Design and Construction of a Satellite Sensor Simulator for Earth Horizon Recognition using Pyroelectric Detectors

Mozhde Heydarianasl and Omid Borazjani

Faculty of Electrical Engineering, Dashtestan Branch, Islamic Azad University, Iran
heydarianasl23@yahoo.com

Abstract: This paper focused on pyroelectric detectors to build satellite sensors for earth horizon recognition, which is important in simulating satellite control systems. Infrared earth horizon sensors were used to determine the satellite direction. These sensors are usually based on the direction of dissociation in infrared radiation on earth. It was necessary that the earth's infrared horizon was simulated for testing and calibration of horizon recognition sensors in earth conditions. This was based on detecting the earth as a spherical warm object in cold-space, unbounded from its infrared radiation waves. In this research, a hemisphere and a pyroelectric infrared detector, with peripheral equipment and circuits, are constructed to simulate and detect the earth, respectively. Step response and field of view of detector are experimentally obtained and they are plotted by Matlab software. The results verified that pyroelectric detectors can be used to simulate satellite sensors and earth horizon can be recognized. When the field of view reduce, object detection increase in far distances. The field of view decreased from 120° to 70° by means of a 10mm plastic pipe.

[Heydarianasl M, Borazjani O. **Design and Construction of a Satellite Sensor Simulator for Earth Horizon Recognition using Pyroelectric Detectors.** *Life Sci J* 2014;11(10s):106-111]. (ISSN:1097-8135). http://www.lifesciencesite.com. 18

Keywords: Satellite sensor; Earth horizon recognition; Pyroelectric detectors; Field of view of detector; Step response of detector

1. Introduction

Thermal detectors, for example pyroelectric, thermopiles and bolometers, were preferred to photon detectors since they do not require being cool. Pyroelectric detectors and bolometers were not used in the DC model; however, the utilisation of thermocouples in the earth horizon recognition sensors were used in the DC model and their detected DC weak signals were electronically changed to electronic AC signals. Subsequently, the signals were amplified.

Thermopiles and thermistors were used to detect live creatures, with the wavelength range of 8 to 10micrometres. While these instruments are relatively inexpensive, their circuits had a low response and low signal to noise; therefore, they were not desirable for detecting human movements. Hence, Tsai, 2003 stated that the pyroelectric effect was the best replacement for thermopiles and thermistors.

Takeo and Shozo, 1999 developed two types of infrared detectors for earth sensors in satellites. Both included a pair of infrared-sensitive elements, which were made of pyroelectric materials that were installed on a lens. The first and second elements were made with lead-titanium ceramic and lead-titanite with a layer of calcium, respectively. The precision earth sensor consisted of a scanning mirror and an infrared telescope which had an extra external lens, relative to the second detector.

The pyroelectric infrared sensors had a high performance when detecting infrared radiation in room temperatures. In recent years, Gopinathan et al., 2003 and Sekmen et al., 2002 explained how pyroelectric infrared detectors were widely used for human detection and optical sensors, since these detectors did not require expensive cooling systems (Hao, 2006).

Humans are good infrared sources. The temperature of the human body is about 37 degree centigrade (98 degree Fahrenheit). There is a constant heat exchange between the human body and the environment due to temperature differences. Wave properties of any object can be analysed by the black body radiation curve using Plank's law (Fang, 2006; Planck, 1901).

Spritzer et al., 1996 used the Stefan-Boltzmann law to estimate the thermal radiation of the human body relative to the environment. Subsequently, Kakuta et al., 2001 asserted that the average thermal radiation for a human is about 100 watt per square meter; furthermore, infrared detectors can detect human movement well in the range of 8 to 14 square micrometres.

Bodor et al., 2003 explained how human movement and the body of live creatures radiated an infrared radiation that can be detected by video cameras. Shankar et al., 2006 and Fang, 2006 proposed that pyroelectric detectors, which are inexpensive and are readily found in human motion detections within security systems or automated systems in homes, could be built in a sensor system that could detect the human movement within large areas; at a distance of 12 meters. The direction of human movement could also be recorded by this system.

