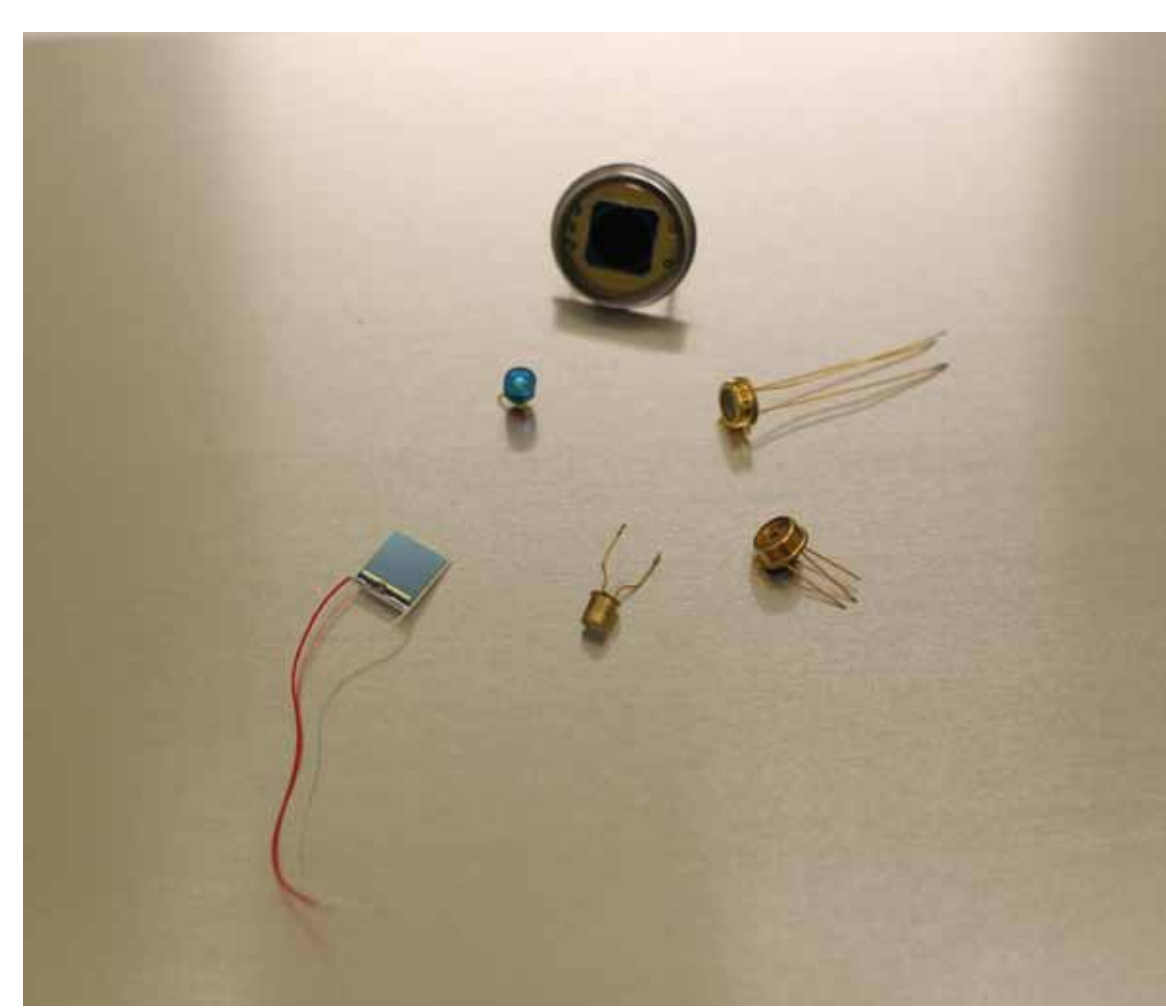


What is a Single-Pixel Camera?

