Investigating Technology and Patent Portfolio of Lens-Less Cameras in the Context of Industry 4.0

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Abstract. Industry 4.0 (I 4.0) is a sum total of technologies such as Cyber Physical Systems (CPS), Internet of Things (IoT), cloud computing and big data analytics combined to achieve a near zero defect state (Cheng et al., 2016). IoT, as one of the core components in I 4.0, is a key enabling framework. The objective of this paper is to investigate one of the visual sensor technology which is gaining prominence for application in IoT, called lens-less camera. A Lens-less camera overcomes weight and minimum size issues that exist in a conventional camera and can be fabricated (or printed) like a microchip, which leads to a huge reduction in production cost. An ultra-low power, cost, and size imaging sensor will have wide applications in IoT and can be deployed in mission critical areas where too much visual detailing is not required and the traditional imaging devices cannot serve efficiently. This paper investigates and summarizes the core technology, leading stakeholders, and intellectual property (IP) portfolio for lens-less cameras. The objective of this paper is to generate interest for the lens-less camera, as one of the latest perception level invention, understand its current technology life cycle, and reveal the future market potentials.

Keywords: Industry 4.0; Industrial Internet of Things (IoT); Lens-less camera; Image sensor, IP analysis.

1. INTRODUCTION

Industry 4.0 deals with the inclusion of Cyber Physical Systems (CPS) and can be seen as an incremental jump from Industry 3.0 where the differentiating trait is the inclusion of micro intelligence. IoT is a key enabler to achieve such intelligence and is a structured way of connecting real-world devices to the Internet as a ubiquitous network that enables objects to connect, collect and exchange information. IoT empowers objects with the ability to sense its surroundings and get computation using analytics, so they can work accurately, learn and optimize while performing their jobs. Architecturally IoT can be seen as consisting of 4 main layers a similar layering structure was previously used by china mobile in telecommunication context.

1.1. IoT Layers

IoT layers as shown in figure 1, starts with the base layer the Perception layer which deals with the types of sensors and actuators that help the physical object to perceive (Sense) its surroundings. Broadly speech, vision, hearing, smell, and touch are the basic form of perceptions which are achieved by sensors that measure temperature, humidity, pressure, magnetic, acceleration etc. The next step after perception (collection of sensor information) is to transmit the information to layers that can convert this perception into applied intelligence. On top of this layer is computation layer describes various elements such as protocols and algorithms to receive data, processing data, making decisions and delivering the decisions to the next layer which is application layer. The computation layer consists of elements including hardware, software, Integrated Development Environment (IDE), algorithms, cloud computing, Big Data analysis and security. The top most layer is the application which provides tactical understanding to the end user who can be classified as either being a consumer (IoT2C) or business (IoT2B) (Elgendy and Elragal, 2014).

This article is centered on one of the perception layer level inventions called lens-less camera with the purpose of bringing into light a latest trend in the area of image sensing both from technological and patent landscape point of views that can find application in areas like manufacturing such as robotic vision, product validation and testing, additive manufacturing and predictive maintenance in the very near future.

2. PERCEPTION LEVEL INVENTION – LENS-LESS FLAT CAMERA

Ever since the invention of the digital camera there has been a megapixel race, the last few years, in particular, have seen a huge increase in camera resolution. We have seen everything from 41-megapixel camera phones to now 50.6 megapixel full-frame DSLR cameras (Mansurov, 2015) it also seems that we will reach the theoretical maximum soon. However, with the advent of Internet of Things (IoT) there is a need for a low cost and power mission-critical imaging technology that can empower devices with the power of sight (vision).

2.1 Review of camera-based imaging.

Imaging, which is at least 150 years old area of science, relies on a basic component called lens to create an image and for recording photons such as an array of pixels, a light-sensitive film or even a retina (MIT Technology Review, 2016). The current age of camera technologies focuses on the digital camera. The widely used sensors in digital imaging are charge-coupled devices (CCD) which have one amplifier for all the pixels and complementary metal–oxide–semiconductor (CMOS) where each pixel has its own amplifier. However, the commonality in all of these sensors is the need for a component called a lens. Scientists and engineers have now built sensors that can make an image without a lens. This concept is called Lens-less camera. Imaging without a lens is not a new idea, pin-hole cameras have been capturing images for a long time. A lens-less camera is an improvement over the concept of a pin-hole camera.