The detection of human movements was also accomplished by pyroelectric detectors that were sensitive to thermal changes. These detectors were very appealing due to their low cost in thermal detection. In addition, they are broadly used for lighting in homes, offices, security systems, thermal imaging (Astheimer, 1968), guided robots (Keller, 1992), radiometric (Pradhan, 1982), and thermometers (Tsai, 2003).

The movement detection arrays, by means of pyroelectric (Vlaam, 2004; Feller, 2002; Armitage, 2003), were adapted instead of expensive thermal cameras that used video tracking (Jones, 2001). These arrays utilised 96 pyroelectric detectors (Hobbs, 2001). The behaviour of two elements of pyroelectric detectors and one array of Fresnel-lens were explained (online).

In order to determine the condition of the location of spacecraft in outer space, several references are needed, such as: the sun, earth, moon and stars. The deduction of the location of these objects required more complex calculations according to their movements in space. The earth, sun and a sample of stars were useful when designing the satellite control part since they were practically applied as references in space. In addition, the most operated satellites are deployed on the earth; hence, the application of earth sensors, especially earth horizon recognition sensors, had attracted much attention.

Earth Horizon Recognition Sensors (EHRS) determine the position of spacecraft relative to the earth’s horizon and centre. These sensors are frequently applied as a closed-loop control in the automatic control system. Furthermore, EHRS are infrared instruments that apply radiations between cold space, which is the black body in 4°Kelvin temperature and earth horizon radiation. This meant that the black body wavelength was equal to 15micrometres at 233°K. Consequently, to attain this accuracy, the sensor was worked in the range of 14-16.3 micrometres; which was the absorption spectrum of carbon dioxide (CO_2). The carbon dioxide spectrum was used around the earth due to several reasons. Firstly, this layer has constant radiation in the range of 14 to 16.3 micrometres. Secondly, this layer has fewer changes in different sensors, in comparison to other layers, such as H_2O. Therefore, its emission had suitable stability. The selection of the type of detectors was based on the spacecraft stabilizer system, in addition to the mission and the amount of stability.

At first, the performance mechanism of pyroelectric infrared detectors was examined in this research. After that, earth's horizon sensor prototype was built by means of pyroelectric detector layers, used in commercial systems; for instance, the human recognition system protection. This model was used in the simulation of satellite control systems. Step response and field of view of detector are two major parameters to determine the performance of detector. Moreover, the elimination of possible defects, survey of behaviour and increment of efficiency of the mentioned model was used as a prototype for the development of the real sample. After the achievement of this process, the operation of the sensors for the sensitivity response rate and noise reduction was improved by switching the pyroelectric sensor parts with other samples. The sensor reacted to the received infrared flux changes; therefore, a mechanical system was suggested for the application of flux changes.

2. Material and Methods

Earth horizon sensors are one of the major instruments in the navigation of satellites. These instruments provide the necessary information through sun and star sensors to determine the satellite situation in space. The performance of this device is based on recognising the earth as a spherical warm object in cold space, unbounded from infrared radiation. After identifying the earth using control algorithms, the centre and horizon of the earth was also determined. According to the temperature difference between earth and unbounded space, thermal infrared detectors such as thermopile, bolometer and pyroelectric, were suitable for the sensitive parts of the device.

In this research, one hemisphere to simulate earth was used, along with a pyroelectric infrared detector that possessed circuits and equipment to detect the earth. This system included: the identification and preparation of required detectors based on the pyroelectric effect; the design and construction of ancillary circuits for converting the sensor response to electrical signals; and the construction of an infrared source to simulate earth’s radiation waves. A chopper was installed in front of the scope of the detector to show that the simulated earth was moving. The output signal of the detector was amplified by an electronic circuit. Afterwards, the amplified signal was transferred to a computer by digital oscilloscope. A schematic of this system was shown in Figure 1.