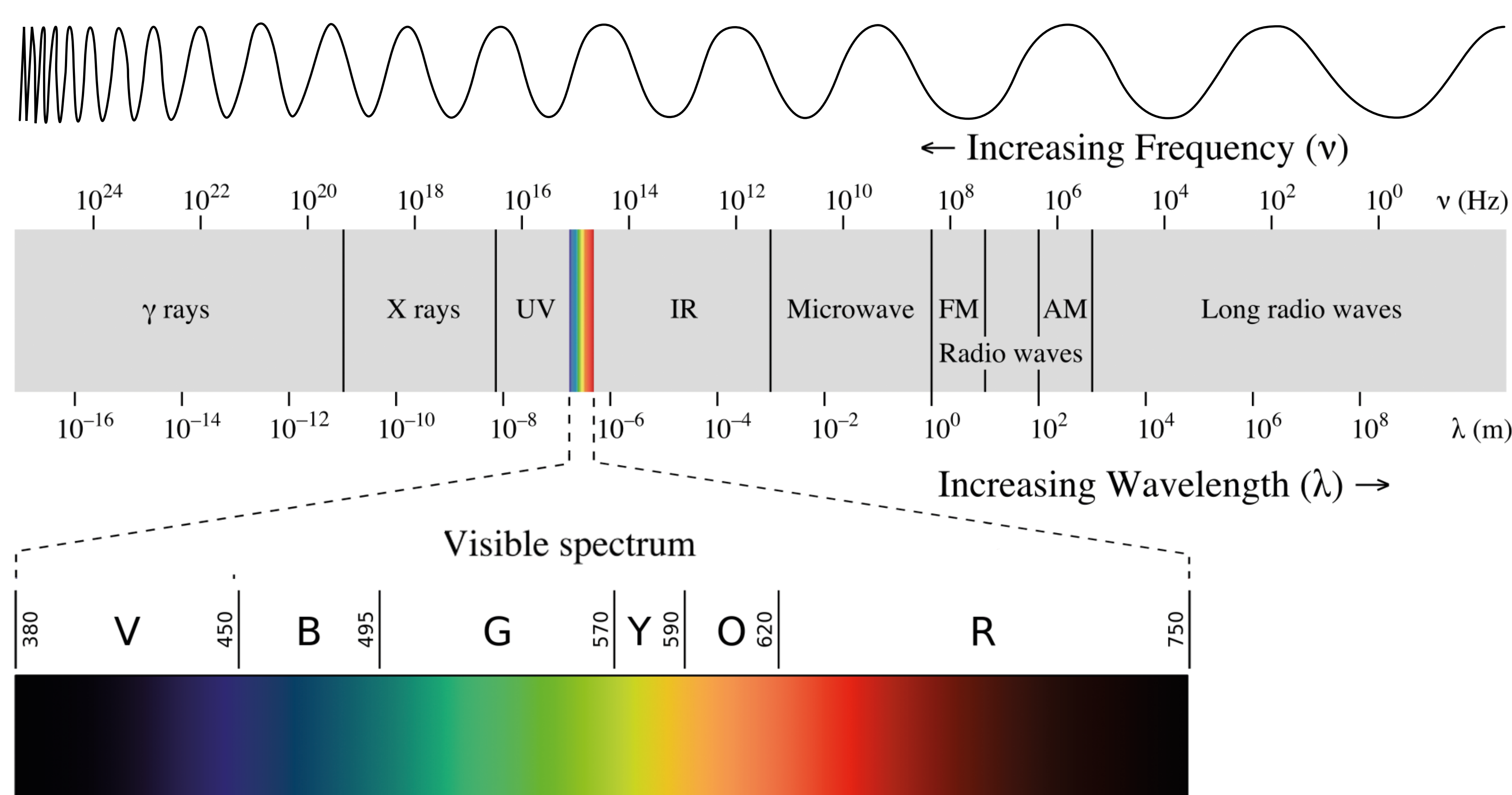
2015 is the International Year of Light and Light-based Technologies. The Hunterian Science Showcase presents new and ongoing research from the School of Physics and Astronomy at the University of Glasgow. Researchers from the Optics Group are developing experimental cameras that don't sense light with millions of pixels, but instead require just one pixel.



Large-area single-pixel detectors made from a variety of materials, including Silicon, Indium-Gallium-Arsenide and Germanium. These detectors are much larger than the pixels in a camera sensor but can be used in conjunction with the experimental equipment in the Optics Group laboratory to enable affordable imaging outside the visible spectrum

