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Element, system having the element, and judging apparatus

Abstract

An element includes a plurality of light-receiving elements to photoelectrically convert light received from an object, a convolution processing unit to perform convolution operation on signals that are output from the plurality of light-receiving elements, and a pooling processing unit to sample a signal that is output from the convolution processing unit, based on a predetermined condition. The convolution operation of the convolution processing unit and the sampling of the pooling processing unit are repeated.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS (1) This a continuation application of U.S. patent application Ser. No. 17/125,415, filed on Dec. 17, 2020, which is a continuation application of U.S. patent application Ser. No. 16/145,875, filed on Sep. 28, 2018, which is a continuation of International Patent Application No. PCT/JP2016/060574, filed on Mar. 30, 2016. U.S. patent application Ser. Nos. 17/125,415 and 16/145,875, and International Patent Application No. PCT/JP2016/060574 are incorporated herein by reference in their entireties.

BACKGROUND

(1) The present invention relates to a feature extracting element, a feature extracting system, and a judging apparatus.

(2) There are some methods for accelerating feature extraction processing by performing it per each of blocks which are obtained by dividing an image into blocks (refer to Patent Document 1, for example). Patent Document 1: Japanese Patent Application Publication No. 2008-148298

(3) Since the feature extraction is performed by processing data that is captured as an image, it takes much time for processing for generating the image, processing for transferring the generated image and the like, and thus the feature extraction processing has not been regarded accelerated enough.

SUMMARY

(4) The first aspect of the present invention provides a feature extracting element including: a light-receiving substrate where a plurality of light-receiving elements for photoelectrically converting received light are two-dimensionally arrayed; and one or more other substrates that are laminated on the light-receiving substrate, wherein the other substrate has: a convolution processing unit which has a plurality of multiplying circuits that are correspondingly provided per the light-receiving element or per a block that is configured of a plurality of the light-receiving elements, and performs convolution operation on signals that are output from the plurality of light-receiving

elements using the plurality of multiplying circuits; a pooling processing unit to sample a signal that is output from the convolution processing unit, based on a predetermined condition; and a connection wiring to pass the sampled signal to the plurality of multiplying circuits.

- (5) The second aspect of the present invention provides a feature extracting system including: the feature extracting element described above; and a controlling unit to control such that convolution operation of the convolution processing unit and sampling of the pooling processing unit are repeated, wherein the controlling unit controls, when the convolution operation is repeated, the convolution processing unit such that predetermined filter coefficients are respectively used.
- (6) The third aspect of the present invention provides a judging apparatus including: the feature extracting element described above; and a judging unit to judge an image-capturing target by feature quantity that is extracted based on an output from the pooling processing unit.
- (7) The summary clause does not necessarily describe all necessary features of the embodiments of the present invention. The present invention may also be a sub-combination of the features described above.
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Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 is a schematic cross-sectional view of a feature extracting apparatus **100**.
- (2) FIG. 2 is a flow chart of processing to be performed in the feature extracting apparatus **100**.
- (3) FIG. 3 is a schematic cross-sectional view of the feature extracting apparatus **100**.
- (4) FIG. 4 is a schematic cross-sectional view of the feature extracting apparatus **100**.
- (5) FIG. 5 is a timing chart of the feature extracting apparatus **100**.
- (6) FIG. 6 is a block diagram of an imaging device **500**.
- (7) FIG. 7 is a schematic cross-sectional view of another feature extracting apparatus **101**.
- (8) FIG. 8 is a schematic cross-sectional view of the feature extracting apparatus **101**.
- (9) FIG. 9 is a partial timing chart of the feature extracting apparatus **101**.

DETAILED DESCRIPTION

- (10) Hereinafter, (some) embodiment(s) of the present invention will be described. The embodiment(s) do(es) not limit the invention according to the claims, and all the combinations of the features described in the embodiment(s) are not necessarily essential to means provided by aspects of the invention.
- (11) FIG. 1 is a schematic cross-sectional view of the feature extracting apparatus **100**. The feature extracting apparatus **100** is a single element including: microlenses **110**, a pixel substrate **120**, an AD conversion circuit substrate **130**, a multiplying circuit substrate **140**, an adding circuit substrate **150**, a convolution operation result adding substrate **160**, an activation function calculating circuit substrate **170**, a pooling circuit substrate **180**, and a coupling circuit substrate **190**, which are laminated sequentially.
- (12) Note that the feature extracting apparatus **100** extracts feature quantity to use for judging an object from received an object luminous flux. The judging an object includes, for an example, identifying what the object is, identifying what category the object falls in, and judging what degree the object is in (e.g. sunset degree, etc.), but not limited to these. The feature quantity extracted here corresponds to features extracted by multi-layer neural networks that are referred to as deep learning. In other words, the feature extracting apparatus **100** can be used for learning processing to extract features by deep learning.
- (13) The substrates in the feature extracting apparatus **100** each have wiring layers **12** respectively which are formed on base substrates **11** by photolithography. Each wiring layer **12** includes circuits that are configured of wirings, elements, etc. That is, a pixel substrate **120**, an AD conversion circuit substrate **130**, a multiplying circuit substrate **140**, an adding circuit substrate **150**, a

