XCT™ Technology from Lutron®:
The New Standard in Sensing

Technical white paper
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Introduction

Occupancy sensors have long been used to control lighting based on the presence or absence of people within a space. They work in two ways: as an occupancy sensor or as a vacancy sensor. An occupancy sensor automatically turns on the lights when a person enters the room and then automatically turns the lights off when the room is vacant. A vacancy sensor requires the person to manually turn the lights on and then automatically turns the lights off when the room is vacant.

Passive infrared (PIR) sensing has been the mainstay technology used in these products. PIR sensors determine when a space is occupied by detecting the heat (in the form of infrared energy) from people moving within a space. The chief benefit of using these sensors is the energy savings that result from automatically turning off lights when the space is unoccupied.

Standard PIR sensors have significant performance problems. Most PIR sensors are good at detecting major motions like a person walking; however, they have difficulty detecting the fine motions made by a person working at a desk or reading a book.

The basic problem is the sensitivity setting. If the sensitivity is set too high background interference and noise trip the sensor and the sensor turns lights on when a space is unoccupied. This wastes energy. If the sensitivity is set too low, the sensor cannot sufficiently detect fine motion and it turns lights off while people are still in a space. These “false on” and “false off” events give users a bad experience and leave them with the impression that the technology doesn’t work.

Within state-of-the-art sensors, sensitivity calculations are computed using an **adaptive sensitivity algorithm**. In this method, the sensor identifies periods of time (from historical recordings) when it is likely detecting only noise, and automatically adjusts the sensitivity so that the lights do not turn on accidentally. This adjustment avoids detecting noise; however, it also reduces the sensor’s ability to detect fine motion.

The new Lutron® XCT™ technology takes measurements in a totally new way dramatically improving the performance of passive infrared sensors.

The algorithms in Lutron sensors with XCT technology accurately distinguish the difference between background noise and actual motion so that sensitivity adjustments are unnecessary. Occupancy decisions are made solely on the basis of actual movement in the space—even fine motion like fingers typing on a keyboard, turning the page of a report, or writing on a tablet.

By acknowledging the fact that noise is present in the measurement, Lutron XCT technology enables the sensor to retain high sensitivity to fine motion **without** creating the “false on” conditions that waste energy, or the “false off” conditions that leave occupants in the dark.

Detecting People's Motion

Passive infrared sensors detect people's movements by detecting the heat of the body. The detector at the heart of the sensor is specially designed to respond to optical energy (light) in the infrared spectrum (Human bodies emit infrared energy at about 9.5 μm). A sensor's operation is illustrated in Figure 1.

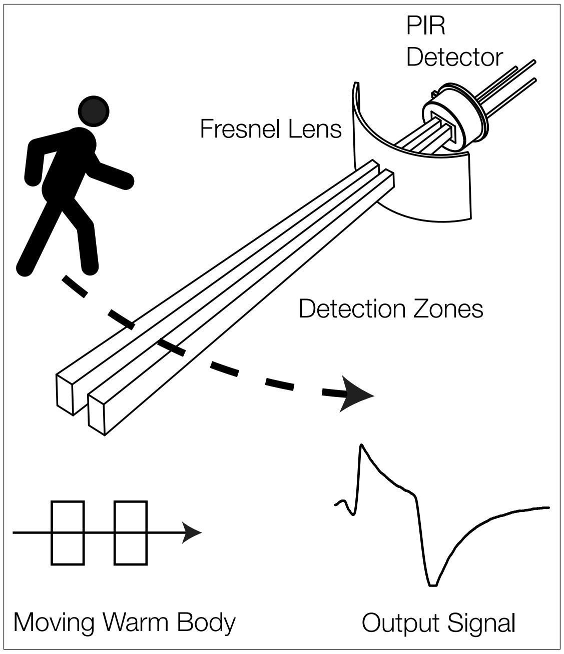

Figure 1. Person walking through the detection zones of a PIR detector equipped with a Fresnel lens.

Standard methods used to detect a PIR signal are simple. Motion from a person passing through the detection zones of a PIR sensor modulates infrared energy across the detector generating a small electrical signal. The signal is amplified and compared to a threshold, as illustrated in Figure 2. If the signal exceeds the threshold, then occupancy is detected.

