AN ESTIMATION OF A PASSIVE INFRA-RED SENSOR'S PROBABILITY OF DETECTION

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Passive Infra-Red (PIR) sensor is one of many detection sensors used to detect any intrusion process in the nuclear sites. In this work, an estimation of a PIR sensor's probability of detection for a hypothetical nuclear facility is presented. Sensor performance testing performed to determine whether a particular sensor will be acceptable in a proposed design. We have access to a sensor test field in which the sensor of interest is already properly installed and the parameters have been set to optimal levels by preliminary testing. PIR sensor construction, operation and design for the investigated nuclear site are explained. Walking and running intrusion tests were carried out inside the field areas of PIR sensor to evaluate its performance during the intrusion process. Ten trials experimentally performed for achieving the intrusion process via a passive infra-red sensor's network system. The performance and intrusion senses of PIR sensors inside the internal zones was recorded and evaluated.

Keywords: Passive infrared sensor, Probability of detection estimation, Sensor evaluation procedures.

INTRODUCTION

Passive Infra-Red Sensors have been around since the 1940s, originally being used for military and scientific applications. Now the technology is being used in a wide range of products designed specifically for commercial and domestic automatic lighting. Today's modern sensor maximizes efficiencies in automatic light control, promoting convenience, safety and cost-savings. PIR sensor is an electronic ON-OFF switch designed specially for switching lighting loads. The alarm system which includes many hundreds of PIR sensors is defined as that part of security system designed to safeguard personnel; to prevent
unauthorized access to equipment, installations, material, and documents; and to safeguard against sabotage, damage, and theft [1].

In our paper titled PIR sensors we introduced passive infrared (PIR) sensors and summarised their operation and design. Of particular interest to us are 12 Volt DC powered PIR sensors and associated circuits since these can be powered directly from a 12 Volt battery which is in turn charged by wind, solar, or other renewable energy sources. In this paper we will look at the ways in which the excellent Honeywell model IS-215T 12 Volt DC PIR sensor can be used by the renewable energy enthusiast with lighting and security systems [2]. PIR sensor's probability of detection should be worked experimentally to verify the data as inputs for models calculations for each site under investigation. The evaluation process shall not depend on listed or measured data such as sensor's probability of detection and delay time path elements for other sites.

PASSIVE INFRA-RED SENSORS (PIRS)

The PIR motion sensors detect a change in the thermal energy pattern caused by a moving intruder and initiate an alarm when the change in energy surrounding environment. These sensors are passive devices. All objects with temperatures above absolute zero radiate thermal energy. The wavelengths of infrared energy spectrum lie between 1 and 1,000 microns. Because the human body radiates thermal energy between 7 and 14 microns, PIR motion sensors are typically designed to operate in the far IR wavelength range of 4 to 20 microns, figure (1) shows the PIR detection region.

![Figure 1: PIR Motion Sensors Detection Field.](image)


All PIR sensors detect changes in infra-red radiation, in the form of heat emitted by a number of bodies including people, cars and, to a lesser extent, dogs or other small animals. In the bigger body, more infra-red radiation is emitted and it is easier for a PIR sensor to detect. The field of view is the area in which changes in infra-red radiation can be detected (figure 2). The field of view can alter with changes in temperature and the size of the heat source. The construction of PIR and the Fresnel lens (Figure 3) divide the field of view into a number of zones both vertically and horizontally, as shown in the diagram overleaf. Each zone is constantly monitored by the sensor. When a person or other heat source enters any zone, the level of infra-red radiation in that zone increases. This change is detected and processed by the sensor, switching on the connected lighting and starting the in-built ‘Time’ process. Providing the heat source (person) continues to move in the field of view, PIR sensor will keep processing the changes in infra-red radiation and the lighting will stay on. If a person stands still in the field of view or moves out of the...
detection area, the sensor will not detect any changes in infra-red radiation between the zones and the lights will go out after the ‘Time’ period is complete.

![Figure 2: PIR Field of View and Detection Zones.](image)

In order to the sensor detect effectively the changes in heat between its zones; it is advisable to walk across the covered zones of it and not up or along detection zones. PIR sensors are passive devices; they do not emit or radiate any energy or beams.

![Figure 3: PIR Constructions.](image)

1.1 Multi element Fresnel lens
The lens focuses the infra-red radiation given out by a heat source (person) on to the pyroelectric sensor. The different elements or facets of the lens divide the incoming infrared radiation into vertical and horizontal zones.

1.2 Pyroelectric passive infra-red sensor
The dual element Pyroelectric sensor receives the incoming infra-red radiation from the various zones. The two elements of the sensor receive varying amounts of infra-red radiation and this difference is amplified, turning into a signal via the integrated circuit.
This signal activates the switching relay. The sensor detects infra-red radiation in the wavelength range (8 – 14) meter.