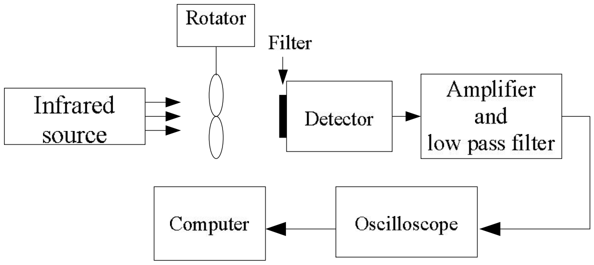

Figure 1. A schematic of used laboratory set in this research

In the static infrared horizon recognition sensors, the main source of error was due to the lack of uniformity in the earth's radiation that originated from satellites. The occurrence of change in the earth's radiation was in accordance to weather and seasonal changes that gently related to time and latitudinal changes. Since one of the objectives of this research was simulating a system to detect the earth's horizon, it was necessary that the performance of the earth's radiation in space was simulated. The earth was observed as a hot spherical object with a spatial angle that equalled to 18 degrees, in view of the satellites located on an altitude of 36000km from the earth. Therefore, a metal hemisphere with a 20cm radius, equipped with heaters, was constructed to achieve this target. A schematic of this system was shown in Figure 2.

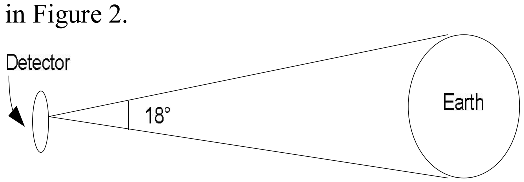

Figure 2. Schematic of earth in view of satellites

An experiment was also carried out to determine the position of hot objects in two- dimensional space. In addition to detecting warm objects, the experiment's performance for the detection of the centre of objects was also proven.

Step response was calculated by a laboratory set, as is shown in Figure 1, to examine the characteristics of pyroelectric detectors. Therefore, detectors and lateral circuits were located in front of a heat source with a temperature of 60°C. The chopper was stopped for a brief moment so that the field of view of detector would be interrupted for one time. The step response was then taken and plotted, once without and once with, a limiter with a distance of 1 metre. They were shown in Figures 3 and 4. The results demonstrated that the step response with a limiter was better. It was more vital when the distance was increased. Object detection will ascend in far distances when the field of view decrease.

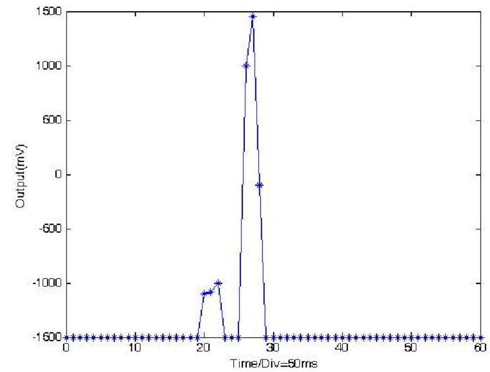

Figure 3. Step response without limiter at distance= 1m

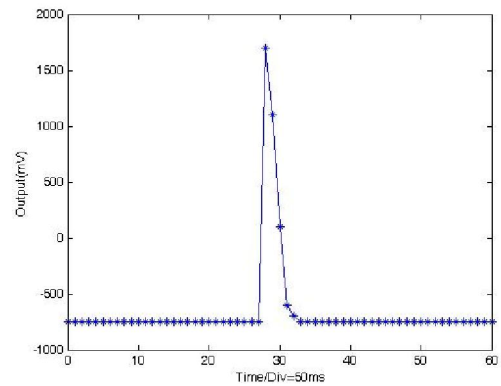

Figure 4. Step response with limiter at distance= 1m

The field of view of the detector was another parameter that had to be determined. In this case, the detector was turned around in its axis, in front of a constant heat source. The field of view of the detector was calculated according to the output signal from the oscilloscope, after setting a reference position, and the values plotted were versus the polar angle relative to the angle of the reference signal, as is shown in Figure 5. The results illustrated that distance did not have an effect on the field of view of the detector.