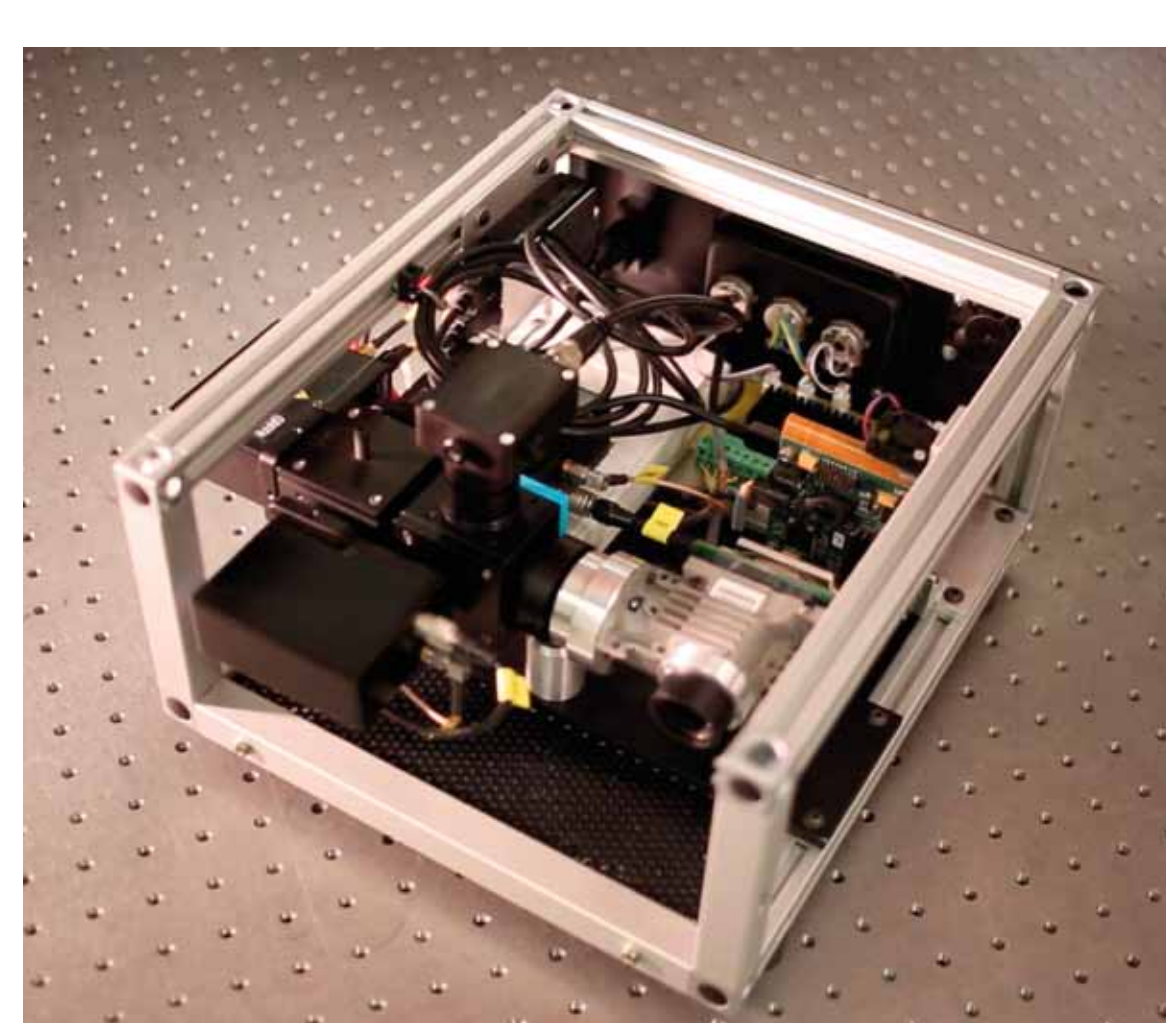
Pixels are light sensitive detectors found in the sensors of digital cameras. Modern cameras typically contain an array of several million pixels (megapixels). Improved manufacturing and high demand has produced cheap cameras for capturing visible light, but cameras that can capture wavelengths of light outside the visible spectrum remain expensive.

A digital camera can cost as little as £5 per megapixel, whilst a shortwave infrared camera can cost over £50,000 per megapixel. Versatile, compact and cheap cameras capable of working over a wide range of wavelengths have potential applications in spotting gas leaks, night vision,



The electromagnetic spectrum ranges from low-frequency, large wavelength radiation like radio waves and microwaves, to high-frequency, short wavelength radiation like x-rays and gamma rays. Only a small portion of the electromagnetic spectrum is visible light

seeing through smoke, infrared microscopes, and medical diagnostics. Affordable high-performance computing has helped to pave the way for a new generation of camera technologies capable of producing images of light across the electromagnetic spectrum using just a few pixels.



