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Innovators behind the Evolution of Modern Cameras: A Quantitative Analysis of Patents on Image Sensors

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This article classifies and analyses the innovations and inventions that were affected in cameras with Charged-Coupled Device (CCD) and Active Pixel Sensors (APS) image sensors. While modern cameras allow greater freedom in image construction and re-construction, it also offers an enlarged scope for creating suitable elemental aesthetics for taking pictures or recording scenes. It has numerous advantages over the cathode ray tube cameras facilitating its use by a large number of people around the world. Modern cameras have evolved in a sustained manner over the years with results that continue to be experienced in novel ways in a range of utility areas. Among its many forms, the smart lenses embedded unobtrusively in state-of-the art smart phones operating in conjunction with the associated software produce quick and highly detailed images that compares only too well with broadcast cameras. A whole host of social media platforms, television broadcasts and online subscription programmes cannot do without the crucial pixel inputs from modern cameras. Insights gained from history and the subsequent inventions, technological progress as well as development and modifications affected in modern cameras over time have added further significance to the area. This article outlines the innovations in the area of modern cameras that has focused on recording of pictures for entertainment and communication by analysing the patenting trends from the year 1984 to 2019.The reason that patenting trends after 2019 have not been considered for analysis owes to the paucity of data chiefly because of the huge dip in technological breakthroughs for image sensor development.

Keywords: APS Sensor, Camera, CCD Sensor, CMOS Sensor, Film, Image Sensors, NMOS Sensor, Patent Analysis, Television, Video Camera

Prior to the introduction of Active-Pixel Sensor (APS) and Charge-Coupled Device (CCD) image sensors, cathode ray tube were used in cameras to scan a scene that is to be captured or recorded. German inventors Max Dieckmann and Rudolf Hell were one of the first few to design a camera with cathode ray tube that could capture a scene. Cathode ray tube used electron emission technique to make a replica of a scene.[1]

The two major image sensors - the Charge-Coupled Device (CCD) and Active-Pixel Sensor (APS) use Metal-Oxide-Semiconductor (MOS) technology. MOS capacitors are the building blocks of CCD. MOSFET (Metal-Oxide Semiconductor Field-Effect Transistor) amplifier constitute the main component in APS. The APS sensors are modified to form CMOS (Complementary Metal–Oxide–Semiconductor) and NCMOS (N-type Metal-Oxide-Semiconductor) used in modern cameras.

Willard S. Boyle and George E. Smith invented the charge-coupled device (CCD) in 1969. In 1959 Mohamed M. Atalla and DawonKahng invented the MOSFET at Nokia Bell Labs in America. They further demonstrated the fabrication process of PMOS (p-type MOS) and NMOS (n-type MOS) in 1960. These processes were used by Chih-Tang Sah and Frank Wanlass at Fairchild Semiconductor to combine and adapt them into the complementary MOS (CMOS) process in 1963. Though the working principle of CMOS was conceived during the 1960s, large scale production and commercialisation was not undertaken until micro-fabrication technologies saw appropriate advancements in the 1990s.[1]

Since 1980s, CCD sensors replaced the cathode ray camera tubes and CCD sensors became a sole companion of digital cameras. The first digital video camera for television broadcasting used CCD circuit to generate image.

The sensors in a modern camera use an array of millions of 'Photosites' to record an image. Photosites are small cavities which serve as an 'electronic eye' which upon exposure to light (with camera's shutter open) collect photons and store them as electrical

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signals. The strength of the electrical signal is measured and quantified as digital values. This principle provides a grey scale recording of an image. To get a colour image, a filter is placed on each cavity. These filters allow particular wavelengths of light to pass through it. The sensors can then capture three primary colours and estimate the rest of the colours to create full colour at every pixel. Nowadays, Lidar sensors are also being used in the Smartphone. This method measures the distances and records an image by illuminating the target with laser light and then quantifying the reflection with a sensor.