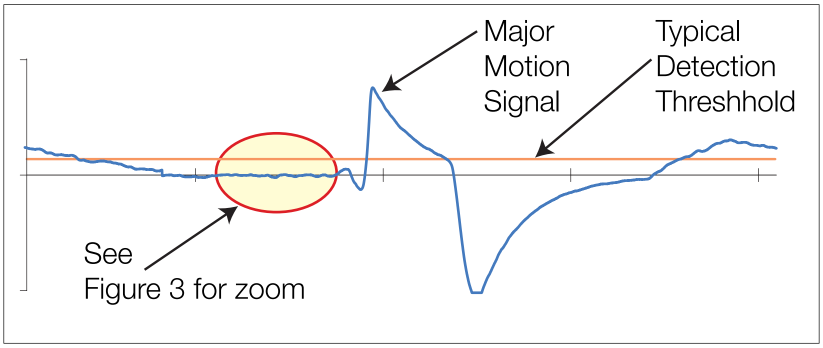

Figure 2. Major motion results in a large PIR signal that far exceeds a typical detection threshold. Occupancy is detected when the signal exceeds the threshold.

The problem with this approach is that the **noise in the detector and the interference in the room limit the sensitivity of the sensor.** This problem is illustrated in Figure 3. The threshold is set so low that noise and interference begin tripping the sensor, erroneously indicating occupancy.

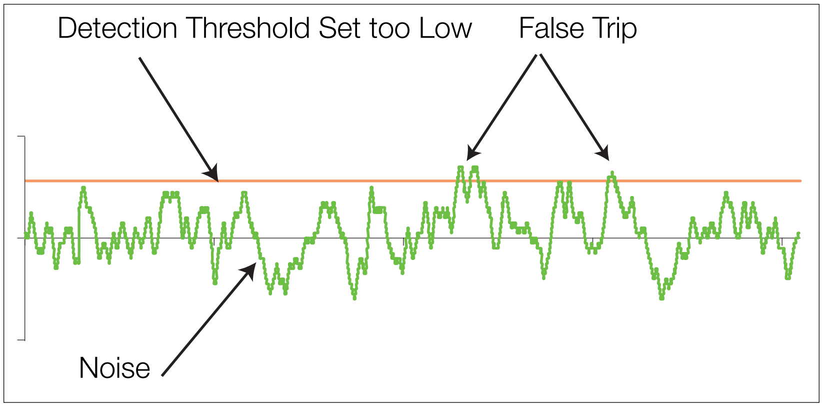

Figure 3. False trips result when the detection threshold is set near the noise level. Note that the scale of this figure is a 20 times zoom of the scale in Figure 2.

This is where the new Lutron® XCT™ approach to detection redefines PIR technology.

Any of the sensors on the market can detect major motion such as a person walking across a room. However, people are not always walking around in the room. Quite often they are sitting still performing a task that consists only of fine motions.

It is in these situations where it is desirable to have a highly sensitive sensor capable of detecting fine motion. A highly sensitive sensor will prevent the lights from turning off while the room is still occupied, eliminating the “false off” condition that annoys occupants.

However, it is also equally important that the sensor doesn’t waste energy by accidentally turning the lights on when no one is present. Standard sensors falsely turn the lights on when their sensitivity is set too high. The Lutron XCT **signal processing technology** prevents this from happening.

Understanding Signal Processing

Signal processing is the mathematical analysis of the nature and characteristics of signals. Signal processing can be used to enhance, manipulate and interpret signals as discussed in the references [1, 2, 3]. Signal processing is the core technology behind computer games, cell phones, high-definition TV, printers, digital cameras, the Global Positioning System (GPS) and other modern conveniences.

To understand signal processing, let's consider the example of a person learning a task; for instance, a toddler learning to drink milk from a cup. It's a messy process of trial and error and training until the child gains the coordination to drink from the cup without spilling the milk. The process is fraught with errors—milk spilling everywhere. The toddler's mind is measuring the error at each attempt and continuously improving.

Clearly, trying to understand the complex processes that take place during human learning would be an impossible task. However, the fundamental objective in this case is to minimize the spilled milk. A mathematician would model this as follows:

Minimize the error where the error equals spilled milk.