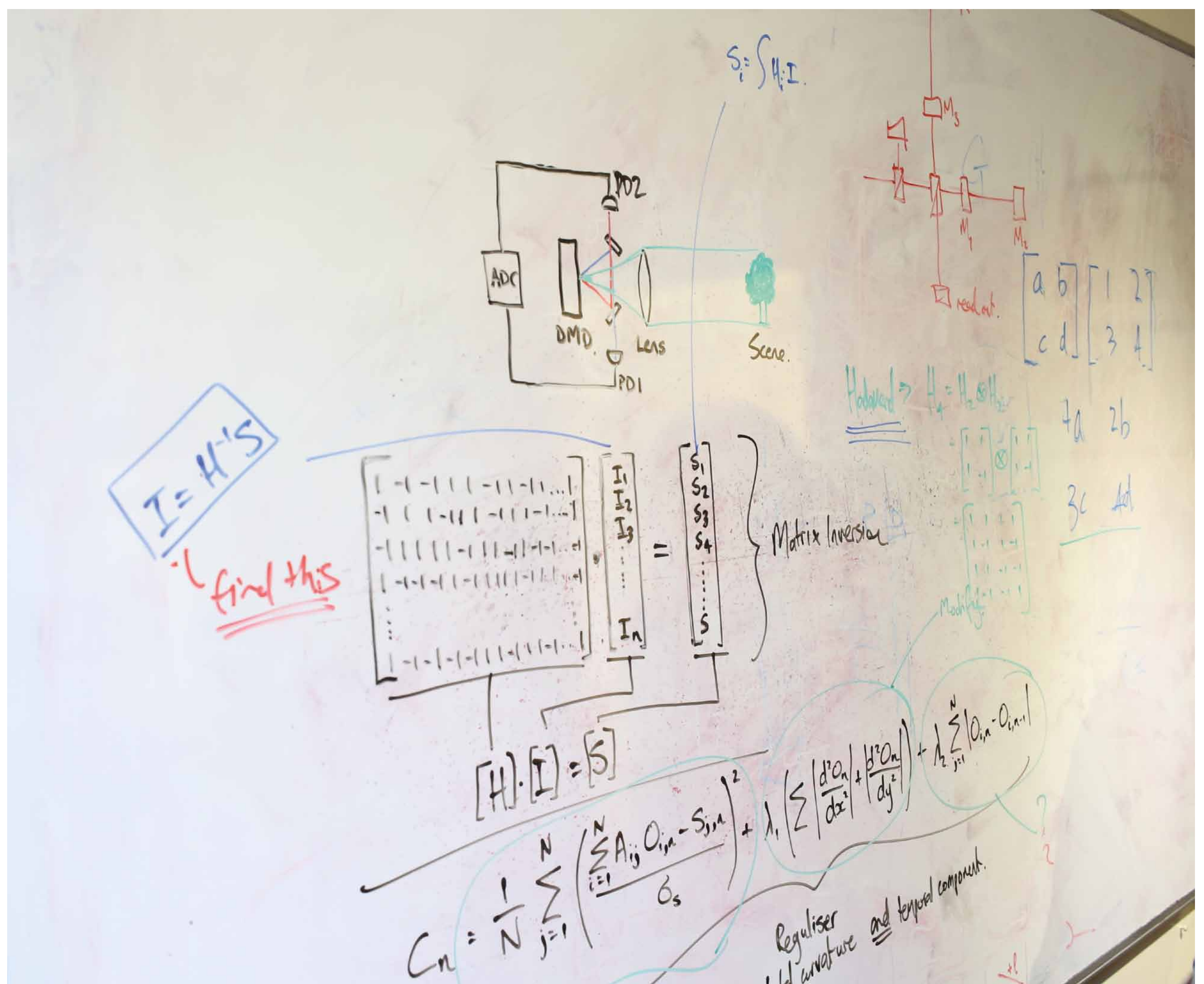
Prototype camera with single-pixel detector, built by the University of Glasgow Optics Group

Single-Pixel Camera Technique



The process of "structured illumination": the objects are illuminated with a rapid series of patterns that resemble crossword puzzles, generated by a digital light projector

The single-pixel camera technique involves illuminating an object with flickering, changing patterns that resemble crossword puzzles. These patterns are generated by a digital light projector, which contains an array of tiny programmable mirrors. A single-pixel detector is used to measure the intensity of the light reflected by the illuminated object. The intensity of the backscattered light from one pattern does not provide enough information to create an image, but by rapidly projecting a known sequence of light patterns, and each time measuring the light reflected by the object, computational techniques can be used to calculate a 2-D image. Another