2.2 Discussion on Lens-less cameras.

A lens-less camera is an ultra-low power, cost, and size imaging device that can be deployed in mission critical areas where too much detailing is not required and places where conventional imaging devices cannot serve efficiently. In simplest terms, a lens-less camera can give objects vision similar to bee eye view which is blurry and hazy from a human perspective but is enough for a bee to live its daily life effectively comparable to the concept of mission criticality (Davies, 2015). A lens-less camera is perfect for embedding in smart objects of the future.

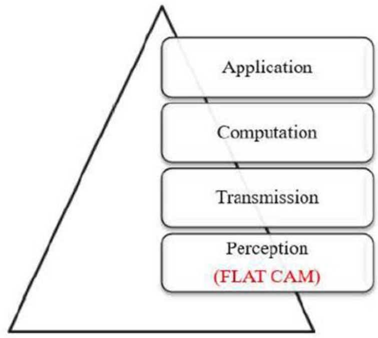

Figure 1. Lens-Less Camera placement in IoT eco-system.

In a lens-based camera the amount of detail captured is too high and combined with the need for post-fabrication assembly to integrate lens they end up being costly, also the idea of miniaturizing the lenses only works to a certain point because the smaller a lens gets, the more difficult it is to make their precise curved surfaces because miniaturization reduces the amount of light collected by the sensor as the lens aperture and the sensor size becomes small (Asif et al., 2015). Consequently, ultra-miniature imagers that scale down the optics and sensors suffer from low light collection. Lens-Less cameras do away with these issues in a camera and is thin and flexible enough for applications that were harder to achieve with traditional imaging devices. Lens-less cameras are now under prototyping, construction and testing in imaging laboratories around the world and a private company, Rambus Inc., has also started production of lens-less camera this year. Lens-less camera assembled by Rice University and produced by Rambus Inc. is shown in Figure 2.

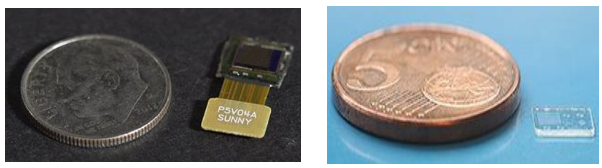

Figure 2. Flat camera produced by (a) Rice University & (b) Rambus, Inc.

Image samples captured by lens-less cameras can be seen in figure 3.

Figure 3. Rice University's Lens-less camera images.

2.3 Technological and feature comparison.

The main technological difference in a lens-less camera is that a single sensor and an array of apertures is used to capture an image rather than a lens, so an image of a scene can be captured using fewer measurements than conventional lens-based cameras. Also in the conventional system a lens is used to project an image onto photographic film or an array of charge-coupled devices while a lens-less camera in principle uses a single point like sensor to record the intensity of light that has passed through an array of tiny apertures (mask) placed between the object and the sensor (Cartlidge, 2013). A mask records each pixel as a linear combination of light from multiple scene elements. A computational algorithm is then used to de-multiplex the recorded measurements and construct an image of the scene. So the resultant image is created in time instead of space using a fraction of the measurements needed when compared to normal digital cameras.

A detailed feature comparison is presented in the comparative study given by (Asif et al., 2015) key points of which is summarized in the table1.

Table 1. Comparative analysis

	Lens-based	Pin Hole	Lens-less
Thickness	10-20mm	10-20mm	10-500nm
Post-Fabrication	Yes	Yes	No
Cost	High	Medium	low
Flexibility	Low	Low	High
Image Quality	High	Medium	low

While a conventional lens-based camera, in general, follows a three-component approach namely lens, sensor, processing and software to generate an image output. The lens-less camera uses only two. A comparative process flow chart is also summarized from the points in this paper which are shown below.

