schematic diagram of an artificial vision system inspired by a cat's eye (B) Measurement results of a cat's eye-mimicking vision system equipped with a commercial camera aperture (C) Measurement results of a cat's eye-mimicking vision system equipped with a cat's eye-mimicking vertical aperture

This study was supported by the National Research Foundation of Korea's Mid-career Researcher Support Program and Sejong Science Fellowship and the Institute for Basic Science (IBS) External Research Group and Mega Project, and was jointly conducted by Professor Young Min Song's team in the School of Electrical Engineering and Computer Science at GIST (first author, Dr. Min Seok Kim (GIST), corresponding author Professor Gil Ju Lee (Pusan National University)), Professor Dae-Hyeong Kim's team in the School of Chemical and Biological Engineering at Seoul National University (first author, Seoul National University doctoral student Young Min Song), and Dr. Mincheol Lee of the Korea Electrotechnology Research Institute (first author). The results of this study were selected as the cover paper in Science Advances and published online on September 18, 2024.



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