convolution operation result adding substrate **160**, an activation function calculating circuit substrate **170**, a pooling circuit substrate **180**, a coupling circuit substrate **190** have pixels **121**, AD conversion circuits **131**, multiplying circuits **141**, an adding circuit **151**, latch B-added adding circuits **161**, an activation function calculating circuit **171**, a pooling circuit **181**, a coupling circuit **191**, respectively.

(14) Also, the substrates described above are electrically connected to other substrates that are laminated adjacent to each other via through-electrodes **13** penetrating each base substrate **11**. Furthermore, a part of the substrates are electrically connected directly to substrates that are not adjacent to the substrates by through-electrodes **14** that are formed penetrating a plurality of substrates. The detail of this will be described referring to FIG. **3** and FIG. **4**.

(15) In the feature extracting apparatus **100**, the pixel substrate **120** has a plurality of pixels **121** that are arranged two-dimensionally and periodically. Each pixel **121** has a light-receiving element such as a photodiode for photoelectrically converting entered light. Note that, in this example shown in the figure, the pixel substrate **120** is of backside irradiation-type, where the entering light is received from the base substrate side, by removing or making thin a substrate having been a base when the pixels **121** are formed.

(16) Also, the pixel substrate **120** may have, in its respective light-receiving elements, transistors to instruct reset, transfer, and selection, and elements to amplify output signals. The microlenses **110** that are laminated on the pixel substrate **120** improve incident efficiency by condensing the entering light into the respective pixels **121**.

(17) The AD conversion circuit substrate **130** has a plurality of AD conversion circuits **131**, latches **132**, and change-over switches **133** which correspond to the respective pixels **121** of the pixel substrate **120**. Thereby, the AD conversion circuit substrate **130** outputs, to the other substrates, either a value obtained by discretizing respective pixel values acquired from the pixels **121** of the pixel substrate **120** or a value held by the latch **132**. The AD conversion circuits **131**, the latches **132**, and the change-over switches **133** operate upon a timing when receiving a timing trigger **210** received from outside.

(18) The multiplying circuit substrate **140** has multiplying circuits **141** that correspond to the respective pixels **121** of the pixel substrate **120**. In other words, the multiplying circuit substrate **140** has the same number of multiplying circuits **141** as that of pixels **121** provided in the pixel substrate **120**. The multiplying circuit **141** is a digital multiplier, and may be configured of shift registers, for example. The multiplying circuit **141** acquires, from outside, a filter coefficient for performing the multiplication processing to be held.

(19) In other words, the multiplying circuit **141** can perform different multiplication processing according to values of the filter coefficient read out from outside. FIG. **1** shows a case where a filter coefficient a is acquired, as an example. The multiplying circuits **141** in the multiplying circuit substrate **140** also operate upon the timing when receiving a timing trigger **210** received from outside.

(20) Note that the multiplying circuit substrate **140** may have one of the multiplying circuits **141** per block that is configured of the plurality of pixels **121** of the pixel substrate **120**. For example, if four pixels of the pixel **121** adjacent to each other in two-dimensional direction are regarded as one block, the multiplying circuit substrate **140** may have one multiplying circuit **141** that is connected to any of the four pixels **121** in the block. In this case, the multiplying circuit **141** performs multiplication processing sequentially upon an output from the respective four pixels **121** in the block.

(21) The adding circuit **151** of the adding circuit substrate **150** sums up values acquired from the plurality of multiplying circuits **141** in the multiplying circuit substrate **140** and outputs the resultant value. The output of the adding circuit **151** can be output to the convolution operation result adding substrate **160** therebelow in the figure. The adding circuit **151** in the adding circuit substrate **150** operates upon the timing when receiving a timing trigger **210** received from outside.