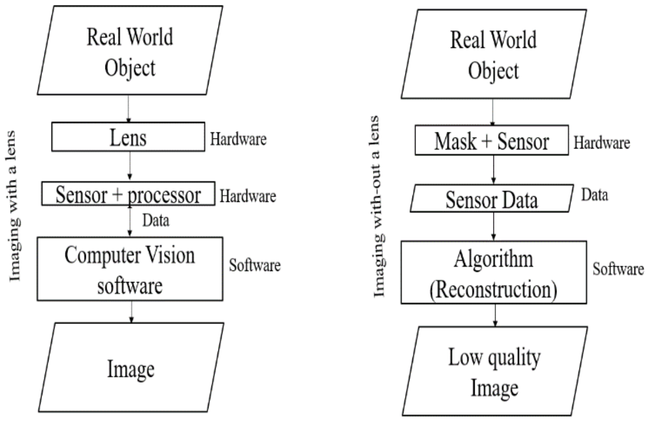

Figure 4. Lens v/s Lens-less camera working mechanism.

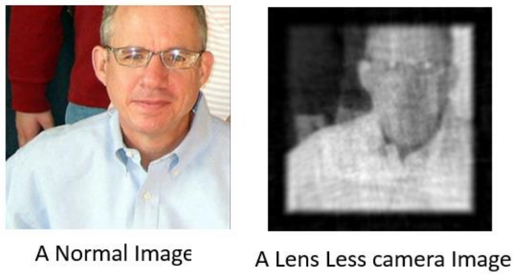

Figure 5. Normal camera image compared with lens-less camera.

2.3 Algorithm to convert sensor data to image.

The base principle of a lens-less camera is the replacement of the lens with a mask which is placed close to the sensor array summarized in Figure 4. The sensor array captures the modulated light, then this sensor data is sent to the algorithm where the image is reconstructed based on the sensor measurements. There are algorithms proposed and explored to achieve this conversion and with time and as computing power advances, people will come up with many different kinds of algorithms to achieve this conversion in better and efficient ways (Davies, 2015) Research papers reviewed show algorithmic explorations in this area majorly are Less Square Method (Asif et al., 2015) where the method of algorithm works based on two techniques, first one is separable mask patterns, later using the least square method and Compressive Sensing algorithm (Huang et al., 2013) .

3. LENS-LESS CAMERA INTELLECTUAL PROPERTY LANDSCAPE

In this analysis, we organize patent portfolios using the Thomson Innovation (TI) patent search system. The patents are searched from January 1st, 2006 to June 31st, 2016 and search scope includes patents in the US, Europe, China, Japan, Korea, France and WIPO (World Intellectual Property Organization). The flowchart below represents the search and dataset refinement strategy to extract IP data that is used to statistically analyze and generate inferences presented further.

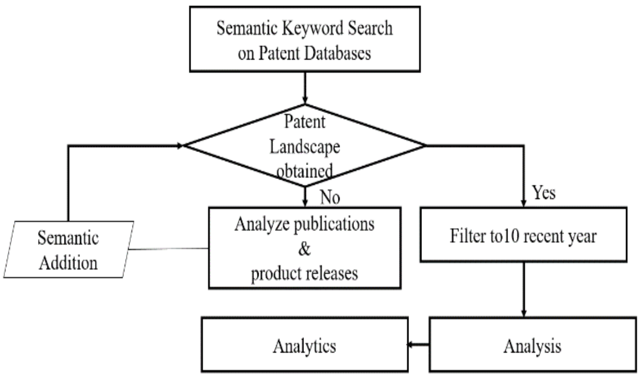

Figure 6. Patent search Strategy

Using the above strategy the below query is finalized for the patent data extraction from the patent database base platform Thomson Innovation. Analytics is performed on the extraction and graph is represented below.

