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GRID-EYE STATE OF THE ART THERMAL IMAGING SOLUTION

WHITE PAPER VERSION 1.0

SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

MARCH 2016

WHITE PAPER VERSION 1.0

INDEX

Introduction IR sensors 3
Photon detecors 3
Thermal detectors 4
Temperature measurement by thermopiles 6
What is Grid-EYE? 8
Application areas 9
- Inanimate objects 10
- Humans 11
- Design of the human detection 12
- Applications for smart buildings 13
- Fall detectors 15

Conclusion 16

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GRID-EYE STATE OF THE ART THERMAL IMAGING SOLUTION

SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

INTRODUCTION IR SENSORS

Recently, the progress of uncooled infrared (IR) sensors has been remarkable due to microelectronic systems (MEMS)-based pixel structure, in which free standing thermal isolation structures are adopted with thin film IR absorbers. Many applications are being developed, such as thermography, human detection, night vision and so on. Quantification of this energy allows users to determine the temperature and thermal behaviour of objects.

Infrared thermal sensing and imaging instruments make it possible to measure and map surface temperature and thermal distribution passively and no intrusively. Infrared radiation is emitted by all objects with a temperature above absolute zero. For an object that has "no colour", which means, no wavelength is selectively emitted or absorbed, the radiation spectrum is completely determined by the temperature alone. With rising temperature, the intensity at every wavelength of the radiation spectrum increases as well. This means that one can remotely determine the temperature of a body or object by measuring its radiated power. Infrared (IR) detectors fall into two main categories, thermal and photon:

PHOTON DETECTORS

In this class of detectors the radiation is absorbed within the material by interaction with electrons. The observed electrical output signal results from the changed electronic energy distribution. The photon detectors show a selective wavelength dependence of the response per unit incident radiation power. They exhibit both perfect signal-to-noise performance and a very fast response. But to achieve this, the photon detectors require cryogenic cooling. Cooling requirements are the main obstacle to the more widespread use of IR systems based on semiconductor photodetectors making them bulky, heavy, expensive and inconvenient to use.

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THERMAL DETECTORS

For a long time the high cost issue posed severe constrains on the development of IR systems for the consumer market. Thermal infrared detectors are distinguished by the advantages of a wide wavelength response, no requirement for cooling, high-temperature stability, high signal-to-noise ratio and low cost. Consequently, they are widely used in consumer products and in instrumentation. In a thermal detector the incident radiation is absorbed to change temperature of the material, and the resultant change in some physical properties is used to generate an electrical output. Thermal sensors are differentiated between pyroelectric and thermopiles:

Pyroelectric Sensors

Here the heat radiation collected by the pyroelectrical material generates a static voltage signal across the crystalline material. Under constant illumination, however, the signal declines which makes a periodical refresh necessary. This is usually achieved by a mechanical chopper in front of the detector. Pyroelectric detectors are applicable for mass production. They have slowly found yet their way into the consumer market through applications in burglar alarm systems and automatic light switches. Here the detector senses the IR radiation from approaching persons. In this case no chopper is needed, because an optics focuses the radiation from the moving persons alternatively onto two detector crystals with opposite polarity. This generates a difference signal, which drives a switch or an alarm. Pyroelectric detectors are distinguished by a much higher (20-40 dB) responsivity and also a higher specific detectivity. Special care must be taken for the microphonic effect. It could be reduced by a special chip mounting to a certain degree but it does not completely disappear. Pyroelectric detectors are used in high performance gas analyzers, flame detection devices and scientific instrumentation. On the other hand for static temperature measurements one still needs a relatively expensive setup which includes mechanical parts.