1.3 Photoelectric Cell (Daylight Sensor)

The photoelectric cell registers the light intensity (Lux level) of the surrounding area. When the light intensity exceeds the pre-set value, the signal from the PIR sensor is then prevented from switching the load. When the Lux level is below the pre-set value, the signal from the PIR sensor is then allowed to switch the load.

1.4 Time, Lux and Sens Potentiometers

Control potentiometers are provided for the external adjustment of time, Lux and PIR sensitivity (for selected models only).

1.5 Integrated Circuit Control Chip (IC)

This is a customized chip which controls the various modes of operation, timing functions and the processing of the signal from the sensor to drive the output relay.

1.6 220/240V Relay

Because all most of PIR sensor types use a 220/240V relay, there is no minimum load requirement. Do not exceed the maximum rating of the sensor especially with fluorescent loads.

2. Effects of Temperature Changes on PIR Sensors

All PIR operate by detecting the temperature difference between the ambient air temperature and a moving heat source (person). Outside air temperature changes have the greatest effect on the operating performance of PIRs, the sensitivity of the sensor increases on cold nights and decreases on hot nights. On cold nights, the difference in temperature between a person (normal body temperature is 37 °C) and the outside air temperature is relatively large, giving an apparent increase in performance of the sensor. On hot nights, this difference in temperature is relatively small and a decrease in performance of the sensor can be expected. At 15–20 °C the sensor should perform according to the stated specifications. If the ambient temperature increases to 30 °C or more, the following changes will occur:

1. The maximum distance and field of view significantly decrease (up to as much as 50%).
2. The distance from a heat source has to move across the zones to activate the sensor increases (fig. 4).
3. The size of the heat source required to activate the sensor increases, and,

At an ambient temperature of 10 °C or less, the opposite occurs: -

1. The maximum distance and field of view increases.
2. The distance from a heat source has to move across the zones to activate the sensor decreases.
3. The size of the heat source required to activate the sensor decreases.
Sensor performance testing performed to determine whether a particular sensor will be acceptable in a proposed design. We have access to a sensor test field in which the sensor of interest is already properly installed and the parameters have been set to optimal levels by preliminary testing. But in our case a hundreds of passive infrared sensors had been installed in an alarm system network and it needs to determine its probability of detection [7]. This will permit us to make an evaluation to the current status of the overall physical security system because the alarm is a part of the overall security system. Looking for low areas, or shadowed areas from uneven terrain, these will be weak (low detection) spots [9]. Performing a few tests near the sensor head to determine where offset occurs. 10 trials at the potentially weakest areas were performed as minimum trials numbers [6]. A medium person was entering the detection view field of the infra-red sensor and causes a disturbance action & showing if the sensor generates an alarm or not. All trials will be worked on different areas and many fields of sensors [4]. Chart recorder will record the data during intrusion process. The intruder makes running, and walking tests inside the internal zones. The AMN124 PIR sensor type will be selected to obtain probability of detection.

1. PIR Sensor Technical Specifications
   Used Type = AMN124 PIR Motion Sensor, 10 meters detection type [2].
   Worked ambient temperature, from -20 C° to 60 C°
   Power supply voltage =7 VDC
   Detection Current =15 m A
   Non-detection currents, from 0 to 2.5 m A
   View Field =5×5 meters
   Vertical angle, from, -11 to 11
   Horizontal angle, from -19 to 19
   PIR dimensions and field view is illustrated in figure (5), and figure (6) describes the digital output circuit of AMN124 PIR Type [5].
2. Evaluation Procedures and Steps

1. Setting the Lux (measure of illumination or light intensity), time and Sensitivity (SENS) where it should be verified the following considerations:

- If set the Lux to the maximum (‘+’ end), it will switch during most light conditions from darkness to sunlight (40 Lux to 2000 Lux). If set to minimum (‘−’ end), the sensor will only operate at dusk or light conditions darker than this. This is the ideal position for general early evening and night operation. If we adjust the Lux control so that the sensor will work in any light level from 40 Lux upwards to approximately 2000 Lux by moving the control further towards the ‘+’ end (See the Lux control setting switcher in figure (7)).

Figure 5: PIR Field View Dimensions.

Figure 6: Block Diagram of the Digital Output Circuit.

Figure 7: Lux Control Setting.
• The PIR sensor has an adjustable ‘Time’ control which is adjustable from approximately 10 seconds to 5 minutes. When infra-red radiation from a moving heat source is detected, the sensor switches on the lighting load and begins timing out according to the pre-set ‘Time’ period. After the ‘Time’ period has elapsed, the lighting load will be switched OFF. If the heat source continues to move in the PIR field of view, the time control will keep resetting itself and the lighting load will remain ON. Once the heat source (intrusion person) stops moving or moves outside the field of view, the time control will start timing out and eventually switch the lighting load off. If the sensor is set at 5 minutes and it detects a moving heat source every three or four minutes, the light will stay on continuously. The ideal ON time for general domestic situations is two to three minutes. Figure (8) shows the time control setting switcher positions.