This is precisely what many signal processing algorithms do: they minimize the error.

Applying Signal Processing to Sensor Operation

Errors can take many forms, but for the purpose of this white paper, we want to **minimize the erroneous behavior of the occupancy sensor.** In our case, clearly identifying the presence of the PIR signal (i.e. human motion) is the goal, and we are trying to minimize errors from the background noise and interference. Detecting whether a PIR signal is present reduces to a test. In this test one cost is assigned to falsely turning on the lights and another cost is assigned to missing the detection of an occupant. This is a classic problem in statistics, which can be solved using a **statistical hypothesis test**.

Suppose we are interested in detecting whether a PIR signal is present in what appears to be "noise." Very small, fine motions generate very small modulations, and these very small thermal signals are barely noticeable when examining the data.

If we designate the PIR signal as **s(t)** and the corrupting noise as **n(t)**, then the only possible observed signal, **x(t)**, is

$$\mathbf{x(t)} = \mathbf{s(t)} + \mathbf{n(t)}$$

When measuring **x(t)** there are two cases: PIR signal present and no PIR signal present. Considering these cases results in two hypotheses:

$$H_1\text{: } \mathbf{x(t)} = \mathbf{s(t)} + \mathbf{n(t)}$$

$$H_0\text{: } \mathbf{x(t)} = \mathbf{n(t)}$$

Making an optimal decision whether the signal is present reduces to solving

$$\frac{P_{x\,|\,H_1}(X\,|\,H_1)}{P_{x\,|\,H_0}(X\,|\,H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \lambda$$

where $P_{x\,|\,H_1}(X\,|\,H_1)$ and $P_{x\,|\,H_0}(X\,|\,H_0)$ are the conditional probability densities of observing **x(t)** when the respective hypothesis are true. Being able to minimize the error when making a decision requires understanding the probabilities associated with both the signal and the noise. The key to developing an algorithm is understanding the underlying probabilistic models of the signal and noise.

The Lutron® Approach to Signal Processing PIR Signals

A properly designed detection algorithm requires an in-depth understanding of all aspects of sensor operation. Figure 4 illustrates the aspects of the problem in a simple block diagram.

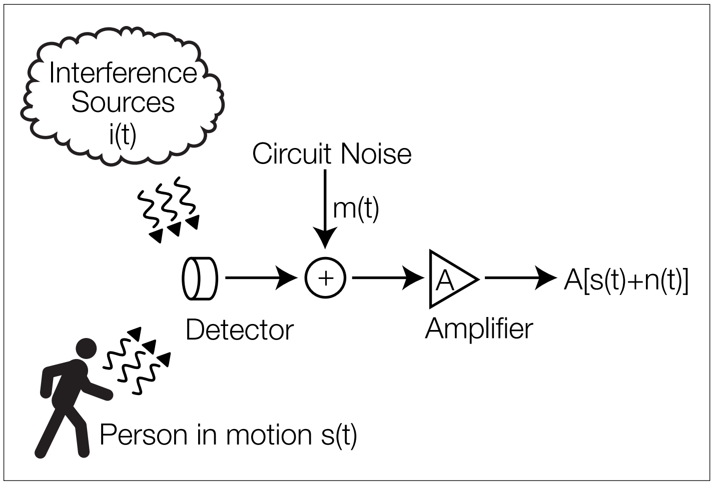

Figure 4. Sensor operation is affected not only by motion, but also by the noise. The noise, n(t), is a combination of interference in the room, i(t), and thermal noise in the circuit, m(t).

Lutron engineers have accumulated and examined massive amounts of data on every aspect of sensor operation including circuit noise, interference sources and human movement. This data was then reduced to statistical models that were used to create the XCT™ algorithm.

For an example of how the statistical models were created, let's look at the physics and statistics involved in sensing a heated object in motion. The object of interest is a person and not every person is alike. They all move differently. They have different heat signatures. They wear different clothing. They sometimes are at rest while other times they are moving ever so slightly. Sometimes they make large movements. Basically, the person's motion is a random process, and that is how Lutron models their motion.