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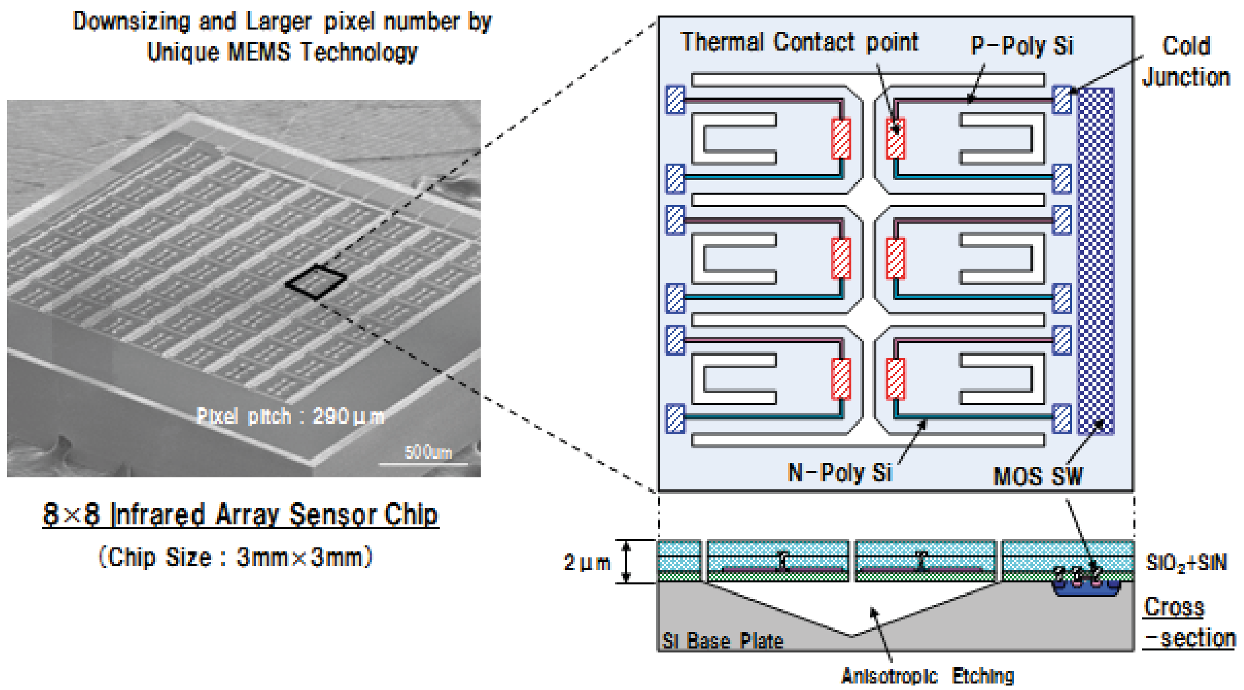
SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

Thermopile Sensors

Thomas Johann Seebeck discovered the thermoelectric effect named after him in the second decade of the 19th century. The Seebeck effect describes the electric current in a closed circuit composed of two dissimilar materials when their junctions are maintained at different temperratures. This phenomenon is applied extensively to temperature measurement by wire thermocouples. The thermopiles or thermocolumn comprises a series of thermoelements, each element being a thin wire made of two materials of different thermal activity. When a temperature difference occurs between the two ends of a wire, an electrical tension (thermotension) develops. The hot junctions are concentrated on a very thin common absorbing area, while the cold junctions are located on a surrounding heat sink with high thermal mass. These devices are prepared preferably by micromachining since the early 90s. The sketch of a MEMS thermopile is shown in Figure 1.

FIGURE 1

MEMS Technology of Grid-EYE



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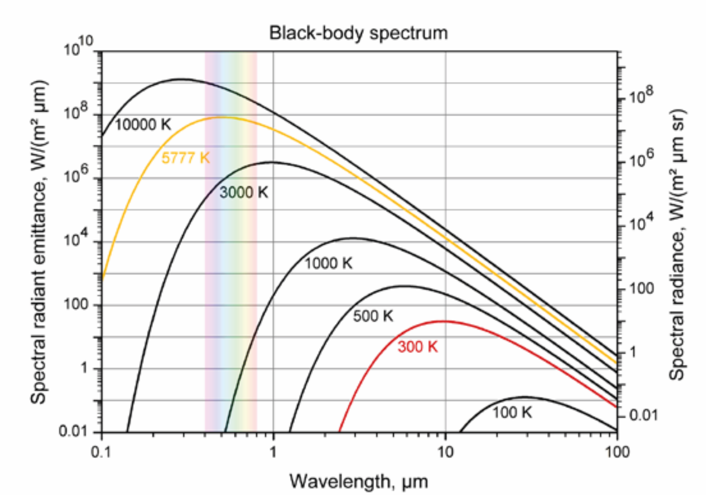
SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