The journey of the modern camera and its evolution is mesmerising. The advantages and ever increasing utility of the modern camera has inspired researchers, technicians and engineers to work on bringing about further modifications in its architecture as well as in its operation ability which has profited a great deal by integrating newer image-creation technologies that allows capture of finer details not experienced earlier. However, the journey has been hardly studied in any greater detail. This paper reports the innovations and research that occurred in the field of modern cameras by analysing the patent documents over the period spanning 1984 to 2019. Since the patents obtained after 2019 in CCD and APS image sensor design, development, and commercialisation have seen a steep downward trend mainly because of newer technologies taking over thus making room for the new age sensors, their analysis were better dropped from the purview of the present study.

Methodology

The patents analysed were curated from the patent database- World Intellectual Property Organisation-PATENTSCOPE. The WIPO-PATENTSCOPE database provides patent documents of participating national and regional patent offices.[2]The search was carried out using the keywords as 'CCD sensor camera', 'APS sensor camera', 'CMOS sensor camera', 'MOS sensor camera' and 'digital camera'-which were included in title, abstract, body or a combination of three. A total of 2365 patents were retrieved from the search results with 116 patents curated manually. The curated patents focused on modern cameras with APS and CCD sensors. Bibliographic information such as document number, patent classification, IPC classifications, name and nationality of the applicant and inventor, and the filing and publication date of the patent have been analysed. These inputs were used to compare and qualitatively analyse the patents relevant to the search field.

Innovations over the Years

The drawbacks of cathode ray cameras created space for the invention of CCD and APS cameras. The contours of the journey of CCD sensor cameras were sketched out from the points the modifications affected in cathode ray camera ended. Starting 1990s, cameras based on APS sensors joined the journey.

Figure 1 establishes that throughout 1990 to 2018, companies and researchers have played a major role in bringing about modifications and innovations in modern camera systems. It also indicates the highest number of patents filed between 2005 to 2010. While a drop in the innovation can be noticed from 2011 to 2017, the numbers again registered a rise in the year 2018.

Innovations in CCD and APS sensor Cameras

Nature of Applicants

The total number of patents filed in the area of APS and CCD sensor cameras totalled 116. Among these, 100 patents were filed by companies, 9 were filed by research institutes or universities and 6 patents were filed by individual innovators (Fig. 2). The research institutes/universities included California Institute of Technology (Caltech), University of Electronic

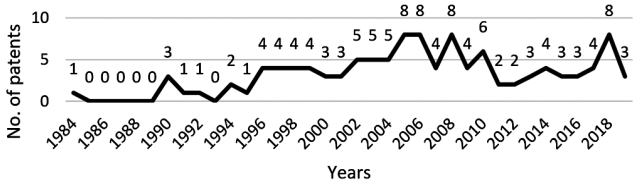

Fig. 1 — Patents filed from 1984 to 2018

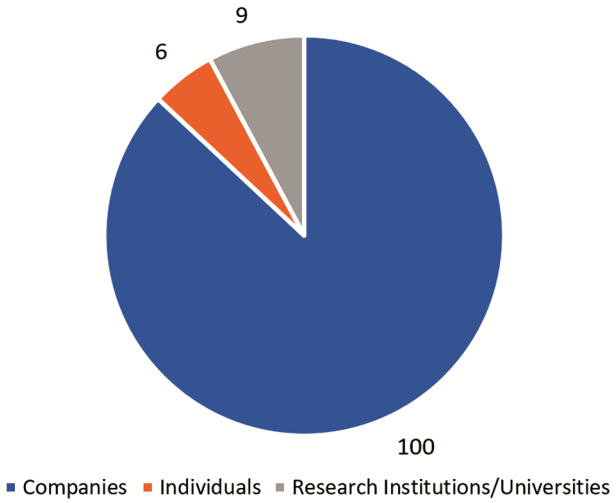

Fig. 2 — Nature of the applicants

Science and Technology of China (UESTC), Xi'an Jiaotong University (XJTU) in China, Hangzhou University of Electronic Science and Technology (now known as Hangzhou Dianzi University or HUD) in China, Kwangwoon University Industry-Academic Collaboration Foundation (Kwangwoon University or KU) of South Korea, Northwest Nuclear Technology Research Institute (NINT) of China, Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Chinese Academy of Sciences (CAS) and Institute of Physical and Chemical Research (RIKEN) of Japan.