- (22) The convolution operation result adding substrate **160** has latch B-added adding circuits **161**, latches A **162**, and multiplexers **163**. The latch B-added adding circuits **161**, the latches A **162**, and the multiplexers **163** are connected to each other, and also, through the through-electrodes **13**, the latch B-added adding circuits **161** are connected to the activation function calculating circuit substrate **170** whereas the multiplexers **163** are connected to the adding circuit substrate **150**. The convolution operation result adding substrate **160** sums up a plurality of signals that are output from the adding circuit substrate **150**, and then outputs the resultant to the activation function calculating circuit substrate **170**.
- (23) The activation function calculating circuit substrate **170** has a corresponding number of activation function calculating circuit **171** to the number of the adding circuits **151** of the adding circuit substrate **150**. The activation function calculating circuit substrate **170** performs, upon receiving an output of the adding circuit substrate **150**, activation function operation, and then outputs the resultant to the pooling circuit substrate **180**. The activation function calculating circuit **171** in the activation function calculating circuit substrate **170** operates upon the timing when receiving a timing trigger **210** received from outside.
- (24) The pooling circuit **181** of the pooling circuit substrate **180** and the coupling circuit **191** of the coupling circuit substrate **190** sequentially perform processing on the input from the previous step. The output value of the coupling circuit **191** in the coupling circuit substrate **190** can be output, as the feature quantity, to outside of the feature extracting apparatus **100**. The pooling circuit **181** and the coupling circuit **191** also operate upon the timing when receiving a timing trigger **210** received from outside.
- (25) Note that, in the feature extracting apparatus **100** described above, the pixels **121**, the AD conversion circuits **131**, the latches **132**, the change-over switches **133**, the multiplying circuits **141**, the adding circuit **151**, the latch B-added adding circuits **161**, the activation function calculating circuit **171**, the pooling circuit **181**, the coupling circuit **191**, and the like are each controlled in their operation timing by a controlling unit not shown by the supplied timing trigger **210**. This controlling unit may be included in the feature extracting apparatus **100**, or a controlling unit of another apparatus including the feature extracting apparatus **100** therein, e.g. an imaging device, may be also used for this controlling unit. The feature extracting apparatus **100** that is a single element and the controlling unit configure a feature extracting system.
- (26) As described above, the feature extracting apparatus **100** has a structure where the multiplying circuit substrate **140**, the adding circuit substrate **150**, the convolution operation result adding substrate **160**, the activation function calculating circuit substrate **170**, the pooling circuit substrate **180**, and the coupling circuit substrate **190** that are involved with feature extraction processing of images, are laminated on the pixel substrate **120** including the light-receiving element. Thereby, the feature extraction can be performed by directly processing pixel values, and thus the processing time can be shorten, thanks to elimination of processing for turning an image into data to be stored and processing for transferring the stored image data.
- (27) Also, hardware resources such as storage apparatuses, transfer apparatuses for image data can be eliminated, which contributes to miniaturization of a device including the feature extracting apparatus **100**. Furthermore, processing substrates are laminated corresponding to the pixels of the pixel substrate **120**, and thus the processing speed is prevented from decreasing while the number of pixels of the pixel substrate **120** increases.
- (28) Note that the feature extracting apparatus **100** described above receives entering light by the plurality of pixels **121** arrayed two-dimensionally, and thus can acquire, from the pixel substrate **120**, two-dimensional luminance distribution information that is used for generating of the image data. Accordingly, the feature extracting apparatus **100** can be used as an image sensor.
- (29) FIG. 2 is a flow chart of feature extraction processing to be performed in the feature extracting apparatus **100**. As shown in the figure, in the feature extraction processing on a pixel value generated by pixel value generation processing **S101** convolution processing **S102**, activation

function calculation processing **S103**, pooling processing **S104**, and coupling processing **S105** are performed, and the extracted feature quantity is output to outside (step **S106**).

(30) Here, in the feature extraction processing corresponding to deep learning, the pixel value generation processing **S101** and the feature quantity output **S106** are each performed once per one feature extraction. However, reading out filter function in convolution processing **S102**, the multiplication processing, and the adding processing are repeatedly performed many times repeatedly, with the filter coefficients to read out changing. Furthermore, the processing results of the activation function calculation processing **S103** and the pooling processing **S104** after the convolution processing are served again to the convolution processing **S102**, and processings from the convolution processing **S102** to the pooling processing **S104** are repeated more. Note that, in some cases, only the activation function calculation processing **S103** is repeated, or the convolution processing **S102** and the activation function calculation processing **S103** are repeated; and in other cases, after the pixel value generation processing **S101**, the pooling processing **S104** is performed, omitting either one or both of the convolution processing **S102** and the activation function calculation processing **S103**.