Modern semiconductor technology makes it possible to produce thermopile sensors consisting of hundreds of thermocouples on an area of several square millimetres. Such a sensor is extremely sensitive, shows a very fast response time and due to its smallness, and it is additionally inexpensive because of the employment of semiconductor mass production means and of photolithography. Recent advances in the production of thermopiles include introduction of silicon (Si) micromachining technology. Unlike the classical thermoelectric sensor materials – bismuth (Bi) and antimony (Sb) – silicon based devices offer compatibility with standard semiconductor integrated-circuit (IC) fabrication processes and consequent cost-effective volume production.

TEMPERATURE MEASUREMENT BY THERMOPILES

As mentioned before, a thermopile sensor can be an instrument to remotely measure the temperature of objects and people. For this purpose one needs to think in terms of heat flow and not so much in terms of temperature when considering the use of a thermopile sensor in an application. Heat can be defined as thermal energy in transition. If we see an object with a certain temperature one should immediately remember that it sends out heat flow of a determined spectral characteristics and density. It flows from one place or object to another as a result of temperature difference, and the flow of heat changes the energy levels in the objects. Temperature is a property of matter and not a measurement of internal energy. The amount of radiative power per wavelength, which is sent out by unit area into the surroundings is given by the curves in Figure 2.

FIGURE 2



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SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

It now depends on the area and the view field of the sensor how much will be absorbed. The absorbed heat then, will be led through the thermocouples and the membrane structure, finally reaching the silicon rim and the housing bottom as the heat sinks. The heat flow through the material results in a temperature gradient. Thus the two thermocouple ends – those located on the absorber and those on the silicon rim – will have different temperatures.

Thermopile temperature or temp sensors offer the advantage of non-contact temperature measurement, making them more and more popular over the standard contact-based temp sensors. Thermopile sensors use infrared (IR) radiation versus conduction for heat transfer, which provides unique solutions that allow for new levels of performance and reliability in many constrained applications.

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Engineers working on the thermal management of electronic equipment have long enjoyed the simplicity and convenience of the digital temp sensing ICs. The new integrated thermopile sensor ICs on the market provide the temperature results in the same convenient digital format. The continuous reduction in their power, size, and cost creates opportunities with consumer devices, medical instruments, office equipment and home appliances.

The pyroelectric and thermopile types have dominated the low-end single-element infrared sensor market. Even though the former type has a large share in the single-element market, only the latter is suitable for array sensors.

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SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

WHAT IS GRID-EYE?

Panasonic started the infrared array sensor business with its innovative 8 x 8 thermopile array called Grid-EYE. Grid-EYE is an infrared array sensor and the first ever 64 pixel IR camera in an all-in-one compact SMD package. Based on Panasonic's MEMS (Micro Electro Mechanical Systems) technology, Grid-EYE combines the MEMS sensor chip, a digital ASIC (I2C interface) and a silicon lens. It has 64 thermopile elements in an 8x8 grid format that detect absolute surface temperature without any contact. Unlike conventional sensors, Grid-EYE uses a patented 60° silicon lens etched out of a silicon wafer, which is (with less than 0.3mm height) the smallest available lens in the market. The combination of these technologies from Panasonic enables to reduce the sensor package size to only 11.6mm x 8mm x 4.3mm, which is around 70% smaller in size than competitor products.