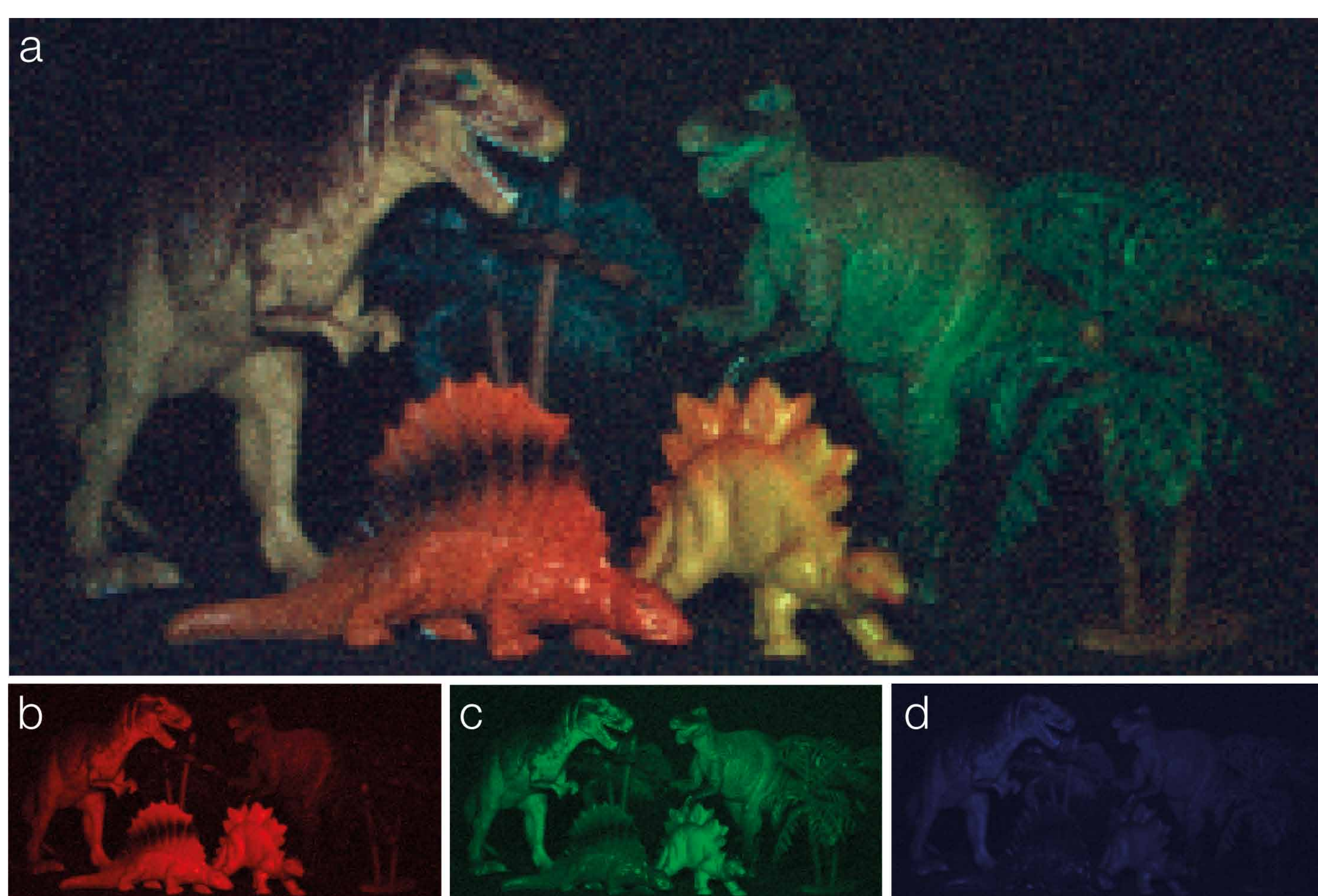
Whiteboards are used extensively throughout the research and development process. The text and diagrams show the experimental layout and mathematical equations used in computational imaging techniques, as well as other writings from different experiments

approach uses the mirrors in the projector not to project light, but rather to mask incoming light from an object with the same rapidly changing sequence of patterns, whereupon the masked light is measured on a single pixel.