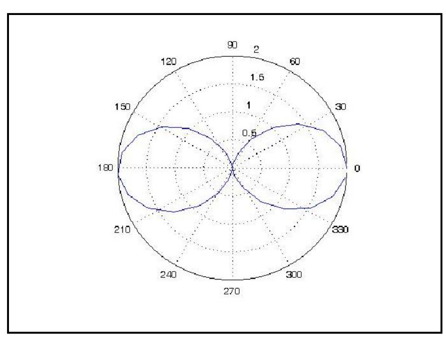

Figure 5. The field of view of detector in distance =50 cm

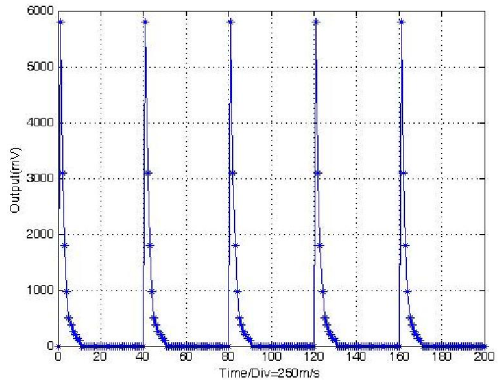

Figure 6. Output signal of detector

Table 1. The output signal to detect object in different distances

Distance (cm)	Amplitude of output signal (V)
25	5.8
50	5.2
75	4
100	3.8
125	2.6
150	2
175	1.35
200	1
225	0.75
250	0.6

The output signal of detection is examined in different distances that it has some limitations relative to distance to target. When the distance is increased, the amplitude of output signal is decreased, which is shown in Table 1. According to this table, the normalized response of detector as the actual curve is shown in Figure7. In addition, the optical signal drop rate as the ideal curve is defined by $1/R^2$ that is also shown in Figure 7, where R is the distance. Hence, actual and ideal curves have great difference because of the rapid reduction of $1/R^2$ at the distance of less than one. Besides they are similar to each other at distances larger than one, as is shown in Figure 8.

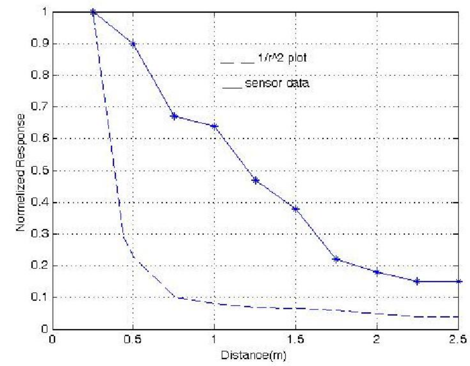

Figure 7. Sensor response in comparison to $1/R^2$

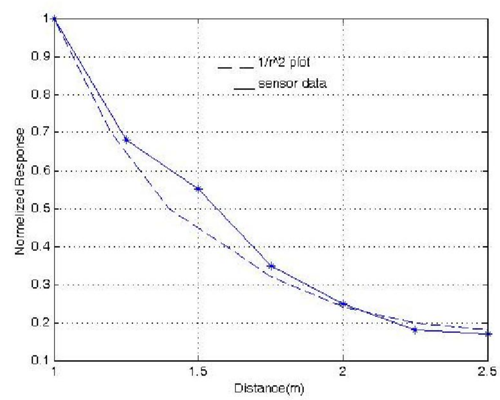

Figure 8. Sensor response in comparison to $1/R^2$ at distance more than 1m

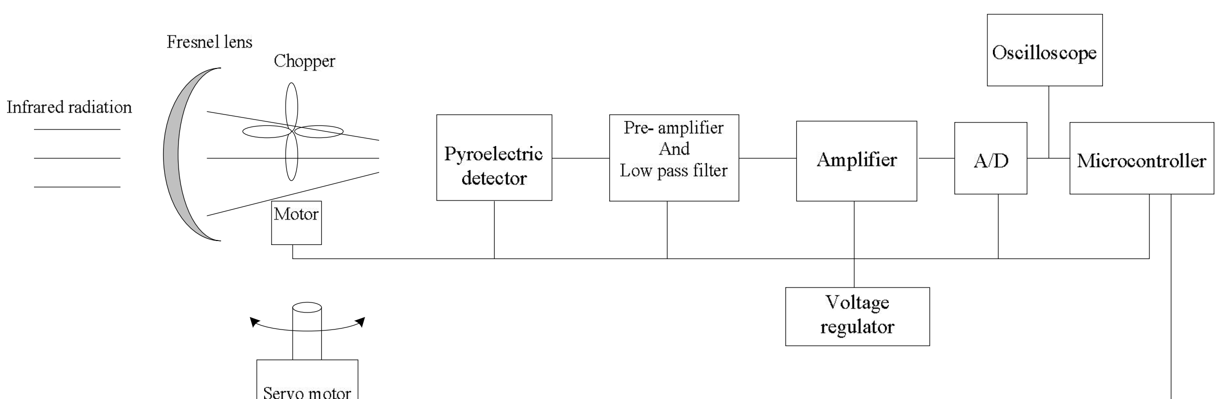

Figure 9. Block diagram of proposed system to determine the position of hot object in two dimensional spaces