Compared to single element thermopile sensors and pyroelectric sensors, it is not only possible to detect moving people and objects but also the position and presence of motionless people and objects, the direction of movements and the accurate surface temperature from -20°C up to +100°C (Figure 3). With this wide range of temperature measurement Panasonic is able to reach a NETD (Noise equivalent temperature difference) of +/- 0.08°C @ 1Hz at room temperature. Its coordinated array of sensing elements can even detect multiple people or objects moving in different directions. At close proximity, Grid-EYE is even capable of detecting hand movements for simple gesture control.

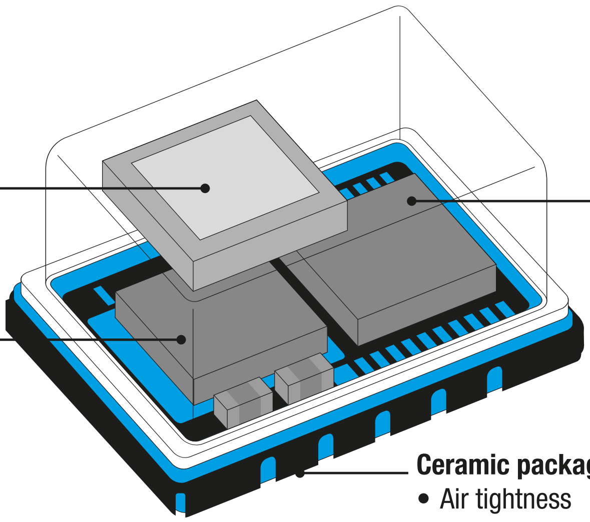

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FIGURE 3

Type \ Detection	Moving Object	Motionless Object	Moving Direction	Temperature Measuring	Thermal Image
Pyroelectric	✓	×	×	×	×
Thermopile (single element)	✓	×	×	✓	×
	⇩	⇩	⇩	⇩	⇩
Grid-EYE	✓	✓	✓	✓	✓

APPLICATION AREAS

Grid-EYE sensor can see light in a wavelength range from 8 to 13µm, which is undetectable to the human eye. Many infrared applications don't need complete image information, but only use specific information extracted from images, such as position, motion, and area of hot (or cold) objects. The new markets include such non-imaging applications that require infrared array sensors based on different concepts from the conventional imaging IRFPAs. Grid-EYE offers two voltage options with a current consumption of 4.5mA. A build in lense offers a 60 degree viewing angle in both horizontal and vertical directions. High gain models offer the highest temperature accuracy and low gain is available for the widest temperature range. Digital output via I²C provides direct temperature values with no conversion required. Other options include a selectable frame rate up to 10fps and operating modes for normal, sleep and stand-by operation. Grid-EYE offers the widest range of features when compared with single element thermopile sensors and multiple element passive infrared sensors. Motionless objet detection, movement direction and a thermal image with 64 pixel resolution are unique features for the Grid-EYE infrared array sensor. This section will survey the applications of thermal imaging systems with two main different categories of subjects: inanimate objects and humans.

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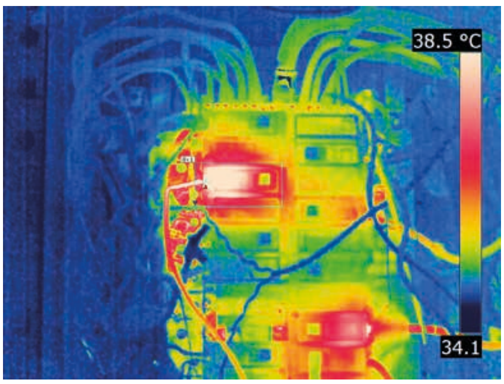
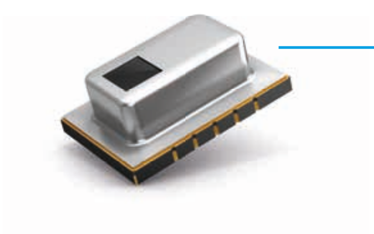
Inanimate Objects

The temperature and thermal behaviour of plant machinery, power generation and distribution equipment, materials, and fabricated parts in process are the most critical factors in the manufacturing process and in the maintenance of safe and cost-effective plant operations. Sudden hot spots can indicate faulty areas and connections. It would obviously be of great value if devices that are starting to overheat could be detected before they breakdown. One of the reasons for using thermal imaging for temperature measurement is that it is not in contact with the target. Thermal imaging can be applied as a diagnostic tool for electrical joints in power transmission systems and for detection of the thermal conditions of other electrical installations. It can also be used to evaluate specific properties in different materials. An unexpected thermal distribution can be an indication of malfunction in the object (Figure 4).