Making a 2-D Full-Colour Image

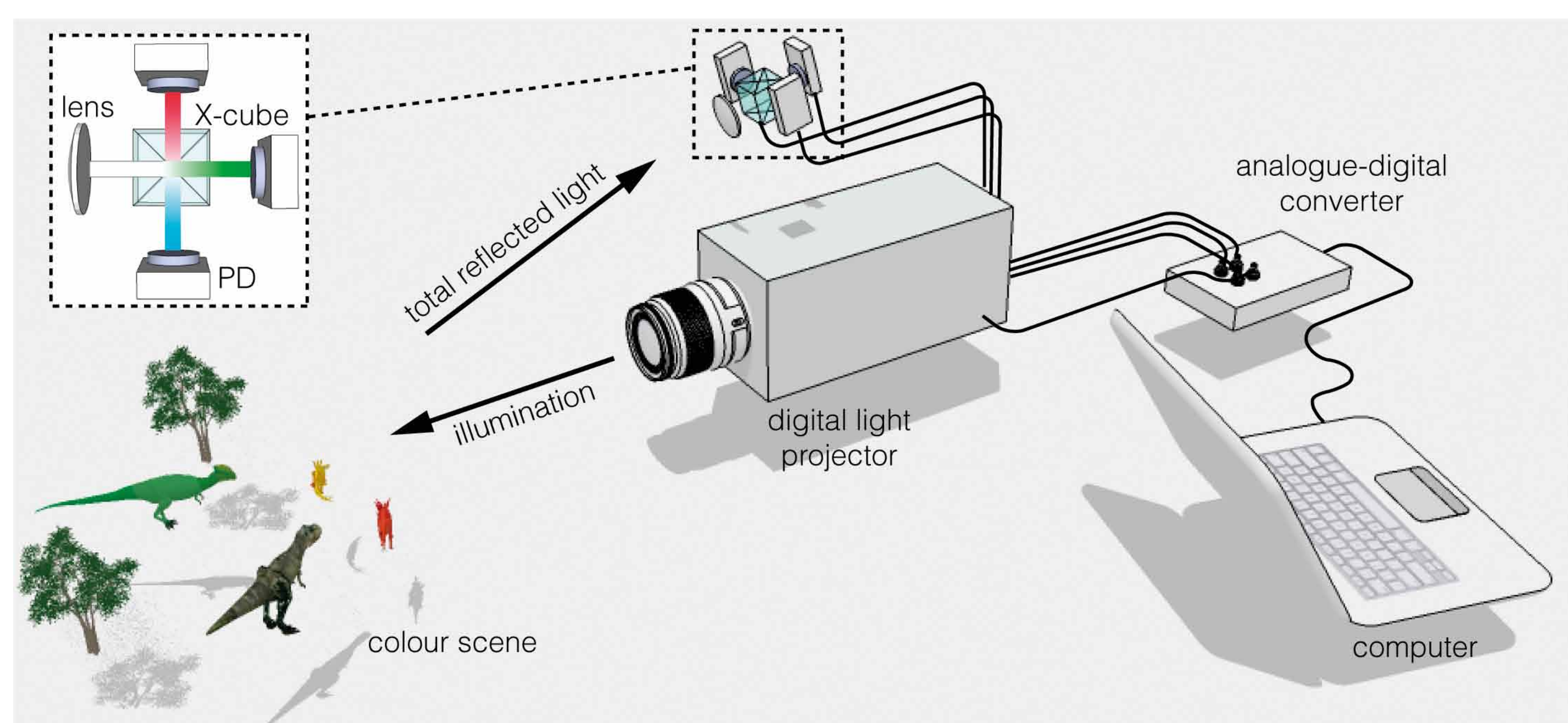
To make a 2-D full-colour image of a group of toy dinosaurs, the projector illuminates the scene with over 1000 different light patterns every second. The backscattered light is separated into red, green and blue light components, which are detected by three single-pixel detectors. The varying intensity of the coloured components of light measured by the single pixels, combined with knowledge of the illuminated patterns, allows for a full-colour image to be computed

The measured reflected light and the projected patterns are combined in a computer algorithm to reconstruct single-colour images of the scene. A full-colour image of the objects is obtained by combining the three separate images