(31) FIG. 3 is a view illustrating operations in the feature extracting apparatus **100** shown in FIG.

1. In the feature extracting apparatus **100** shown in the figure, a function of the through-electrodes **13** connecting the substrates adjacent to each other is indicated emphasized with a hatched bold line.

(32) As indicated with the bold line in the figure, in the feature extracting apparatus **100**, the pixel **1**, the pixel **2** and the pixel **3** in the pixel substrate **120** are each connected to the corresponding AD conversion circuits **131** in the AD conversion circuit substrate **130**, and to the corresponding multiplying circuits **141** in the multiplying circuit substrate **140** via the change-over switches **133**.

(33) On the other hand, the multiplying circuit substrate **140** acquires respective filter coefficients a, b, c of the multiplying circuits **141** corresponding to the pixels **1** to **3**, respectively. The pixel value output by the pixel **1** in the pixel substrate **120** is, after multiplied using the filter coefficient a by the multiplying circuit **141** corresponding to the pixel **1** in the multiplying circuit substrate **140**, input to the adding circuit substrate **150** through the through-electrode **13**.

(34) Similarly, the pixel value output by the pixel **2** in the pixel substrate **120** is, after multiplied using the filter coefficient b by the multiplying circuit **141** corresponding to the pixel **2** in the multiplying circuit substrate **140**, input to the adding circuit substrate **150** through the through-electrode **13**. Furthermore, the pixel value output by the pixel **3** in the pixel substrate **120** is, after multiplied using the filter coefficient c by the multiplying circuit **141** corresponding to the pixel **3** in the multiplying circuit substrate **140**, input to the adding circuit substrate **150** through the through-electrode **13**.

(35) The adding circuit **151** in the adding circuit substrate **150** sums up the plurality of multiplied results that are input, and outputs the resultant to the convolution operation result adding substrate **160**. In this manner, processing similar to filtering such as smoothing is performed. However, by filter coefficients in the multiplying circuits **141** being predetermined by pre-learning, the series of processings are performed as convolution processing.

(36) The latches A **162** in the convolution operation result adding substrate **160** hold signals output from the adding circuit **151** via the multiplexers **163**. Thereafter, upon multiplied by the multiplying circuits **141** with the filter coefficients set differently from the last time and the multiplied results are summed up in the adding circuit **151**, the latch B-added adding circuits **161** hold the adding processing result of the adding circuit **151** via the multiplexers **163**.

(37) The latch B-added adding circuits **161** read out the last adding processing results that are held in the latches A **162** to add to new adding processing results, and the added results are again held by the latches A **162**. By repeating this processing predetermined prescribed times, a plurality of processing results obtained by performing convolution operation on the pixels in the same group (the pixels **1** to **3**) with different filter coefficients can be summed up. In other words, this

corresponds to the repeated convolution processing **S102** shown in FIG. 2. Such convolution operation is performed on all the pixels in the pixel substrate **120**, that is, on the whole input image. (38) In the feature extracting apparatus **100**, the processing result by the convolution operation result adding substrate **160** is input to the activation function calculating circuit **171** of the activation function calculating circuit substrate **170** through the through-electrode **13**. The activation function calculating circuit **171** converts information that is passed from the convolution processing to the pooling processing. Such functions include, for example, a ReL U (Rectified Linear Unit) function as shown in Equation 1 below, where input values smaller than 0 are all turned into 0 whereas input values greater than 0 are returned as they are. $f(x)=\max(0,x) \dots$

(Equation 1)

(39) The output of the activation function calculating circuit **171** is passed to the pooling circuit **181** of the pooling circuit substrate **180** through the through-electrode **13**. In the pooling circuit **181**, subsampling is performed based on predetermined conditions. The conditions for the subsampling performed here include a condition, e.g. in Max Pooling method, where the maximum value at a window size is taken as a representative value.

(40) Regarding the predetermined conditions, as long as the processing gathers a plurality of outputs from the activation function calculating circuit **171**, the processing may be Average Pooling method to output the average value, or the like. In this manner, the processings from the convolution processing (step **S102**), the activation function calculation processing (step **S103**), to the pooling processing (step **S104**) are performed, and the subsampled value that is generated from the pixel values is generated.

(41) FIG. 4 is a view illustrating other operations in the feature extracting apparatus **100** shown in FIG. 1. In the feature extracting apparatus **100** shown in the figure, the through-electrode involved with operations described next is indicated emphasized with a hatched bold line.