Among these institutions and universities, Hangzhou University of Electronic Science and Technology filed two patents. While Lenz Reimar, Desgigot Francois Pierre, Wang Junyi, Cho and Hee Young, Girard, Pierre Pelletier, Jean-Guy Cote, and Chen Sayu applied for one patent each, only Lenz Reimar applied for two patents.

Companies and Patents

Interest of the Companies

The nature of the companies were not limited to optical device manufacturer, electronic companies or technological product manufacturer alone, but were as diverse as surveillance camera manufacturer, tele-robotics company, air conditioner manufacturer, automobile manufacturer, and valve and pipe manufacturer (Fig. 3).

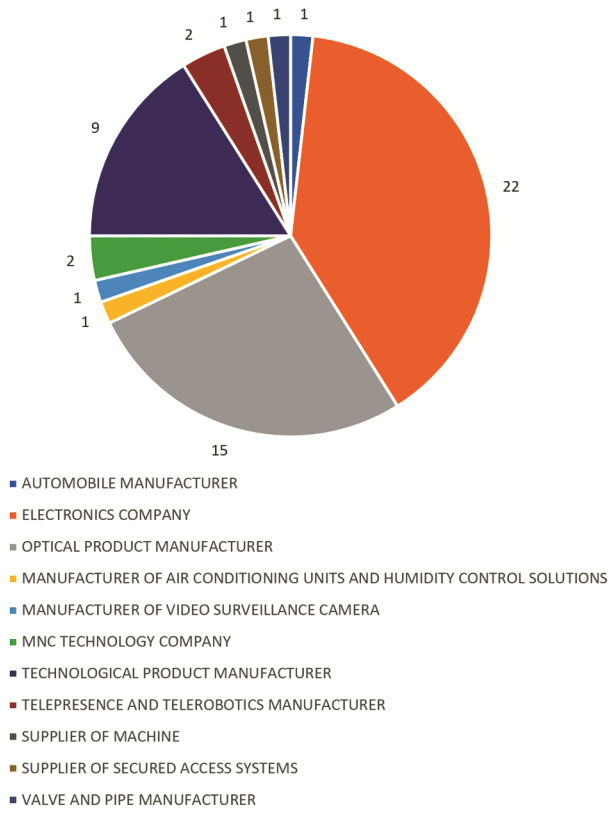

Fig. 3 — Pie chart showing the interest of the companies

Electronics companies were the first in the list in applying for patents. The twenty one electronics company included Panasonic Corporation, Chengdu Shenguoke Semiconductor Co. Ltd., Samsung Electro-Mechanics Co. Ltd., Kunshan Xitai Microelectronics Technology Co. Ltd., Wuxi Brightsky Electronic Co. Ltd., Ningbo Semiconductor International Corporation, Shenzhen Cmy Precision Electronics Co. Ltd., Meizhou Xiuying Ind Co. Ltd., Magnachip Semiconductor Ltd., Seiko Epson Corporation, Guangzhou Xinyi Electronic Technology Co. Ltd., Shanghai Like Semiconductor Technology Co. Ltd., Kocom Co. Ltd., C Pro Electronics Co. Ltd., JiangmenJianghai District Aochuang Electronic Technology Co. Ltd., Sony Corporation, Nec Home Electron Ltd., Ricoh Co Ltd., Terminal Data Corporation, Sanyo Electric Co. Ltd., Hitachi Ltd and Oppo Guangdong Mobile Communication Co. Ltd.