From Welsh, Edgar et al., "Fast full-colour computational imaging with single-pixel detectors" OPTICS EXPRESS 21 no. 20 pp. 23068-23074 (23 September 2013). Reprinted with permission from Optical Society of America.

in a matter of seconds. The mirrors in a projector can mask and reflect at a wide range of wavelengths, not just the visible spectrum. This means the single pixel computational imaging technique can be extended to wavelengths such as infrared.



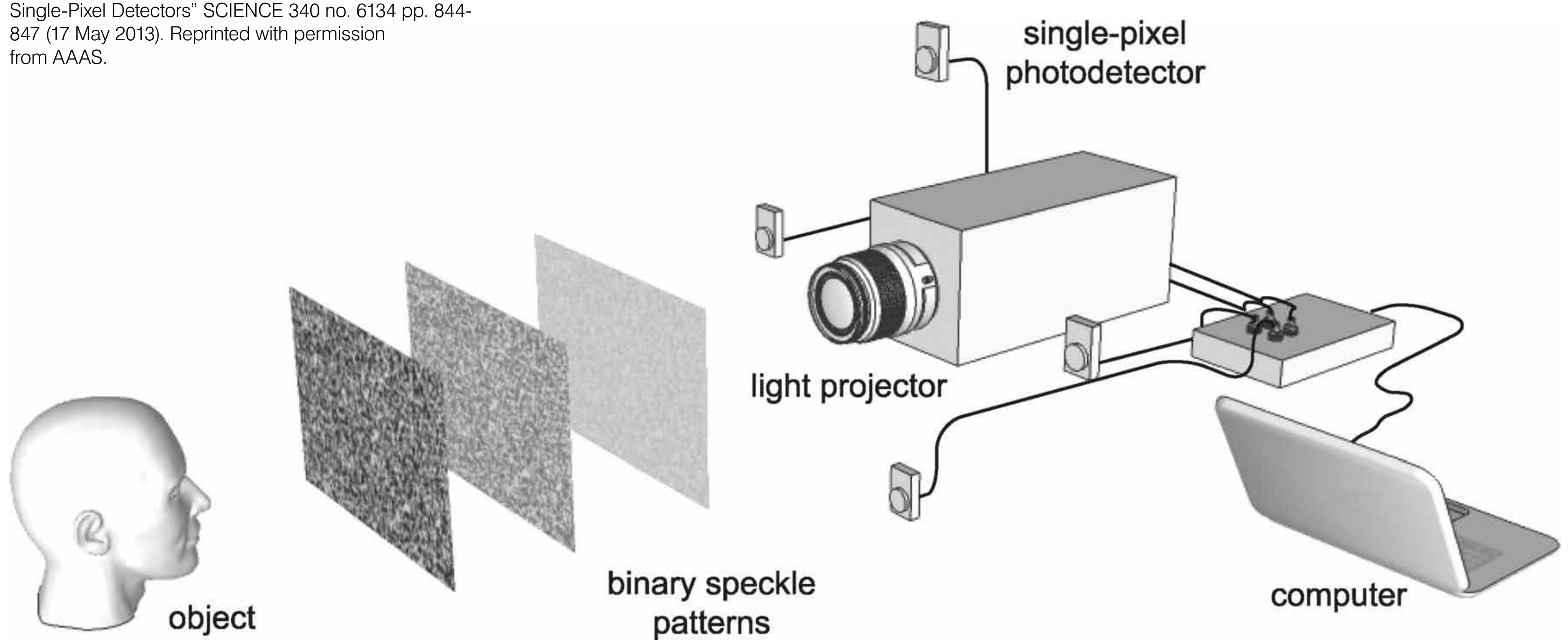
Schematic diagram of the experimental system for producing a full-colour image, showing projected light patterns reflected from a scene