(42) As indicated with the bold line in the figure, in the feature extracting apparatus **100**, signals can be transmitted and received also between substrates that are not adjacent to each other. Accordingly, for example, the output of the pooling circuit substrate **180** can be stored, through the through-electrode **14**, in the latches **132** of the AD conversion circuit substrate **130** to be multiplied again in the multiplying circuits **141**. Thereby, the convolution processing is again performed on the subsampled values. Such repeating convolution processing is performed predetermined times, e.g. 2000 times or above, with the filter coefficients a, b, c changing.

(43) Furthermore, the signals processed up to the predetermined times among the AD conversion circuit substrate **130**, the multiplying circuit substrate **140**, the adding circuit substrate **150**, the convolution operation result adding substrate **160**, the activation function calculating circuit substrate **170**, and the pooling circuit substrate **180**, are turned into one-dimensional by the coupling circuit **191** in the coupling circuit substrate **190**. Thereby, a value indicating certain feature quantity of the image for each component.

(44) FIG. 5 is a timing chart illustrating operations in the feature extracting apparatus **100**. The pulses in the figure represent signals that are supplied to respective substrates as the timing triggers **210**.

(45) As shown in FIG. 5, each circuit in the feature extracting apparatus **100** is supplied with the timing trigger **210** sequentially from the uppermost layer in FIG. 1. Also, the multiplying circuit substrate **140** has the multiplying circuits **141** corresponding to the respective pixels **121**, and thus, in the feature extracting apparatus **100**, the processings performed in the order shown in FIG. 2 can be performed on the respective pixel values. Thereby, feature quantity of high judging accuracy can be extracted efficiently.

(46) Note that a section P represents a section where the convolution processing **S102** is repeated. A region surrounded by a dotted line A represents a section where convolution operation is performed with the same-sized filter on a group of pixels that configured of a plurality of pixels (e.g. 3×3 pixels). Furthermore, a region surrounded by a dotted line B represents a section where convolution

operation is performed with other filters on the pixels in the same group.

(47) Also, a section Q represents a section where the processings from the convolution processing **S102** to the pooling processing **S104** are repeated. Note that, in reality, in the operation result adding processing in the convolution processing **S102**, timing triggers of the latches A or the latch B-added adding circuits are supplied every time signals from the adding circuit are input, but, to simplify the description, a timing trigger of the final adding processing is only shown.

(48) Note that processing load of the coupling processing in the coupling circuit **191** is smaller than that of the processings in the other substrates. Accordingly, the coupling circuit substrate **190** for the coupling circuit **191** may not be provided in the feature extracting apparatus **100**. In this case, the feature extracting apparatus **100** outputs, to outside, signals that are repeated up to predetermined times and eventually pooling-processed in the pooling circuit **181**. Then, the coupling processing is performed in an external substrate.

(49) FIG. **6** is a block diagram of an imaging device **500** that includes the feature extracting apparatus **100**. The imaging device **500** includes a feature extracting apparatus **100**, a system control unit **501**, a driving unit **502**, a photometry unit **503**, a work memory **504**, a recording unit **505**, a display unit **506**, and a main power supply **507**.

(50) Also, the imaging device **500** includes a main optical system **520** that leads an object luminous flux to the feature extracting apparatus **100**. The main optical system **520** may be exchangeable so as to be attachable and detachable to the imaging device **500**.

(51) The main optical system **520** is configured of a plurality of groups of optical lenses, and images, near its focal plane, an object luminous flux from the object field. Note that, in the figure, the main optical system **520** is expressed by a single virtual representative lens arranged near the pupil.

(52) The driving unit **502** is a control circuit to perform electrical charge accumulation control such as timing control, region control or the like of the feature extracting apparatus **100** according to instructions from the system control unit **501**. The driving unit **502** performs, for example, a series of controls to make the feature extracting apparatus **100** accumulate electrical charge generated by photoelectrically converting the entering light to output the pixel value. Also, the driving unit **502** supplies the timing trigger **210** to the feature extracting apparatus **100**.

(53) Feature quantity of the object output from the feature extracting apparatus **100** is passed to the judging unit **513** of the system control unit **501**. Thereby, in the system control unit **501**, judging processing to judge an object is performed. Note that the feature extracting apparatus **100** may transmit, from the pixel substrate **120** to the image processing unit **511** of the system control unit **501**, information including a luminance distribution of the object to generate an image data of the object. The image processing unit **511** performs processing with the work memory **504** as a workspace.

