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Scanning Thermal Imaging Systems with Thermopile Array Modules

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Abstract

Optical electronic modules with uncooled IR focal plane arrays (FPA) based on thermocouple sensors due to the small dimensions and low weight provide the simple and inexpensive low-inertia scanning thermal imaging systems with wide fields of view. Such systems can find applications in intelligent systems of fire safety, thermal imaging monitoring, security and in other areas where small weight and dimension parameters are significant.

This work presents the results of developing the prototypes of thermal imaging scanning systems based on optical-electronic modules HMLX90620 (HTPA 4x16) and HTPA 32X31L17/0.8 thermocouple FPA with a 4x16 and 32x31 format offered on the market by Heimann Sensor Gmb [1]. For the purpose of practical applications, several versions of optical-electronic systems based on these modules are considered.

Keywords: scanning system, infra-red (IR) imagers, MEMS, thermopile array (TPA), focal plane array (FPA), noise equivalent temperature difference (NETD), array format, field of view (FOV), pixel pitch, framerate.

INTRODUCTION

Uncooled infra-red (IR) imagers have been actively developed lately based on MEMS technology compatible with silicon CMOS batch technology. Successful progress in this direction is due to development of technological processes of thin dielectric membranes. Due to high thermal insulation and low weight of MEMS elements IR FPA on their basis are characterized by high sensitivity, low power consumption, linearity and high speed of response to thermal radiation.

The main reason for the development of uncooled IR imagers is their ability to detect long-wave infrared radiation in the range from 7.5 to 14 μm. Recent improvements of their parameters (the degree of integration and NETD) has played an important role in the penetration of uncooled IR imagers on the commercial market. The development of uncooled IR imagers led to a radical reduction in the cost of thermal imaging systems from about $50,000 to $10,000 and even in some cases up to several thousand dollars. Uncooled IR imagers open up new markets for infrared cameras, making them more affordable, compact and lightweight without compromising performances. All this has led to rapid growth of uncooled thermal cameras sales.

The capabilities of modern silicon technology allow to create infrared MEMS sensors with sensitive elements based on different physical effects. The world's leading electronic companies made serious efforts in research and development to determine the most effective ways to implement these elements. The main ones of them are sensors based on thermoresistive, thermocouple and thermomechanical effects.

The physical principle of a thermomechanical sensors is based on the known spatial deformation effect of microcantilevers, consisting of materials with different coefficients of thermal expansion. The spatial displacement of the thermomechanical MEMS elements is in nanoscale range, so one of the main problems when designing is to develop reading schemes of ultra-small mechanical deformations. Thermomechanical sensors are being actively developed by some companies [2-4]. Experimental samples IR imagers based on the thermo-mechanical MEMS elements with optical readout was obtained, however, tradable products on the market are not represented.

Thermoresistive effect is the electrical resistance change of heat-sensitive material due to its heating under the influence of absorbed IR electromagnetic radiation. Uncooled microbolometric IR imagers that use thermoresistive effect, widely represented in electronic market. Modern microbolometric technology demonstrates the possibility of creating IR FPA with 1024x768 elements and pixel pitch up to 17 μm [5-6]. They have small dimensions, weight, power consumption. However, although their cost is significantly (10-100 times) less than the cost of quantum IR FPA with cryogenic cooling, prices of bolometric thermal imaging systems are still quite high. This significantly limits their wide usage.

Thermocouple sensors occupy the low-price sector among uncooled thermal MEMS sensors [7-13]. The sensing element of the sensor is a membrane with good thermal insulation, on which a thermocouples are placed. "Hot" junctions of thermocouples are located on the heat absorbing membrane and «cold» junctions have good thermal contact with the substrate. The thermopower arising under the influence of thermal radiation (Seebeck effect) is amplified and read by CMOS circuits that are located directly on the crystal.

The evident advantages of the thermocouple sensors are:

- compatible technological processes of sensitive elements manufacturing with standard CMOS technology,
- the possibility of realization IR FPA without cooling,
- low cost of the IR thermal imaging modules and IR systems based on them,
- the sensing elements consume no power,
- volt output provides the ability of the electrical signal readout,
- high operating speed (response time ~0.05 s),
- high sensitivity (NETD ~0.15K).

Despite the fact that their parameters still yield microbolometric sensors, the low price level and not yet used possibilities of improvement allow us to predict the active development on this direction.