Among these twenty one companies, Panasonic Corporation, Samsung Electronics, Seiko Epson Corporation and Sony Corporation filed more than one patent.This was followed by the optical product manufacturers- Fuji Photo Film Co. Ltd., Canon Inc., Minolta Co. Ltd., Eastman Kodak Corporation, Nikon Corporation, Concord Camera Corporation, General Imaging Corporation, Asia Optical Ltd., Olympus Imaging Corporation, Z/I Imaging GMBH, Shanghai Ruishi Machine Vision Technology Co. Ltd., Fowler Boyd BAE Systems Imaging Solutions Inc., Chongqing TS-Precision Technology Co. Ltd., E-Phocus Incorporated and Truly Opto-Electronics Ltd.

Canon Inc., Fuji Film Co. Ltd., Minolta Co. Ltd., Eastman Kodak Corporation, Olympus Imaging Corporation and Chongqing TS-Precision Technology Co. Ltd. applied for more than one patent.

Technological Product Manufacturers were third in the list. These companies included - Shanghai Huazhang Information Technology Co. Ltd., Kunshan Q Technology Co. Ltd., Guangzhou Melux Information Technology Co. Ltd., CasWeizhi Intelligent Manufacturing Technology Jiangsu Co. Ltd., Beijing Wenxiang Information Technology Co. Ltd., Shenzhen Shidai Technology Co. Ltd., JieJie Technology (Beijing) Co. Ltd., Hangzhou Morui Electromechanical Science & Technology Co. Ltd. and Ichiwa Corporation. Except Ichiwa Corporation located in Japan, all the other companies in this were from

China. Other than these, there were telepresence and tele-robotics manufacturers - Telepresence Systems Limited of UK and VR Interactive Corporation of Canada; multinational technological companies- Google Inc. and Robert Bosch GmbH of Germany; automobile manufacturer, Tokai RiKa Co. Ltd. of Japan; valve and pipe manufacturer FTC: KK located in Japan; supplier of secured access system- Skidata AG of Germany and Hikvision Digital Technology Co. Ltd.- manufacturer of surveillance cameras. Companies from India did not figure in the list.

Filing of patents by companies with diverse interests explains the popularity of modern day cameras. Electrical companies mainly focussed on the modification of digital cameras which are compatible with phones which clearly establishes the popularity of cameras even among common people. This paper focusses exclusively on the patents on modern day cameras that are used to generate pictures for television broadcast or for allied entertainment and communication. The patents filed by surveillance camera manufacturers, automobile manufacturers, tele-robotics companies, air conditioner manufacturers, and valve and pipe manufacturers have in general focussed on modification of cameras that can also be used to modify or update cameras required for production of films/videos. However, the inventions and innovations mentioned in these patents can also be used in their related fields.

Companies with more than One Patent

It is interesting to note a number of companies who took keen interest to engage in innovating for improved image acquisition systems through modern cameras over a limited period of time. Panasonic Corporation led the list with 16 patents. Panasonic (formerly known as Matsushita), a major Japanese multinational electronics company was followed by Canon Inc with 14 patents, a Japanese multinational corporation with specialisation in optical, imaging, and industrial products such as lenses, cameras, medical equipment, scanners, printers, and manufacturing of semiconductors (Fig. 4).

Fuji Photo Film Corporation or Simply Fuji, a Japanese multinational company with business interests in imaging, printing, medical equipment, chemicals as well as biotechnology filed 13 patents. Minolta Co. Ltd. and Eastman Kodak Co. filed 4 patents each. While Eastman Kodak Company of America produced various products related to photography, Minolta was a Japanese manufacturer of

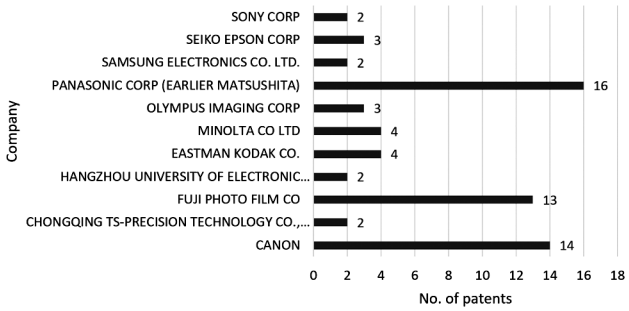

Fig. 4 — Companies who have filed more than one patent

cameras, camera accessories, photocopiers, fax machines, and laser printers which merged with Konica to form Konica Minolta in 2003.