There are different methods to increase output response of the system. The system detection distance as output response of the system can be increased by ascending gain rate of amplifiers, using Fresnel lens to focus the infrared waves on detector level, using material with high pyroelectric rate to build detector, increasing the received signal power by detector, and decreasing the field of view of detector.

Reduce the field of view of object detection makes it better off in long distances. At first, the aluminium pipes with different lengths are used to descend the field of view of detector, but the result is not acceptable. Then, the industrial pipes of plastic with different lengths are considered. These pipes lead to reduced field of view of detector. In this test, field of view of detector is practically decreased from 120° to 70° by means of a 10mm pipe.

Block diagram of proposed system to determine the position of hot object in two dimensional spaces is shown in Figure 9. At first, it is assumed that the target location is constant and invisible, which is shown as noise in the output of system. Calibration of system should be done in a place without infrared source. The maximum amount of noise for output of system in temperature room about 25°c is 0.5v. Then, the output signal with calibrated noise level is compared and two different cases are created. The simplest method to reduce error is Bi-section technique, which determines the target location and especially the centre of target relative to a reference location.

The frequency of rotation of chopper is significant since detector does not sense temperature changes in the very low frequency and leads to restrictions on low- frequency of system. On the other hand, in the too high frequency as defined in the system, due to rapid changes in temperature by chopper, the detector is not able to respond to temperature changes (infrared light). The amplitude of the output signal decreases because of increasing in frequency of rotation of chopper. In the field of view equals to 71°, the minimum and maximum frequency of chopper is 5.83×10^{-2} Hz and 5.8×10^{-1} Hz, respectively.

4. Discussions

The main objective of this research was to design and construct a functional simulator for satellite sensors with earth horizon recognition by means of pyroelectric infrared sensors. To attain this purpose, the initial process of the operation of pyroelectric infrared detectors was examined, and appropriate circuits were designed and constructed to apply these sensors. Next, all system components were completed by connecting the sensors to appropriate circuits.

In terms of the actual work of satellites, unbounded space temperature was equal to 4°K and the earth was detected in the form of a sphere with 233°K in ambient temperature: about 4°K. These conditions were created to test the system performance in real terms; however, given that the temperature of 4°K was not available for testing, the ambient temperature was considered as room temperature (about 303°K) and the temperature of the earth's model was stabilized around 333°K. Hence, this experimental system recognised the temperature difference of about 30°K instead of recognising a temperature of around 299°K. The difficulty was greater than real terms in these conditions. As expected, experimental results did not change.

Several tests were implemented to evaluate the performance of the system in which hot objects were identified as infrared sources in the field of view of the system. The observed results of the digital oscilloscope verified the performance of the system. Next, a spherical model with a specified temperature was made to simulate the earth; then, the detector response of the spherical model was analysed. Several parameters, such as: step response, maximum board, the field of view of detector, minimum and maximum frequency of the chopper and the minimum detectable output, were calculated and the methods were examined to reduce environmental noise.

5. Conclusion

Given in real systems, earth horizon recognition was done by determining centre and diameter of a spherical object. Therefore, the diameter of the spherical object was established by moving the detector in front of the spherical object and applying proven techniques. The centre of the spherical object was determined using its diameter. The earth centre was used as a reference to assess the situation of satellites, and the satellites' axis were placed on the centre of the earth.

A laboratory set, including a heat source to produce infrared waves, digital oscilloscope and pyroelectric detectors with amplifier circuits were utilised to experimentally examine detector parameters. The detector was sensitive to the power supply; therefore, a battery was used to eliminate electrical noise due to the changes of power supplies. In addition, plastic pipes were employed to decrease the field of view of the detector. Moreover, the detector was covered by Fresnel lens to remove the noise of the wind from its performance. The utilisation of the Fresnel lens's coating led to the use of the detector in an open environment.