THERMOPILE ARRAY MODULES

There are many types of scanning thermal imaging systems differing in scanning methods, signal readout and processing and methods of image formation. Scanning space implemented by these systems provides the ability to view a thermal scene with large fields of view. In systems with opto-mechanical the image of the scan field is moved relative to the stationary detector by means of movable mirrors or prisms, which are installed in the path of heat flow. This method of scanning is used in the apparatus with cooled photodetector devices. Inclusion the cooling system with a large mass in the thermovision block does not allow you to realize another variant of a scan when the photodetector module including the input optics and FPA is set on a turntable, changing position of the optical axis by a specific algorithm.

A convenient solution for designers of thermal imaging systems are finished products in the form of modules, which includes TPA chip placed in the insulating casing with optical input and output circuit readout and signal processing.

Thermopile array modules due to the small dimensions and low weight enable you to create a simple and inexpensive low-inertia scanning thermal imaging systems with wide fields of view. Such systems can find applications in intelligent systems of fire safety, pilotless transport vehicles, thermal imaging monitoring, protection and in other areas where small weight and dimension parameters are significant.

Among thermocouple modules that are available today in the electronic market, the most attractive for designing are the modules proposed by Heimann Sensor GmbH [1]. They have a wide variety of different options for the TPA format, the input optical parameters and electronic output. Some of the modules are presented in table 1.

Table 1.

	HTPA series parameter overview		
Parameter	HTPA4x16	HTPA32X31	HTPA64x62
Array format	16(h)x4(v)	32(h)x31(v)	64(h)x62(v)
Pixel pitch, μm	220	220	110
Absorber size, μm^2	180x180	150x150	60x60
Framerate, Hz	0,5-512	>20	5-10
NETD, mK	230	100	50-150

In this work the results of design thermal scanning systems using the thermopile array modules HTPA4x16 (MLX90620) and HTPA32X31L17/0.8.

Taking into account the practical applications we implemented different operation options of scanning systems based on these modules using the control electronic circuits, actuators and special software.

The main ones are:

- horizontal scanning mode over a wide (up to 180 deg.) the range of viewing angles,
- two-dimensional panoramic scanning mode, which is carried out through an additional shift of the optical axis of the system relative to the horizon within ± 45 degrees,
- capture and retain heat target in field of view.

Scanning in all modes is carried out in discrete steps. The scan step can be set programmatically in the range of 0...16±10% deg. The angular scan velocity is equal to 0...32±10% deg./sec. Reading frame sequence while scanning provides the possibility of processing with improving the quality of the resulting image. It was also provided spatial filtering of the image and its output on the monitor with various options for color coding.

To implement the observed functionality of the systems we have developed models, which include:

- rotary electromechanical mechanism, enabling horizontal and vertical rotations of the system optical axis,
- electronic units that control actuators of the rotary mechanism,
- electronic components providing agreement of readout and signal processing schemes with control units of the system
- software that implements the specified algorithms of control system blocks.

Horizontal scan mode with FOV ~60x100 deg. in the scan system with module HTPA4x16 is illustrated in figure 1. The instantaneous FOV of the scanner is ~16x60 deg. and is determined by the matrix format defined by 4x16 pixels.

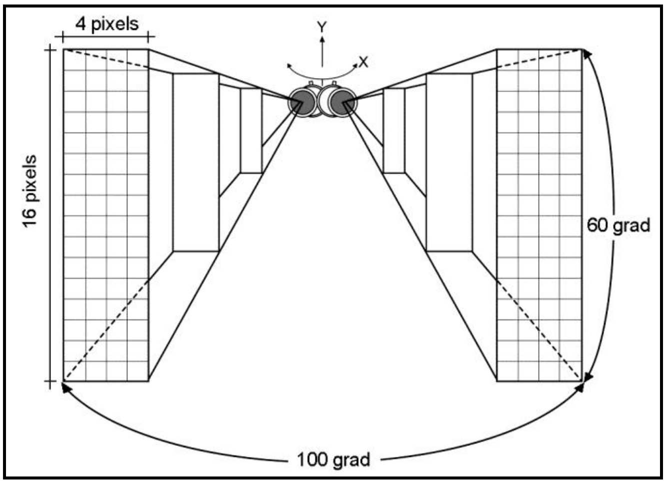

Figure 1. Horizontal scan mode with FOV ~60x100 deg. in the scan system with module HTPA4x16

When the scan step is equal to ~4 degrees (a shift of the focal plane by one pixel), a scanner reads the 24 frames for one horizontal sweep. Since HTPA4x16 has 4 pixels in the scanning direction each element of the thermal scene is read four times, providing the possibility of signals integrating to improve sensitivity.

An example of an image with a raster of 16x24 pixels obtained by this scanning are presented in figure 2.

Figure 2. The image with a raster of 16x24 pixels obtained by horizontal scanning mode in the system with HTPA4x16 module

Functioning in the capture and holding of thermal target mode, the system first detects the appearance in the system FOV of the object having a temperature above a level specified by the program, and then, carrying out the rotations on the axes X and Y provides the output image of this thermal source in the center of the raster with the further retention of the image in this position when the object moves.