![TIME SETTING](image)

Figure 8: Time Control Setting switcher.

• The sensitivity adjustment affects the following:-
- Minimum and maximum range
- Amount of infra-red radiation (heat) required to trigger the sensor. The sensitivity adjustment can also be used to compensate for the changes in outside air temperature in winter and summer. With the sensitivity control set to the middle position and the ambient air temperature between (15–20) °C, the sensor will perform similar to the specified range and performance, with nuisance tripping to a minimum.

2. Turn on power to the sensor and wait one or two minutes for the sensor to stabilize.
3. Turn the ‘Time’ control to minimum (‘−’) and the ‘Lux’ control to maximum (+).
4. Repeat step 2 and adjust the angle of the sensor head until the optimum field of view is achieved.
5. Turn the ‘Time’, ‘Lux’ and ‘Sens’ (where available) controls to the desired positions for AUTO mode operation (See figure (9)).
6. Turn off power to the PIR sensor
7. Connect an oscilloscope device (for testing the operation of PIR) to the comparator output circuits (Output-Ground (GND)) of PIR circuit (See timer circuit output in figure10) [8].
8. Turn on power to the oscilloscope device.
9. Turn on power to the PIR sensor again and wait 3 minutes.
2. Timer circuit example

1) Digital output

![Diagram of a digital output circuit]

**Figure 10:** PIR's Timer Circuit Diagram

10. Walk by medium person in front of the sensor unit so that the light comes on. This initiates the operation of the sensor and disturbs the field of view. Once the light comes on, move to a new position and stand still until the light goes out (approx. 10 sec), move again until the light comes on. The ideal direction of movement is across the field of view, not along it. PIR sensors detect changes in heat between zones. The more zones the heat source crosses, the more easily it is detected.
11. Measures the output currents at output connection port and records the alarms which generated when intruder in the view field.
12. Repeat intrusion process for 10 trails. After each test ensure that the PIR detection view field is ready, and then go through the field. Adjust all setting after each test.
13. Repeat all steps with another PIR sensor at another location.
14. Plotting the output signals and recording alarms.
15. Obtain P (d)

RESULTS AND DISCUSSION

1. PIR Timer Circuit Output Results

During the PIR intrusion process and recording the output results; the timing diagram in each intrusion process case is plotted and obtained from the oscilloscope device. It is noticed that there are 10 trials had been worked and illustrated in figure (11).

![Timing Diagram](image)

Figure 11: PIR Timer Circuit Output Results.

Four trials (trials 4=2mA, 6=0mA, 8=0mA, 10=1.5mA) the PIR sensor failed in detection the intrusion process and the output current was 0-2.5mA, and these values considered not alarm values. One trial (trial no 7) recorded 12mA (it considered a fraction of alarm value=15mA) and the remained five trials (trials 1, 2, 3, 5, 9), PIR sensor success in recording alarms and the output current was 15mA (detection current). See figure 11.

2. PIR Probability of Detection Results

PIR probability of detection and output results is illustrated in table (1).

Table 1: PIR Output Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Sensor's type (PIR)</th>
<th>No. of trials</th>
<th>Successes trials (Alarm)</th>
<th>Failed trials (no signals)</th>
<th>Record trial small current &quot;Alarm&quot;</th>
<th>Probability of detection P (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrusion</td>
<td>Passive Infrared</td>
<td>10</td>
<td>5 Io/p=15mA</td>
<td>4 Io/p=2.5mA</td>
<td>One trial Io/p=12mA</td>
<td>58%</td>
</tr>
</tbody>
</table>
CONCLUSION

- An estimation of a passive infra-red sensor's probability of detection for a selected nuclear site peripheral fence was carried out experimentally.
- 10 trials performed for achieving the intrusion process via an alarm network system includes a hundreds of PIR sensors installed on it. In 5 trials, PIR module sensors successes in recording intrusion alarms, and fails in 4 trials to detect the intrusion process. In one trail, PIR sensors record small alarm current and it is not sufficient to generate alarm.
- The obtained results showed that the tested and experimented PIR sensors have a probability of detection P (D) value 0.58 founded and the sensor performance is reported.
- The probability of detection for PIR sensors is a necessary factor for the physical protection system evaluation.
- The experimental verified data is necessary as inputs for models calculations for each site under investigation.
- The evaluation process will not depend on listed or measured data such as sensor's probability of detection and delay time path elements for other sites.

REFERENCES