(54) The photometry unit **503** detects a luminance distribution of the object, prior to a series of sequences to generate pixel values, by feature extracting apparatus **100** photoelectrically converting the entering light. The photometry unit **503** includes an AE sensor of about one million pixels, for example. The calculating unit **512** of the system control unit **501** calculates, upon receiving an output of the photometry unit **503**, the luminance per region of a scene.

(55) Furthermore, the calculating unit **512** determines the shutter speed, diaphragm value, ISO speed according to the calculated luminance distribution. The photometry unit **503** may be also used in common in the feature extracting apparatus **100**. Note that the calculating unit **512** performs various types of necessary operations for making the imaging device **500** operate.

(56) In such manner, the imaging device **500** has a judging function to judge an object by the feature quantity acquired from the feature extracting apparatus **100**. Here, the feature extracting apparatus **100**, in itself, transmits the extracted feature quantity to the system control unit **501**. Accordingly, the system control unit **501** can acquire the feature quantity without taking load of the feature quantity extraction processing to judge the object. Also, the system control unit **501**

receives feature quantity as the extraction result, and thus increase in the communication quantity between the feature extracting apparatus **100** and the system control unit **501** is prevented.

(57) FIG. **7** is a schematic cross-sectional view of another feature extracting apparatus **101**. The feature extracting apparatus **101** has the same structure as that of the feature extracting apparatus **100** shown in FIG. **1**, excluding the part described next. The common elements are given the same reference numerals, and overlapping descriptions thereof will be omitted.

(58) The feature extracting apparatus **101** has a different structure from that of the feature extracting apparatus **100** in a point that a plurality of multiplying circuit substrates **1400**, **1401**, **1402**, . . . , **140n** are included between the AD conversion circuit substrate **130** and the adding circuit substrate **150**. The plurality of multiplying circuit substrates **1400**, **1401**, **1402**, . . . , **140n**, like the multiplying circuit substrate **1400** of the feature extracting apparatus **100**, has a plurality of multiplying circuits **141** corresponding to the respective plurality of pixels **121** of the pixel substrate **120**, and operates upon the timing when receiving a timing trigger **210** received from outside.

(59) The multiplying circuit **141** acquires, from outside, filter coefficients for performing the multiplication processing to be held. Also, the multiplying circuit **141** can hold filter coefficients whose values are different for respective substrates and perform multiplication processing. Accordingly, the multiplying circuit substrates **1400** to **140n** can perform multiplication processing under conditions different from each other.

(60) FIG. **8** is a schematic cross-sectional view illustrating operations in the feature extracting apparatus **101**. As indicated with hatched bold lines in the figure, a pixel value output by the pixel **1** in the pixel substrate **120** is, after multiplied by the multiplying circuit **141** formed in the multiplying circuit substrate **1400** in the upper part in the figure, input to the adding circuit substrate **150** through the through-electrode **13**. Also, a pixel value output by the pixel **2** in the pixel substrate **120** is, after multiplied by the multiplying circuit **141** formed in the multiplying circuit substrate **1401** in the upper part in the figure, input to the adding circuit substrate **150** through the through-electrode **13**. Furthermore, a pixel value output by the pixel **3** in the pixel substrate **120** is, after multiplied by the multiplying circuit **141** formed in the multiplying circuit substrate **1402** in the upper part in the figure, input to the adding circuit substrate **150** through the through-electrode **13**.

(61) Note that respective filter coefficients **a1** of the plurality of multiplying circuits **141** provided in the multiplying circuit substrate **1400** take the same value among the multiplying circuits **141** provided in the same multiplying circuit substrate **1400**. Similarly, in the other multiplying circuit substrates **1401**, **1402**, . . . , **140n**, a plurality of multiplying circuits **141** in each substrate has common filter coefficients **b1**, **c1**, . . . , **n1**. Accordingly, if performing the convolution processing, the filter coefficients **a1**, **b1**, **c1**, . . . , **n1** can be selected by selecting substrates to perform the multiplication processing. In other words, in the example shown in FIG. **8**, a pixel value output by the pixel **1** is multiplied by the filter coefficient **a1**, a pixel value output by the pixel **2** is multiplied by the filter coefficient **b1**, and a pixel value output by the pixel **3** is multiplied by the filter coefficient **c1**.

(62) FIG. **9** is a partial timing chart of the feature extracting apparatus **101**. In the feature extracting apparatus **101**, pixels **121** are multiplied by different multiplying circuit substrates **1400** to **140n**, respectively. Accordingly, after acquiring all the filter coefficients first, the multiplication processing that is performed many times in the convolution processing equivalent to one single filtering for a group of pixels can be performed in parallel and simultaneously, and sequentially as indicated with dotted lines A and B in the figure.