Figure 3 presents a video fragment of the system functioning with HTPA 4x16 module demonstrating the capabilities of the system for tracking movements of a human hand.

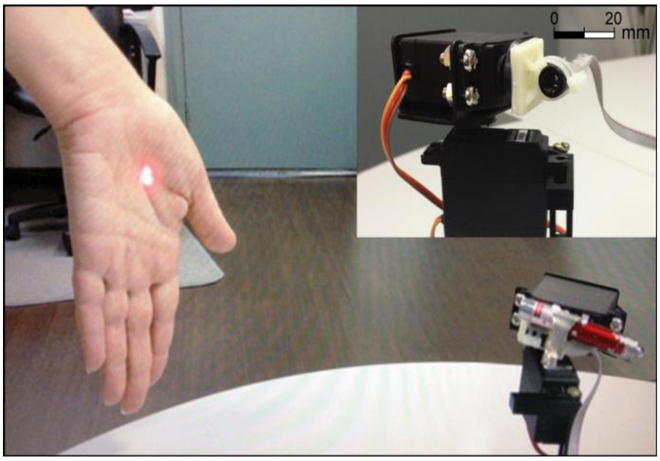

Figure 3. Scanning system with HTPA4x16 module performing the functions of detection, capture and tracking of a moving thermal object (fragment of video)

An important feature of the modules is the ability to specify the temperature threshold of the thermal image reproduction that provides selective registration of only those thermal objects that have a temperature above a preset level. Figure 4 presents a thermal images obtained by thermovision system with HTPA 32X31L17/0.8 module, which demonstrate the ability of selection of cigarette image at the threshold of the minimum temperature Tmin = 35C.

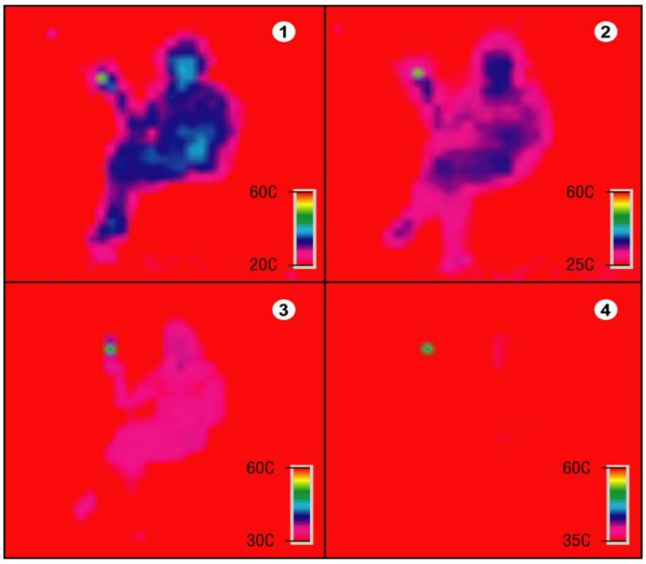

Figure 4. Selection of cigarette thermal image:

1) Tmin = 20C, 2) Tmin = 25C, 3) Tmin = 30C,

4) Tmin = 35C.

In Fig. 5 shows a scanning system with a module HTPA 32X31L17/0.8 and the thermal images obtained when scanning scenes with different spatial angles (~27x26 to ~135x78 deg.), which correspond to the dimensions of the raster images from 32x31 to 160x93 pixels. Scanning of the scene with the appropriate software makes it possible to realize the output images without docking spaces and record the temperature topography with a resolution of up to 0.2 K due to the integration of signals from separate elements of the thermal scene.

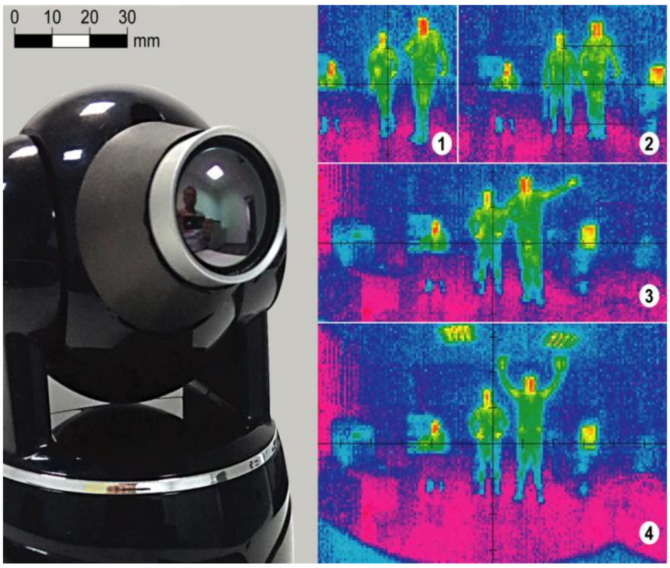

Figure 5. Scanning system with HTPA 32X31L17/0.8 module and the thermal images obtained when scanning.