Olympus Imaging Corporation and Seiko Epson Corporation filed 3 patents each. While Olympus Corporation is a Japanese manufacturer of optics and reprography products, Seiko-Epson is a Japanese electronics company specialising in computer printers and imaging related equipment.

The other companies with two patents each were Philips, Matsushita Electric Corporation Limited, JDC Engineering limited, International Business Machines (IBM), Hitachi Limited, Eastman Kodak Corporation, and British Broadcasting Corporation. The other companies with 2 patents each included Sony Corporation, a Japanese multinational conglomerate corporation and one of the world's largest manufacturers of consumer and professional electronic products, Samsung Electronics Co. Ltd., a South Korean multinational conglomerate company and Chongqing TS-Precision technology Co. Ltd., a Chinese company specialisation in mobile phone photography equipment manufacturing. On record also was Hangzhou University of Electronic Science and Technology who filed two patents.

Other than these eleven companies who have filed more than one patent, there were other reputed and globally recognised companies and corporations who filed patents in this field. Some of them were- Concord Camera Corporation, who was a camera manufacturer based in the United States, Nikon Corporation, a Japanese multinational corporation with specialisation in optics and imaging products, Guangdong Oppo Mobile Telecommunications Corp. Ltd., or Oppo, a Chinese consumer electronics and mobile communications company, Google LLC, an American multinational technology company with specialisation in Internet-related services and products, air conditioner manufacturer Fujitsu General Limited of Japan, Z/I Imaging Corporation, a

German company specialising in aerial cameras, Robert Bosch GmbH or Bosch - a German multinational engineering and technology company, NEC Corporation (Nippon Denki Kabushiki-Gaisha), a Japanese multinational information technology and electronics company, Ricoh Ltd., a Japanese multinational imaging and electronics company, Hitachi - a Japanese multinational conglomerate company, SKIDATA GmbH - an Austrian company with business interests in access systems in vehicles, Tokai Rika - a Japanese Company which manufactures electronic parts for automobiles, and the Chinese company, Hangzhou Hikvision Digital Technology Co. Limited, a supplier of video surveillance equipment. Most of the companies mentioned in the previous two segments were based in Japan and China.

Countries' Interest in Cathode Ray Camera System

Among the 116 patents, Japan filed the most number of patents in the field of APS and CCD sensor cameras with a total of 58 patents. This was followed by China with 30 patents. The USA filed 10 patents, Korea filed 7 patents, Germany filed 5 patents and Canada filed 2 patents. Australia, France and the UK published one patent each (Fig. 5).

Patent Trends with respect to IPC (International Patent Classification)

The IPC or the International Patent Classification is a hierarchical patent classification system. A patent classification is a system which is used by examiners of patent offices and applicants to categorise documents according to the technical features of their content. IPC codes are designated by letters and numbers. Patent classifications makes it easy to search for patent documents and it is used to track technological trends in patent applications.

From Fig. 6, it can be seen that the curated patents had mentions of IPC codes –while 'B' is related to performing operations and transportation, 'G' encompasses Physics and 'H' covers electricity. The maximum number of patent documents mentioned the code H, followed by G and B.

The first three maximum number of IPC subcategory included H04 (basic electric elements) with 113 mentions, followed by G03 (photography; cinematography; analogous techniques using waves other than optical waves; electrography; holography) with 44 mentions and GO2 (computing; calculating or counting) with 17 mentions.