(63) Accordingly, there is no need to acquire and set the filter coefficients every time when performing the multiplication processing, leading to shorter time to acquire and set the filter coefficients, and thus throughput of the feature extracting apparatus **101** as a whole can be improved. Such feature extracting apparatus **101** can be used, for example, as an image sensor with

a feature extraction function by incorporating the feature extracting apparatus **101** into the imaging device **500** as an alternative to the feature extracting apparatus **100**.

(64) The feature extracting apparatus described in the present embodiment has the multiplying circuit **141**, the adding circuit **151**, the activation function calculating circuit **171**, the pooling circuit **181**, and the coupling circuit **191** arranged respectively in the multiplying circuit substrate **140**, the adding circuit substrate **150**, the activation function calculating circuit substrate **170**, the pooling circuit substrate **180**, and the coupling circuit substrate **190**. However, the feature extracting apparatus may not necessarily have only one single circuit for one single substrate provided. In other words, one single substrate may have a plurality of circuits arranged therein, or one single circuit may be arranged over a plurality of substrates.

(65) Also, the lamination order of the plurality of substrates in the feature extracting apparatus is not limited to the example described above, as long as they can be arranged using through-electrodes. Furthermore, the convolution operation result adding substrate **160** is not limited to the example described above, as long as it is configured to add a plurality of values to be held.

(66) Also, the feature extracting apparatus described in the present embodiment enables, with a single sensor of a laminated structure, feature extraction using convolution neural networks to perform the convolution processing in multi-layer neural networks. Note that, by using the same value for the filter coefficient of the convolution processing that is performed a plurality of times, it is also possible to achieve recursive convolution neural networks. Note that methods are not limited to these, as long as feature extraction can be performed by the feature extracting apparatus in the present embodiment.

(67) While the embodiments of the present invention have been described, the technical scope of the invention is not limited to the above described embodiments. It is apparent to persons skilled in the art that various alterations and improvements can be added to the above-described embodiments. It is also apparent from the scope of the claims that the embodiments added with such alterations or improvements can be included in the technical scope of the invention.

(68) The operations, procedures, steps, and stages of each process performed by an apparatus, system, program, and method shown in the claims, embodiments, or diagrams can be performed in any order as long as the order is not indicated by “prior to,” “before,” or the like and as long as the output from a previous process is not used in a later process. Even if the process flow is described using phrases such as “first” or “next” in the claims, embodiments, or diagrams, it does not necessarily mean that the process must be performed in this order.

Claims

1. A semiconductor element comprising: a first semiconductor layer including a first photoelectric converting unit for converting light into electrical charge, a second photoelectric converting unit for converting light into electrical charge and provided at a position in a first direction from the first photoelectric converting unit, a third photoelectric converting unit for converting light into electrical charge and provided at a position in a second direction intersecting the first direction from the first photoelectric converting unit; a second semiconductor layer laminated on the first semiconductor layer and including a first converting unit for converting a signal on the basis of the electrical charge converted by the first photoelectric converting unit into a first signal having a digital value, a second converting unit for converting a signal on the basis of the electrical charge converted by the second photoelectric converting unit into a second signal having a digital value, and a third converting unit for converting a signal on the basis of the electrical charge converted by the third photoelectric converting unit into a third signal having a digital value; a third semiconductor layer laminated on the first semiconductor layer and including a first multiplying circuit for performing a multiplication processing on the first signal, a second multiplying circuit for performing a multiplication processing on the second signal, and a third multiplying circuit for