FIGURE 4



Detected Temperature



(degC)

36	40	43	36	35	37	36	36
37	41	41	42	43	42	39	36
38	43	58	65	67	68	38	37
36	43	60	75	75	68	45	37
37	42	59	72	73	60	42	37
37	40	51	58	58	50	40	36
36	36	40	41	36	35	35	36
36	35	35	33	36	35	37	35

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SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

Consumers have high expectations when it comes to the availability, reliability, and quality of food and perishable goods. The ambient conditions in the cold chain transport for those e.g. climacteric fruits, fish but also sensitive drugs like insulin are of great importance. On the one hand ambient conditions in a container or transport compartment are a prerequisite to maintain the freshness of the transported perishable cargo while, on the other hand, by controlling the conditions, a specific behaviour of the commodity – like reduced metabolism and hence respiration – can be ensured. Low temperature remains the key to maintain good fish quality and is mandatory to ensure that the cold chain is not interrupted during transport. A very good example of the consequences of changes in ambient conditions is the transport of tuna. Frozen tuna, which will eventually be eaten in its raw state as the Japanese product "Shasimi" requires to be reduced to a lower temperature than other fish products and changes it taste as soon as it is exposed to a room temperature which differs +2°C to the predefined ideal ambient conditions. One of the biggest logistics companies in Japan approached Panasonic in 2014 with exact this problem and started a field test equipping trucks with Panasonic Grid-EYE sensors which monitored in real time temperature shifts in the cargo and reported via a display directly to the driver in case of a temperature change. The system proved that successful that the company has equipped more than 40 trucks with the Grid-EYE system since then.

Humans

In computer vision research, humans are often the subjects observed. Its application areas are very wide, from surveillance through entertainment to medical diagnostics. Passive infrared sensors work well when it comes to instant occupancy or object detection. They can only sense people or objects in motion, which makes them conditionally useful in building automation and security systems. These simple IR sensors have traditionally had limitations that kept them out of more advanced detection applications. For example, passive IR sensors cannot sense motionless objects. They cannot accurately detect direction of movement. Neither can they create thermal images nor detect temperature. All three of these tasks are essential for the next generation of intelligent automation and security systems as well as digital signage and medical imaging applications. Passive IR technology, however, continues to evolve, and the Grid-EYE sensor eliminates the traditional limitations. Instead of the single thermal sensing element employed by most passive IR sensors, Grid-EYE employs an array of IR sensing elements to measure actual temperature as well as temperature gradients within a 60º viewing area. Based on thermopile technology, this IR array sensor can simultaneously detect the direction of moving people and objects – up, down, left, right and diagonally. Its coordinated array of sensing elements can even detect multiple people or objects moving in different directions.

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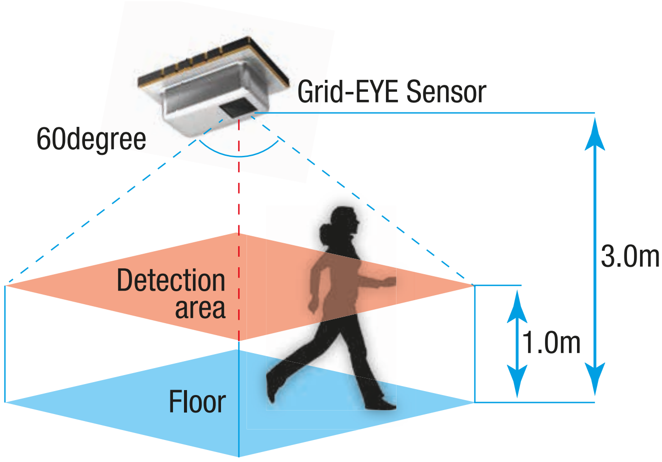
SMALLEST SIZE SOLUTION FOR INFRARED DETECTION