From Welsh, Edgar et al., "Fast full-colour computational imaging with single-pixel detectors" OPTICS EXPRESS 21 no. 20 pp. 23068-23074 (23 September 2013). Reprinted with permission from Optical Society of America.

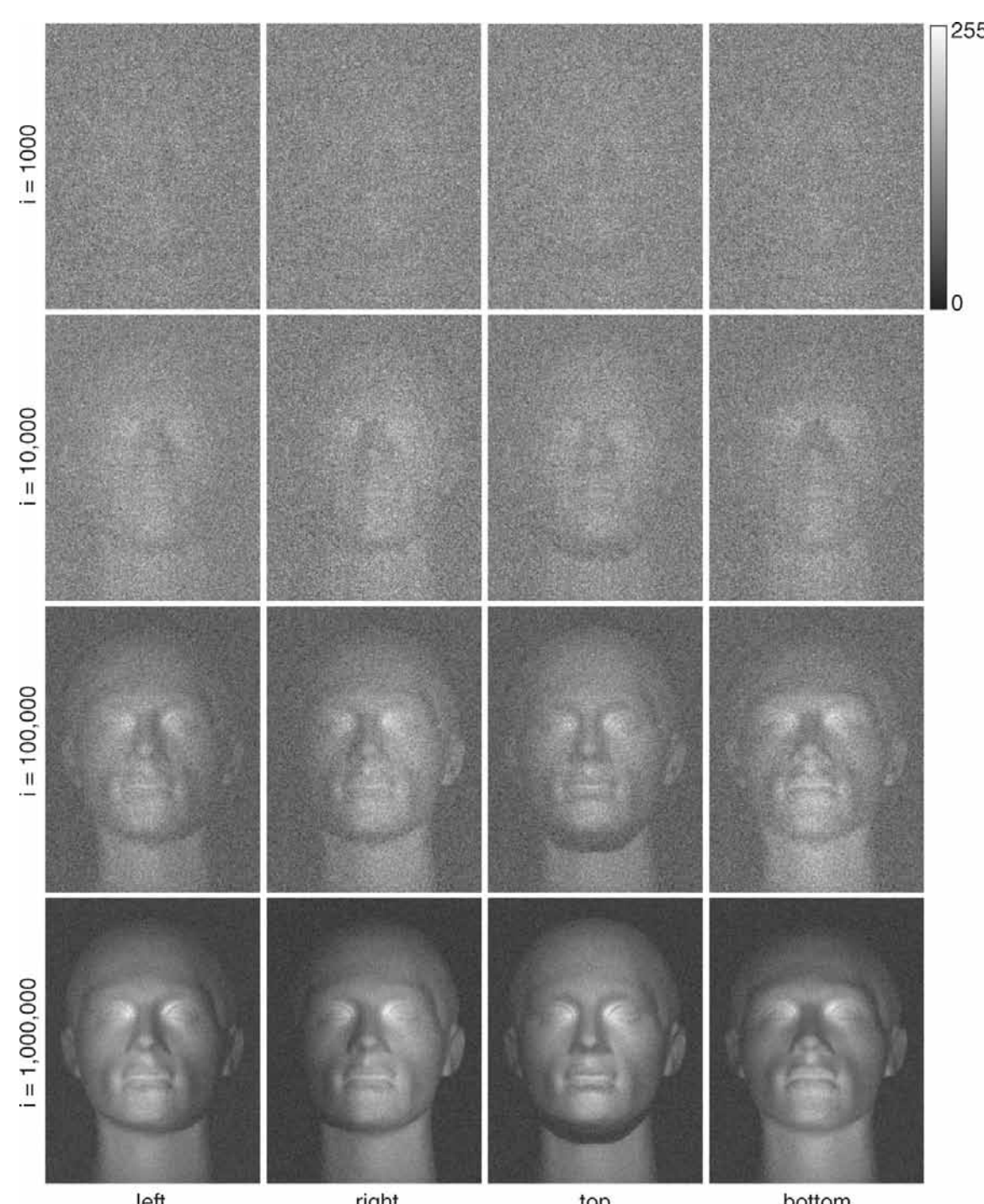
Making a 3-D Image

Schematic diagram showing the experimental setup used for computing a 3-D image using four single-pixel detectors

From Sun, Edgar et al., "3D Computational Imaging with Single-Pixel Detectors" SCIENCE 340 no. 6134 pp. 844-847 (17 May 2013). Reprinted with permission from AAAS.



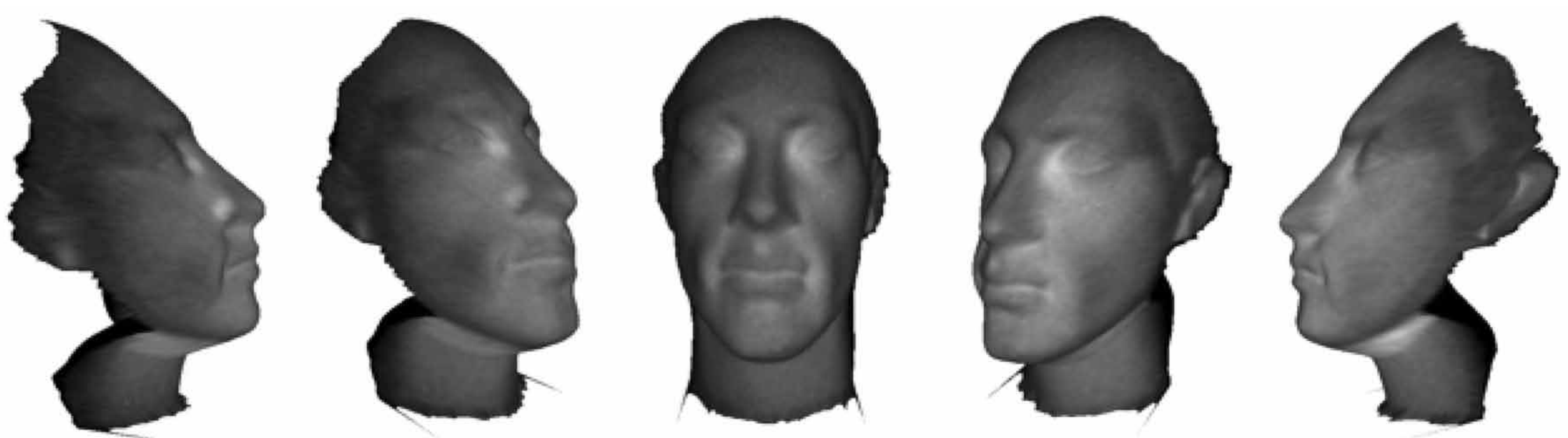
To make a 3-D image of a mannequin head, four pixels are placed in different locations around the digital light projector to measure the intensity of backscattered light from different directions.



Source images from the four single-pixel detectors. The spatial information in each image is identical; however the apparent illumination source is determined by the location of the relevant detector

From Sun, Edgar et al., "3D Computational Imaging with Single-Pixel Detectors" SCIENCE 340 no. 6134 pp. 844-847 (17 May 2013). Reprinted with permission from AAAS.

Each pixel is used to produce a separate image of the head, but interestingly, each image is spatially identical. In other words, even though the detectors are in different positions, they do not provide different perspectives. Instead, the location of the detectors determines the apparent illumination in each image, and the perspective of the image is set only by the position of the light projector. This means that the detectors are behaving like sources of light, casting shadows differently depending on the geometric features of the scene, whilst the projector acts like a camera. This unusual effect has important practical consequences: current commercially available 3-D imaging technologies require multiple and precisely aligned cameras in different locations, to create a "stereo image". With this technique, 3-D information can be calculated from just one perspective and very simple detectors.



3-D reconstruction of the mannequin head

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