CTB=(lensless ADJ camera) OR SSTO=("lensless camera") AND PA=(Rambus) OR PA=(Rice ADJ UNI) OR PA=(Bell ADJ lab) AND DP>=(20060101) AND DP<=(20160601);

Figure 7. Computed Search Query

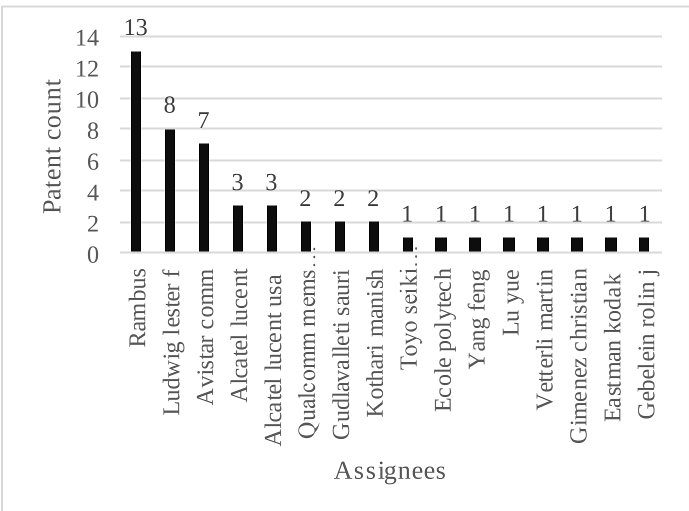

Figure 8. Top assignees ranking

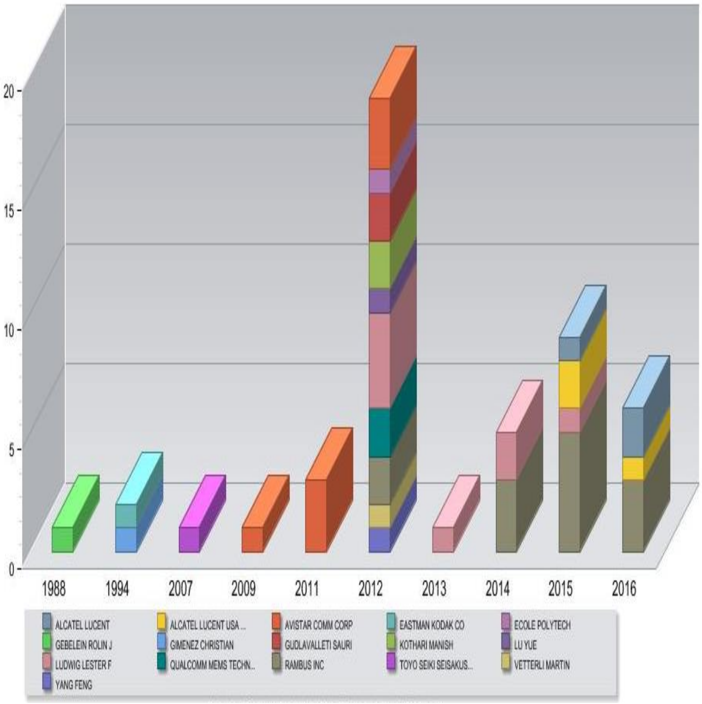

Figure 9. Patent count

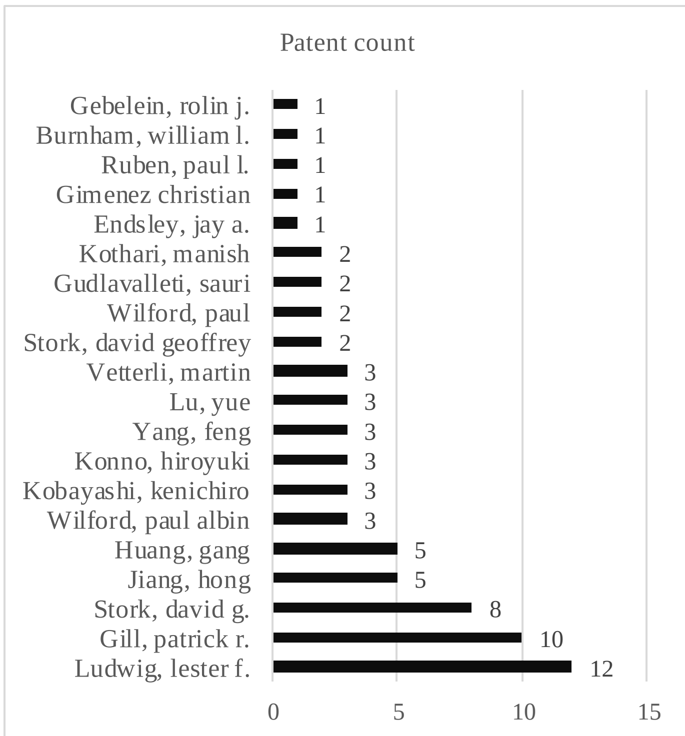

Figure 10. Top Researchers

Table 2. Technology Function Matrix (TFM)

Classification	Technology	Patent count
Hardware	Sensing	9
	Imaging	2
	Controller	2
	Processing	2
Software	Compressive Sensing	5
	Numerical Image Formation	2
	Large Photo-sensor Imaging	2
Application	Pattern Detection	7
	Surveillance	1
	Viewfinder	1
	Multimedia conferencing	2
	Lens Correction	1
	Integrated Display	1
	Touch Sensor	1