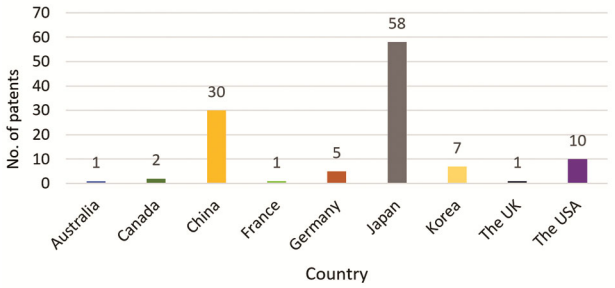

Fig. 5 — Number of patents published by different countries

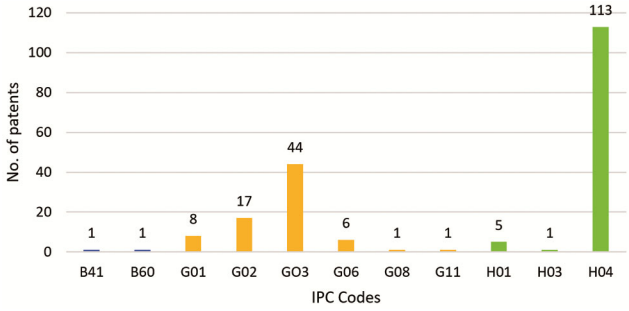

Fig. 6 — Number of different IPC codes included in different patents

The other IPC codes mentioned were- B41 (printing; lining machines; typewriters; stamps), B60 (vehicles in general), G08 (signalling), G11 (information storage) and H03 (basic electronic circuitry) with one mention each. G01 (measuring; testing) got 8 mentions, G06 (computing, calculating and counting) got 6 mentions and H01 (basic electric elements) got 5 mentions.

Conclusion

The importance of patent is all encompassing, ranging from safeguarding one's invention, increasing the reputation of companies, researchers or countries to making it legally available for commercial use. Patenting products costs huge amount of money and resources, but the profit and benefits are huge as well.[3-5] Patent doesn't allow copying a product or idea and therefore limits the competition in a commercialised market by legally assisting and supporting those with innovative and creative minds. The multi-faceted benefits of patent had inspired the world's big think tanks to apply for patents and develop their own unique products.[6-8]

The expectation of gaining a critical insight into the dynamics of patent applications have regularly emerged from 'patent documents'. Patent documents are made available through different databases. There are some which are free of cost while some others hide

behind a paywall. There are some patent documents which come with periods of embargo. WIPO-PATENTSCOPE is one such database that discloses patent documents without paying incentives. The trusted organisations classifies the patent documents and presents the information in a standard format with relatively simple search facilities. However, the task of mining relevant data has never been as easy as it is purported to be, especially because the available information in the databases are stupendously huge. Choosing the right keywords to extract the documents also requires a special skill in these instances.[9,10,5]

The growing need of regular technological innovations in imaging devices and sensors has brought researchers, engineers, technicians and companies increasingly together to engage in innovating a product every now and then that suits the contemporary electronic image-creation ecosystem. Looking the future in its 'electronic eye' calls for a fuller appreciation of specific tech-information contained in the previously innovated products and discrete devices besides a strategic plan to bring them to the fore for larger public good. Patent documents have proved as the most dependable source to obtain clearly laid out and valid information on a subject of interest. Analysing and reporting the result on a particular patent, therefore, have gained additional importance since it makes the task of researchers a lot easier by allowing them to focus on a specific aspect of research and innovation, rather than rummaging through its history.[11-17]

Since one of the foremost objectives of this study has been to highlight the innovations in the field of modern cameras by individuals, institutions and companies across the world, this study, therefore, analysed a focused area of the patent documents in the field of CCD and APS sensor cameras which may provide a useful insight and prove as an asset to quantify the information.

Further qualitative study in this field can be undertaken with an aim to identify indicators of future directions that would lay out a possible path for attempting breakthrough innovations in the applied sciences of more modern electronic image creation. Technological innovations and its resultant effect on the evolution of film production and post-production could also be a future study consideration since studies in this rather unexplored area are crying for scholarly attention.

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