- performing a multiplication processing on the third signal; and a fourth semiconductor layer laminated on the first semiconductor layer and including an adding circuit for performing an adding processing by using at least two data among data acquired by the first multiplying circuit, data acquired by the second multiplying circuit, and data acquired by the third multiplying circuit.
2. The semiconductor element according to claim 1, wherein the adding circuit performs the adding processing by using the data acquired by the first multiplying circuit, the data acquired by the second multiplying circuit, and the data acquired by the third multiplying circuit.
 3. The semiconductor element according to claim 1, further comprising: a wiring layer provided between the first semiconductor layer and the second semiconductor layer in a laminate direction in which the first semiconductor layer and the second semiconductor layer are laminated, the wiring layer including a first wire electrically connected to the first converting unit and to which the signal on the basis of the electrical charge converted by the first photoelectric converting unit is output, a second wire electrically connected to the second converting unit and to which the signal on the basis of the electrical charge converted by the second photoelectric converting unit is output, and a third wire electrically connected to the third converting unit and to which the signal on the basis of the electrical charge converted by the third photoelectric converting unit is output.
 4. The semiconductor element according to claim 3, wherein the second semiconductor layer is provided between the first semiconductor layer and the fourth semiconductor layer in the laminate direction.
 5. The semiconductor element according to claim 4, wherein the third semiconductor layer is provided between the second semiconductor layer and the fourth semiconductor layer in the laminate direction.
 6. The semiconductor element according to claim 1, wherein the second semiconductor layer is provided between the first semiconductor layer and the fourth semiconductor layer in the laminate direction.
 7. The semiconductor element according to claim 6, wherein the third semiconductor layer is provided between the second semiconductor layer and the fourth semiconductor layer in the laminate direction.
 8. The semiconductor element according to claim 1, further comprising: a pooling processing unit for performing a pooling processing on data acquired by the adding circuit.
 9. The semiconductor element according to claim 8, further comprising: a fifth semiconductor layer laminated on the first semiconductor layer and including the pooling processing unit.
 10. The semiconductor element according to claim 9, wherein the second semiconductor layer is provided between the first semiconductor layer and the fifth semiconductor layer in a laminate direction in which the first semiconductor layer and the second semiconductor layer are laminated.
 11. A semiconductor element according to claim 10, wherein the third semiconductor layer is provided between the second semiconductor layer and the fifth semiconductor layer in the laminate direction.
 12. A semiconductor element according to claim 11, wherein the fourth semiconductor layer is provided between the third semiconductor layer and the fifth semiconductor layer in the laminate direction.
 13. A semiconductor element according to claim 1, wherein the first semiconductor layer includes a fourth photoelectric converting unit for converting light into electrical charge and provided between the first photoelectric converting unit and the second photoelectric converting unit in the first direction: and the first converting unit converts a signal on the basis of the electrical charge converted by the fourth photoelectric converting unit into a fourth signal having a digital value.
 14. A semiconductor element according to claim 13, wherein the fourth photoelectric converting unit is provided adjacent to the first photoelectric converting unit in the first direction.
 15. A semiconductor element according to claim 13, wherein the first multiplying circuit performs a multiplication processing using the fourth signal.

16. A semiconductor element according to claim 13, wherein the first semiconductor layer include a fifth photoelectric converting unit for converting light into electrical charge and provided between the first photoelectric converting unit and the third photoelectric converting unit in the second direction; and the first converting unit converts a signal on the basis of the electrical charge converted by the fifth photoelectric converting unit into a fifth signal having a digital value.
 17. A semiconductor element according to claim 16, wherein the fourth photoelectric converting unit is provided adjacent to the first photoelectric converting unit in the first direction; and the fifth photoelectric converting unit is provided adjacent to the first photoelectric converting unit in the second direction.
 18. A semiconductor element according to claim 16, wherein the first multiplying circuit performs a multiplication processing on the fourth signal and the fifth signal.
 19. A semiconductor element according to claim 1, wherein the first semiconductor layer includes a fourth photoelectric converting unit for converting light into electrical charge and provided between the first photoelectric converting unit and the third photoelectric converting unit in the second direction; and the first converting unit converts a signal on the basis of the electrical charge converted by the fourth photoelectric converting unit into a fourth signal having a digital value.
 20. A semiconductor element according to claim 19, wherein the fourth photoelectric converting unit is provided adjacent to the first photoelectric converting unit in the second direction.
 21. A semiconductor element according to claim 19, wherein the first multiplying circuit performs a multiplication processing on the fourth signal.
 22. A semiconductor element according to claim 1, wherein the second photoelectric converting unit is provided adjacent to the first photoelectric converting unit in the first direction.
 23. A semiconductor element according to claim 22, wherein the third photoelectric converting unit is provided adjacent to the first photoelectric converting unit in the second direction.
 24. A semiconductor element according to claim 1, wherein the third photoelectric converting unit is provided adjacent to the first photoelectric converting unit in the second direction.
 25. A semiconductor apparatus comprising the semiconductor element according to claim 1.
 26. An imaging device comprising: the semiconductor element according to claim 20; and a detection unit electrically connected to the semiconductor element and configured to detect an object based on an output signal from the semiconductor element.
 27. An imaging device comprising: the semiconductor element according to claim 1; and an optical system for emitting light to the semiconductor element.
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