Design of the human detection

The thermopile infrared array sensor Grid-EYE measures the temperature of the objects in the detection area. Temperature outputs of the sensor are transferred to the respective mainboard and readout by the software which can be easily connected via existing APIs by Panasonic. Then position and number of humans are calculated. The schematic image of using human detector is shown in Figure 5. Grid-EYE is used by mounting under the ceiling for detecting the presence of humans. People stay or move around in the detection area.

Human tracking or detection has all-pervasive applications beyond mere surveillance, for example in education, health monitoring, marketing, energy management and so on. Image and video based tracking systems are intrusive. Thermal array sensors on the other hand can provide coarse-grained tracking while preserving privacy of the subjects. Basu and Rowe developed a low cost method to estimate number of people and direction of motion within the field of view of the Grid-EYE sensor. Using Support Vector Machine classification on connected component based features and local peak counts they estimated the number of instances with more than 80% accuracy (Basu and Rowe, Tracking Motion and Proxemics Using Thermal-Sensor Array, 2014, Carnegie Mellon University). A more sophisticated approach was presented 2014 by Jeong, Yoon and Joung who developed on the Grid-EYE sensor a method to determine human subjects via a probabilistic method with multiple pre and post image processing techniques. Preprocessing and segmentation provide the base structure then a probabilistic method calculates how likely a heat signature is to be a human subject. Even if a human segment temporarily disappears, their proposed idea is able to track it with the local adaptive threshold (Jeong, Yoon and Joung, Probabilistic Method to Determine Human Subjects for Low-Resolution Thermal Imaging Sensor, 2014, Institute of Electric and Electronics Engineers).

FIGURE 5



Thermal array sensors can provide coarse-grained tracking while preserving privacy of the subjects.

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Applications for Smart Buildings

Applications for smart buildings (e.g. environmental control, intrusion detection, and occupancy counting) are examples of Cyber-Physical Systems. Most of the time, these applications need different types of sensors, network topologies, and configurations in order to accommodate the users' requirements, which necessitates redeployment and/or reconfiguration of sensor hardware. However, the redeployment of same hardware for multiple applications is not a practical (or sometimes even feasible) option due to the limitation of accessing the sensor nodes or the cost of redeployment. Grid-EYE has multiple applications as mentioned above. By using the occupancy information from the Grid-EYE sensors, integrated home automation and Heat, Ventilation and Air Conditioning (HVAC) can be enabled. The same sensor can be used for security purposes as well. Counting people is helpful in the scenarios where there is limitation on occupancy in confined space like lecture halls and seminar places.

Occupancy, security and building automation are basic functions of smart buildings. Occupancy of the room allows a building manager to control the HVAC system accordingly to achieve sustainability. The number of connected components in a 8x8 binary matrix gives us the number of people staying in the cicinity of the sensor (occupancy). This number, greater than zero, indicates presence of at least one human body.

For security applications, the detected occupancy could be an intrusion condition to initiate alarm sounds or text messages for home owners. For home-automation applications, it could be used as a condition to activate HVAC systems or home appliances (Figure 6). In particular heating, cooling and ventilation systems which account for between 30 and 40% of the EU's annual energy consumption must be made more efficient. Not all areas of a building are created equally. Some parts may flurry with activity at one time of the day and be virtually unoccupied during others – meaning money is being wasted when an HVAC uniformly heats or cools a building that doesn't have uniform occupancy and usage. The University of California, Merced (Beltran, Erickson and Cerpa; ThermoSense: Occupancy Thermal Based Sensing for HVAC Control Buildsys'13, November 13-14, 2013, Rome, Italy) demonstrated in 2013 on a Grid-EYE based system for estimating occupancy that they were able by conditioning spaces based on occupancy that they can save more than 25% energy annually while maintaining room temperature effectiveness. Beltran, Erickson and Cerpa pointed out that unlike the CO2 sensor, the thermal array can measure occupancy in near real-time and underlined the advantage of Grid-EYE being not sensitive to optical issues, such as lighting or background changes.