In conclusion, the position of a hot object was verified by using a pyroelectric detector. The desired results were achieved. In addition, the pyroelectric detector was suitable as a satellite sensor simulator, according to its performance.

Corresponding Author:
Mozhde Heydarianasl
Faculty of Electrical Engineering
Dashtestan Branch
Islamic Azad University, Iran
E-mail: heydarianasl23@yahoo.com

References

1. Armitage A, Binnie D, Kerridge J, Lei L. Measuring pedestrian trajectories using a pyroelectric differential infrared detector. 2003.
2. Astheimer R W, Schwarz F. Thermal imaging using pyroelectric detectors. *Applied optics*, 1968; *7*(9): 1687-1695.
3. Bodor R, Jackson B, Papanikolopoulos N. Vision-based human tracking and activity recognition. In *Proc. of the 11th Mediterranean Conf. on Control and Automation* (Vol. 1). June 2003.
4. Fang J S, Hao Q, Brady D J, Shankar M, Guenther B D, Pitsianis N P, Hsu K Y. Path-dependent human identification using a pyroelectric infrared sensor and Fresnel lens arrays. *Optics express*, 2006; *14*(2):609-624.
5. Feller S D, Cull E, Kowalski D P, Farlow K, Burchett J, Adleman J, Brady D J. Tracking and imaging humans on heterogeneous infrared sensor arrays for tactical applications. In *AeroSense 2002*; 168-175. International Society for Optics and Photonics.
6. Fresnel Technology Inc., http://www.fresneltech.com/arrays.html.
7. Gopinathan U, Brady D, Pitsianis N. Coded apertures for efficient pyroelectric motion tracking. *Optics express*, 2003; 11(18): 2142-2152.
8. Hao Q, Brady D J, Guenther B D, Burchett J B, Shankar M, Feller S. Human tracking with wireless distributed pyroelectric sensors. *Sensors Journal, IEEE*, 2006; 6(6): 1683-1696.
9. Hobbs P C. Ten-dollar thermal infrared imager. In *Intelligent Systems and Advanced Manufacturin.* 2001; 42-51. International Society for Optics and Photonics.
10. Jones G D, Hodgetts M A, Allsop R E, Sumpter N, Vicencio-Silva M A . A novel approach for surveillance using visual and thermal images. 2001.
11. Kakuta N, Yokoyama S, Nakamura M, Mabuchi K. Estimation of radiative heat transfer using a geometric human model. *Biomedical Engineering, IEEE Transactions on*, 2001; 48(3): 324-331.
12. Keller H, Cima D, Instruments, E. L. T. E. C. *Choosing and using pyroelectric detectors* (Vol. 101). Eltec Instruments Application Note. 1992.
13. Keller H J . Passive infrared technology for security systems and law enforcement. In *Proc. AES Conf., Madrid*. 1984.
14. Pradhan M M, Garg R K. Pyroelectric null detector for absolute radiometry. *Applied optics*, 1982; 21(24): 4456-4458.
15. Planck M. On the law of distribution of energy in the normal spectrum. *Annalen der Physik*, 1901; 4(553), 1.
16. Sekmen A S, Wilkes M, Kawamura K. An application of passive human-robot interaction: human tracking based on attention distraction. Systems, Man and Cybernetics, Part A: *Systems and Humans, IEEE Transactions on*, 2002; 32(2): 248-259.
17. Spitzer V, Ackerman M J, Scherzinger A L, Whitlock D. The visible human male: a technical report. *Journal of the American Medical Informatics Association*, 1996; 3(2): 118-130.
18. Shankar M, Burchett J B, Hao Q, Guenther B D, Brady D J. Human-tracking systems using pyroelectric infrared detectors. *Optical Engineering*, 2006; 45(10): 106401-106401.
19. Takeo I, Shozo T. Pyroelectric detectors for space application. *Journal of the Japan society of I.R. science and technology*,1999; 9(1): pp. 34-40.
20. Tsai C F, Young M S. Pyroelectric infrared sensor-based thermometer for monitoring indoor objects. *Review of Scientific Instruments*, 2003; 74(12): 5267-5273.
21. Vlaam S. Object tracking in a multi sensor network. *Master's thesis (Delft University of Technology, The Hague, 2004)*.

6/6/2014