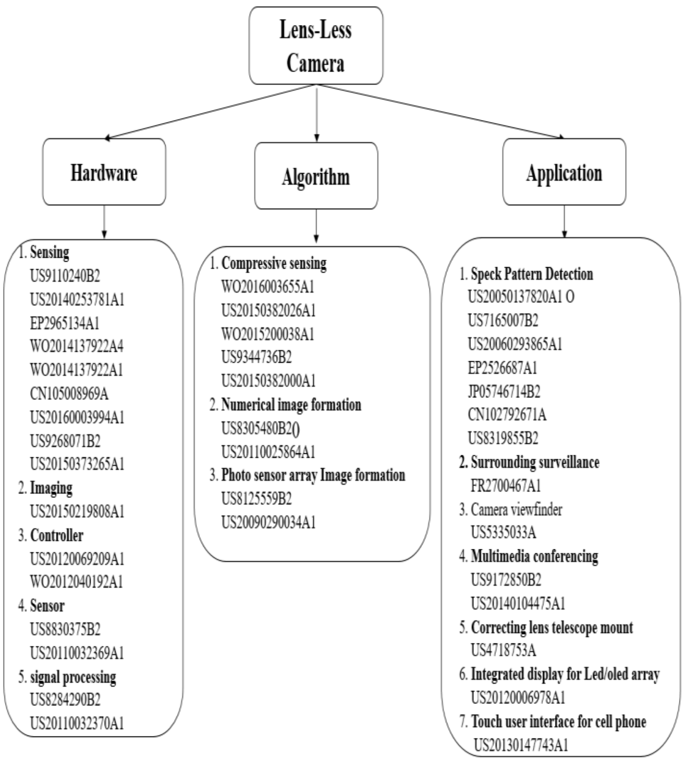

Figure 11. IPC Classification map

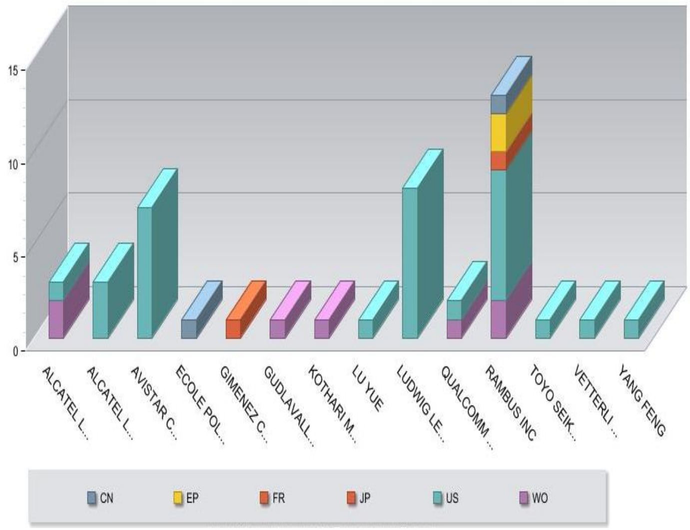

Figure 12. Company's v/s Countries patent holding

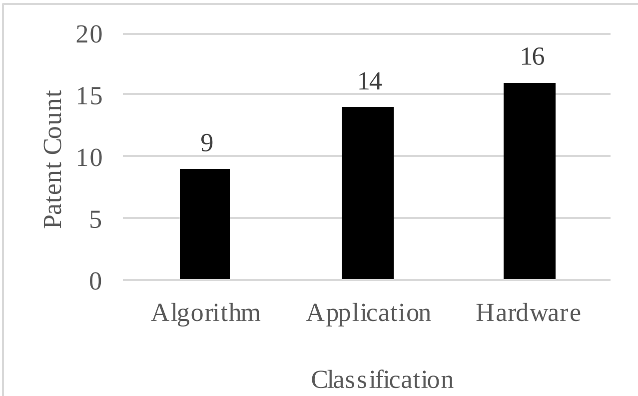

Figure 13. Patent Distribution in category

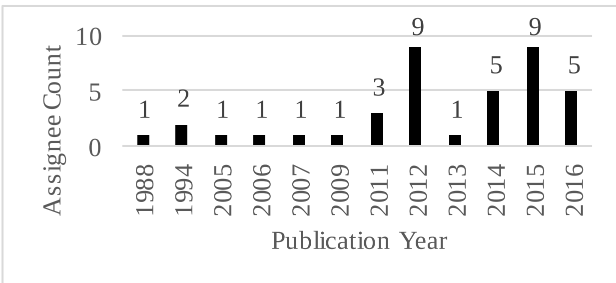

Figure 14. Count of Assignee - Original by Publication Year

Figure 8 to 14 shows quantitative analysis to represent IP landscape for the Lens-less camera technology obtained by the refinement in search query shown in figure 7. Figure 8 shows the top assignees to represent stakeholders for the technology against the number of patents they hold. Figure 9 is a further extension of figure 8 and shows the stakeholders and their IP filling on a year wise timeline order. Figure 10 is a graphical representation of top researchers who have been responsible for a patent generation for the stakeholder companies. Figure 11 shows the patent classification map for the sake of simplicity and understanding our research classifies patent data for the lens-less camera technology to fall under 3 categories namely hardware, software, and algorithm, this kind of classification is useful to view the patent clustering. The figure also shows that companies tend to file similar patents with minor modifications or customization in different countries where there might be a future market. Figure 12 shows companies patent holding for the technology in different countries. Figure 13 places the no of patents in the earlier classified 3 categories. Figure 14 is patent assignee count against year.

Table 2 is a qualitative analysis of patent data mining results using which a Technology Function Matrix (TFM) is constructed. A TFM gives specific function level visualization of activities happening in the patenting domain.

4. INDUSTRY 4.0 CONSIDERATION

Industry 4.0 while considered a luxury initially, is now a necessity given the constantly changing industry dynamics. Manufacturing is constantly under pressure because of the growing consumer demand, raising labor cost and the shortening product life cycle. Companies today are deploying Cyber Physical Systems to reduce cost, increase precision and productivity for the products they manufacture. It is an understood fact that CPS end implementation in higher levels is only as efficient as the quality and quantity of information collection and sensing in lower layers. The Lens-less camera is a promising imaging area invention and given the low cost, power and processing required to operate this imaging technology it can be deployed in areas where conventional camera embedding may be expensive in terms of process, power, and processing needed. To meet advanced manufacturing needs such as real-time dynamic product testing, embedding in robotics arms to visualize features and conduct predictive maintenance which is a set of activities that detect changes in the physical condition of equipment (signs of failure) in order to carry out the appropriate maintenance work for maximizing the service life of equipment without increasing the risk of failure (Wang, 2016).