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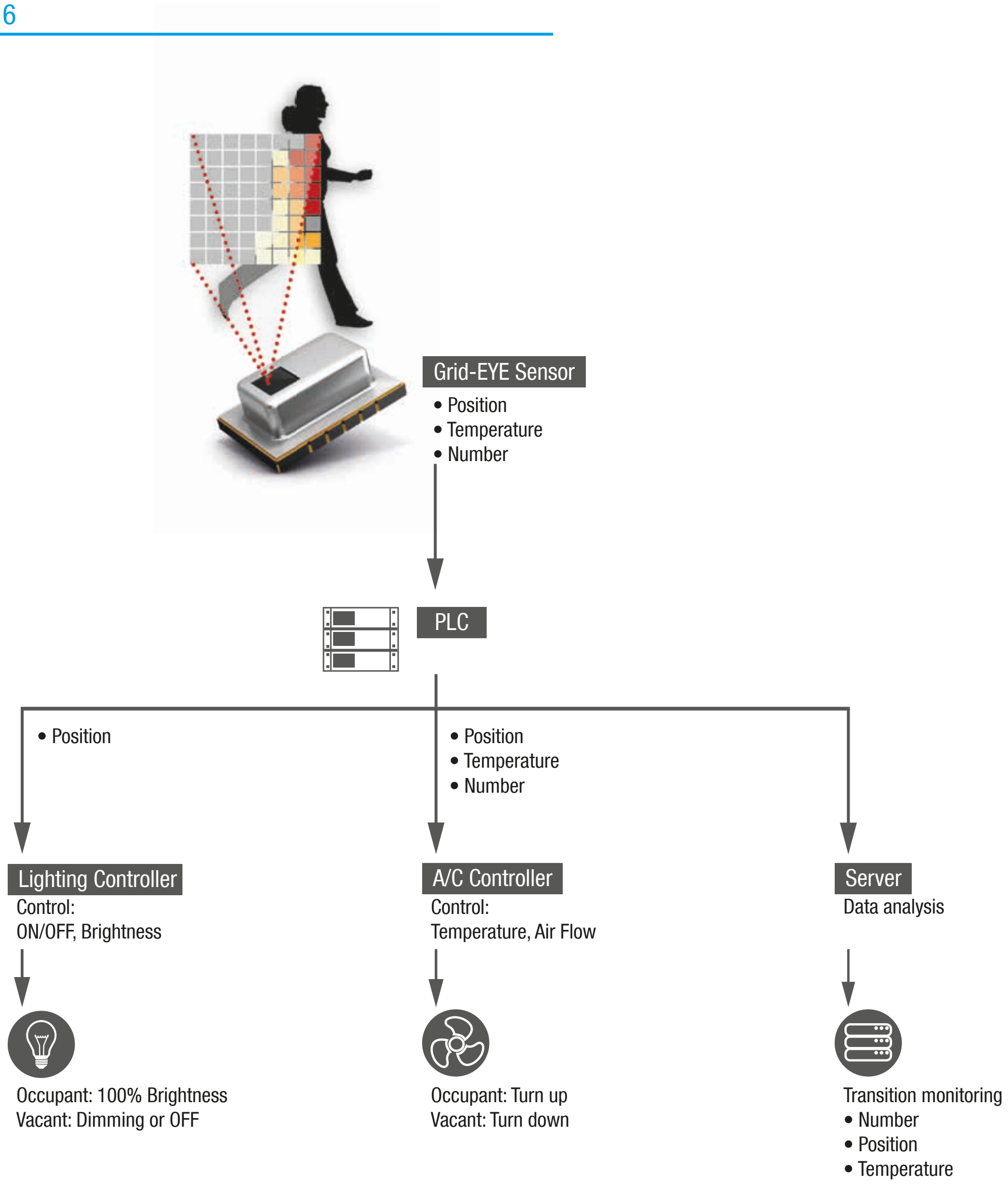
FIGURE 6



