Queen Elizabeth Prize for Engineering

Image Sensor Technology

Three innovations across three decades have revolutionised our visual world: the charge-coupled device (CCD); the pinned photodiode (PPD) and the complementary metal oxide semiconductor (CMOS) image sensor.

Together, this image sensor technology has transformed medical treatments, science, personal communication and entertainment - from Skyping, selfies, computer games and feature length digital movies - to reporting live from wars using the small camera on a smartphone. It saves lives, by using non-surgical pill cameras and endoscopes inside our bodies to diagnose medical problems, as well as helping to reduce X-ray doses to patients and improving dental care.

Image sensors inside cars increase driver safety, enhance security on the streets and expand our knowledge of the Universe through images from the surface of Mars or a comet, from spacecraft in orbit around other planets, and the breathtaking pictures of some of the billions of galaxies surrounding the Milky Way.

The revolution began in the 1970s with the CCD. It was improved in 1980 by the PPD and the invention of the CMOS, in 1992, enabled a “camera on a chip”. This resulted in today’s small cameras that can fit on a fingertip and can be found in billions of portable devices.

Charge-coupled device (CCD)

A CCD is the image sensor found inside early digital cameras and converts light into electricity. When ‘particles’ of light, or photons, are detected on a small light-sensitive area or pixel, it produces an electrical signal. The sensor reads the amount of accumulated charge in every pixel - up to millions on a single array. The charge, proportional to the light’s intensity, is transported across the device and measured at one corner of the array. An analogue-to-digital converter turns each pixel’s measurement into a digital binary form, from volts to bits, and the image is transferred into the camera’s memory as digital data.

The principle underlying the CCD was co-invented by George Smith and Willard Boyle (now deceased) at Bell Laboratories. The original intended use of the concept was solely for computer memory, until British-born Dr Michael Tompsett invented semiconductor imagers. Many years later he invented the key missing component, an integrated analogue-to-digital converter. On seeing its potential application, Tompsett patented the first digital imager while working at Bell Labs in America.

Pinned photodiode (PPD)

A diode is a semiconductor device that allows the flow of current in one direction only, rather like a one-way valve. A photodiode does this when exposed to light and is made of a semiconductor material such as silicon.

Professor Nobukazu Teranishi invented the pinned photodiode, or PPD, for CCD image sensors while at the NEC Corporation, in Japan, in 1980. A PPD is a more efficient photodiode with low noise for better colour and luminance, no image lag and low dark current - the extraneous current generated without light that must be minimised for better image quality. Its improved performance meant that pixel sizes could be reduced, resulting in higher resolution images. The PPD was introduced into CMOS image sensors in the late 1990s and is a crucial part of most CCD and CMOS image sensors.

Complementary metal oxide semiconductor (CMOS) image sensor

Every second of the day, every day of the year, around 50 cameras are made using the second generation technology, the CMOS sensor. Instead of transferring charge to be read at the corner of an array, this second generation image sensor is more flexible as it uses several transistors at each pixel to convert a signal charge into a voltage signal and amplify it.. As a result, although light intensity is lowered, CMOS sensors consume far less power - up to 100 times less - than a CCD.

Working at NASA's Jet Propulsion Laboratory in 1993, Dr Eric Fossum and his team discovered that high energy cosmic particles can ruin an image sensor on a spacecraft, and developed CMOS technology as a solution. CMOS improved the reliability of CCD imagers in space and paved the way for "camera on a chip" miniaturisation, essential for space travel as lowering the size and weight of components reduces spacecraft launch and operation costs.

CMOS chips are cheaper to produce than CCDs so CMOS cameras are usually less expensive and have a longer battery life.