5. CONCLUSION

The vertical movement from invention to innovation is by the application. Currently Lens-less camera technology is in an invention phase and it can be seen from the IP landscape analysis presented in the paper that this technology is showing promising growth in terms of IP volume (almost doubling up every year) also Moore’s law guarantees us that this technology will get better with time because of the predictable increase in computing power. Further, we can see there is the absence of Industrial intellectual property footprint. Companies can use this technology review and patent portfolio research to further explore lens-less camera CPS implications, collaborate with key players involved using the concept of patent pooling and enjoy first movement advantage in manufacturing application.

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Appendix A. Lens-Less Camera Key Patents Classification.

Table A1. Lens-less camera hardware related patents

Publication Number	Title	Purpose
US9110240B2 US20140253781A1 EP2965134A1 WO2014137922A4 WO2014137922A1 CN105008969A US20160003994A1 US9268071B2 US20150373265A1	Phase gratings with odd symmetry for high-resolution lensed and lensless optical sensing	Lens-less Sensing

US20150219808A1	Patchwork Fresnel Zone Plates For Lensless Imaging	Lens-less Imaging(ZONE PLATES)
US20120069209A1 WO2012040192A1	Lensless Camera Controlled Via Mems Array	Controller (MEMS)
US8830375B2 US20110032369A1	Vignetted optoelectronic array for use in synthetic image formation via signal processing, lensless cameras, and integrated camera-displays	Imaging Sensor (Optical-electronic array for image formation)
US8284290B2 US20110032370A1	Synthetic image formation signal processing hardware for vignetted optoelectronic arrays, lensless cameras, and integrated camera-displays	Image formation signal processing hardware

Table A2. Lens-less camera software (systems, algorithms, etc) related patents

Publication Number	Title	Purpose
WO2016003655A1 US20150382026A1 WO2015200038A1 US9344736B2 US20150382000A1	Compressive sense imaging system has processing device for determining intermediate compressive measurements and generating compressive measurements representing compressed image of object using intermediate compressive measurements	Compressive sensing
US8305480B2 US20110025864A1	Synthetic image formation via signal processing for vignetted optoelectronic arrays, lensless cameras, and integrated camera-displays	Numerical image formation algorithm.
US8125559B2 US20090290034A1	Image formation for large photosensor array surfaces	Image formation for large photosensor array surfaces

Table A3. Lens-less camera application patents

Publication Number	Title	Purpose
US20050137820A1 US7165007B2 US20060293865A1 EP2526687A1 JP05746714B2 CN102792671A US8319855B2	Direct granular speck pattern image pickup method for use during displacement measurement of object e.g. integrated circuit wafer, involves using shielding tube for shielding extraneous light rays in front of line sensor	Speck Pattern Detection
FR2700467A1	Lensless camera and tactile plate for surrounding surveillance uses tubes carrying photodetectors assembled into plates for adjusting angle and direction of view using optical fibre	surrounding surveillance
US5335033A	Improved camera viewfinder without refracting optical elements, which is small in size so that it can be accommodated within the body of modern compact cameras and yet provides accurate framing of the picture both at the center and the outer limits of the field of view.	Lensless camera viewfinder
US9172850B2 US20140104475A1	Lensless imaging camera performing image formation in software employing micro-optic elements creating overlap of light from distant sources over multiple photosensor elements.	Multimedia conferencing device
US4718753A	Telescope with correcting lens	Automatic correcting lens mounted on telescope
US20120006978A1	LED/OLED array approach to integrated display, lensless-camera, and touch-screen user interface devices and associated processors	Led/oled array approach to integrated display, lensless-camera.
US20130147743A1	Spherical Touch Sensors and Signal/Power Architectures for Trackballs, Globes, Displays, and Other Applications	System for implementing touch-based user interface integrated into cell phone