The raster sizes: 1) 64x62, 2) 96x62, 3) 160 x62, 4) 160 x93

CONCLUSION

Thus, optical-electronic modules with small format uncooled thermocouple IR FPA are suitable for thermovision scanning systems with wide fields of view. In contrast to the application of optical scanners for these purposes the proposed technical solutions use integration in a miniature module of all hardware control and signal processing of the image, while providing a low moment of inertia of the module.

Therefore, the development of uncooled thermal sensors based on MEMS thermocouples for infrared optical-electronic thermovision systems seems very promising.

The main applications of such systems are energy saving, environmental management, safety, special equipment. It should be noted important civilian applications of equipment such as:

- energy systems monitoring and control of technological processes and equipment;
- inspection of facilities (energy conservation and ecology);
- medical equipment;
- active safety system;
- passive automated systems thermal locations.

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REFERENCES

[1] www.heimannsensor.com

[2] Yi Ou, Z. Li, F. Dong, D. Chen, Q. Zhang, C. Xie, Design, Fabrication, and Characterization of a 240 × 240 MEMS Uncooled Infrared Focal Plane Array With 42-µm Pitch Pixels, Journal of Microelectromechanical Systems, Vol. 22, no. 2, 2013, pp. 452-461.

[3] R.Z. Khafizov, E.F. Fetisov, R.V. Lapshin, E.P. Kirilenko, V.N. Anastasyevskaya, I.V. Kolpakov, Thermomechanical sensitivity of uncooled bimaterial detector of IR-range fabricated by technology of microoptomechanical systems, Advances in Applied Physics, Vol. 1, no 4, 2013, pp. 520-523.

[4] A.M. Belin, M.A. Belin, V.A. Fedirko, E.A. Fetisov, R.Z. Khafizov, Design Principles and Numerical Simulation of Microthermomechanical IR Imagers

with Optical Readout, // Proceedings of VI All-Russia Science&Technology Conference MES-2014, Extended abstracts, Part II, Institute for Design Problems in Microelectronics of Russian Academy of Science, 2015, pp. 48.

[5] J. L. Tissot, C. Trouilleau, B. Fieque, A. Crastes, O. Legras. Uncooled microbolometer detector: recent developments at ULIS, Opto-Electronics Review 14(1) (2006) 25-32

[6] S.M. Johnson and E.P.G. Smith, Next Generation EO/IR Detectors, Raytheon Technology Today 2014, Issue 1, pp.

[7] Paul W. Kruse, David D, Editors. Skatrud, Uncooled Infrared Imaging, Arrays and Systems // Semiconductors and Semimetals, Vol. 47, Academic Press, USA, 1997

[8] A. Rogalski, Infrared detectors: status and trends. Review, Progress in Quantum Electronics, Pergamon Press, Oxford and New York, 2003, pp. 59–210.

[9] M.C. Foote, M. Kenyon, T.R. Krueger et al., 2004. Thermopile Detector Arrays for Space Science Applications. Proceedings of SPIE, 2474: 98-109.

[10] T. Kanno, M. Saga, S. Matsumoto, M. Uchida, N. Tsukamoto, A. Tanaka, S. Itoh, A. Nakazato, T. Endoh, S. Tohyama, Y. Yamamoto, S. Murashima, N. Fujimoto, N. Teranishi, Uncooled infrared focal plane array having 128x128 thermopile detector elements // Proc. SPIE, 1994, Vol. 2269, pp. 450–459.

[11] M. Hirota, Y. Nakajima, M. Saito, F. Satou, M. Uchiyama, 120x90 element thermopile array fabricated with CMOS technology // Proc. SPIE, 2003, Vol. 4820, pp. 239–249.

[12] M. Hirota, Y. Ohta, Y.Fukuyama, Low-cost thermo-electric infrared FPAs and their automotive applications // Proc. of SPIE, 2008, Vol. 6940, pp.694032-1-16.

[13] R.Z. Khafizov, Infrared Focal Plane Array (FPA) with Termopile Thermal Radiation MEMS Sensors // Proceedings of VI All-Russia Science&Technology Conference MES-2014, Extended abstracts, Part II, Institute for Design Problems in Microelectronics of Russian Academy of Science, 2015, pp. 49-50.