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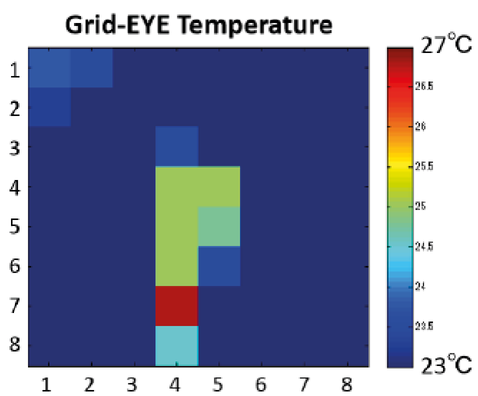
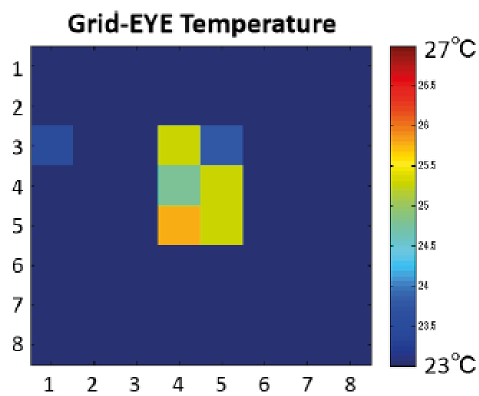
Fall Detectors

Thermal sensors can be used in systems for the detection of fall accidents or unusual inactivity, which is an important safety tool for the independent living of especially elderly people. Grid-EYE is favourable in comparison to usual methods like using a video camera or a wearable device which have some issues in privacy and convenience. In light of current state of domestic accidents of elderly people, an accident likely to happen the most is a fall at home with main accident locations are living room and stairs. Mashiyama, Hong and Ohtsuki (A Fall Detection System Using Low Resolution Infrared Array Sensor, 2015, IEEE) proposed a system using the Grid-EYE sensor. First the infrared array sensor sends a temperature distribution of interest to the computers. Second the computer extracts features from the temperature distribution sent from the sensor. Finally, features (input data) are compared with training data in database and the temperature distribution is classified as a fall or a non-fall (Figure 7).

FIGURE 7



Temperature distribution when Grid-EYE detects a human falling below the sensor. The number of high temperature pixels is larger when sitting.



Temperature distribution when Grid-EYE detects a human sitting below the sensor.

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CONCLUSION:

Low cost and easy to manufacture, IR detectors have been used in a wide diversity of markets such as construction, security, appliances, and industrial, and for a wide variety of functions, e.g. motion detection, temperature measurement, counting, fire detection, etc. Initially limited to single pixel pyroelectric detectors with a basic motion detection function, IR detectors have progressively been used in more complex systems which diversified the market into higher-end applications such as temperature sensing, spectroscopy…

At the end of 2000, that diversification has been pushed further into the high end of the market by the introduction of array detectors. Multiple companies adopted a "technology push" strategy to introduce IR detector arrays either based on pyroelectric technology or thermopile technology. Coming from the MEMS industry especially Panasonic has ensured the domination of thermopile technology on the array detector market by capitalizing on their knowhow in complex MEMS structure manufacturing and by introducing the Grid-EYE sensor to the market.

Along with an evaluation kit, Panasonic is providing customers with a free PC software. This can be downloaded under: eu.industrial.panasonic.com/grideye-evalkit. The kit is a "plug & play" device when used with this software on PC. Costumers have also access to all source codes for Python and LabView that can be further used by them to develop their own application. Moreover, you can also find the three level APIs of Grid-EYE developed by Panasonic and available free of charge for customers.

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