Processing the raw PIR signal through the algorithm enables the sensor to pull a clear PIR signal out of the background and make it easier to detect. Figure 5 shows how the Lutron® XCT™ technology detects a fine-motion PIR signal buried in noise. Before processing, the signal could be mistaken for noise. After processing, the signal is easy to detect. Simply setting the threshold low without processing the signal will result in many false trips.

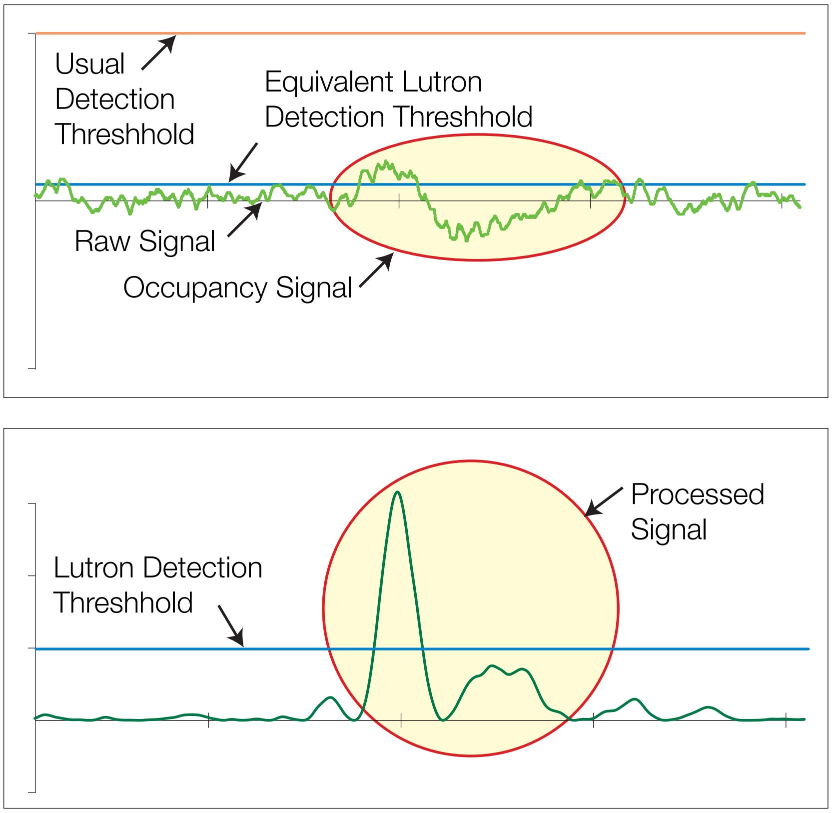

Figure 5. A fine-motion PIR signal buried in noise (upper graph) and the processed signal (lower graph). The fine motion is clearly identified after being run through the detection algorithm.

Based on testing and statistical analysis of the data, **the algorithm doubled the sensor's ability to detect fine motion.**

Testing Sensor Performance

The National Electrical Manufacturer's Association (NEMA) creates standards and guidelines for testing products. The guideline that governs occupancy sensors is WD 7-2000, see reference [4]. Many manufacturers test their products to this guideline, as does Lutron®.

The test uses two test subjects; one is an actual person and the other is a robotic arm. The test facility is large, typically in excess of 50' by 50'. The space is marked off into a grid with each cell of the grid measuring 3' by 3'. The sensor under test is positioned in an appropriate location. If it is a wall sensor, it is placed at an edge of the grid. If it is a ceiling sensor, it is placed in the center of the grid.

The first test is the **major motion test**. The test person is specified to be of a certain size (5'5" and 130 lbs) and dressed in a certain way. The person walks from cell to cell at a prescribed rate and stops in each cell before proceeding. The results are recorded on a diagram of the test space. These tests are used to derive the range for the major motion specifications of the product.

The second test is the **minor motion test**. A robotic test arm is specified to be 3" by 15" and heated to 95° F. The robot is moved from cell to cell before each test. The arm is then moved in a prescribed direction at 90° per second. The results are recorded on a diagram of the test space, and are also used to derive the range for the minor motion specifications of the product.

In general, the two diagrams are combined into one with the major motion covering a larger area than the minor motion. The coverage of the new Lutron® wireless ceiling mount sensor (LRFx-OCRB-P) is shown in Figure 6 as an example.

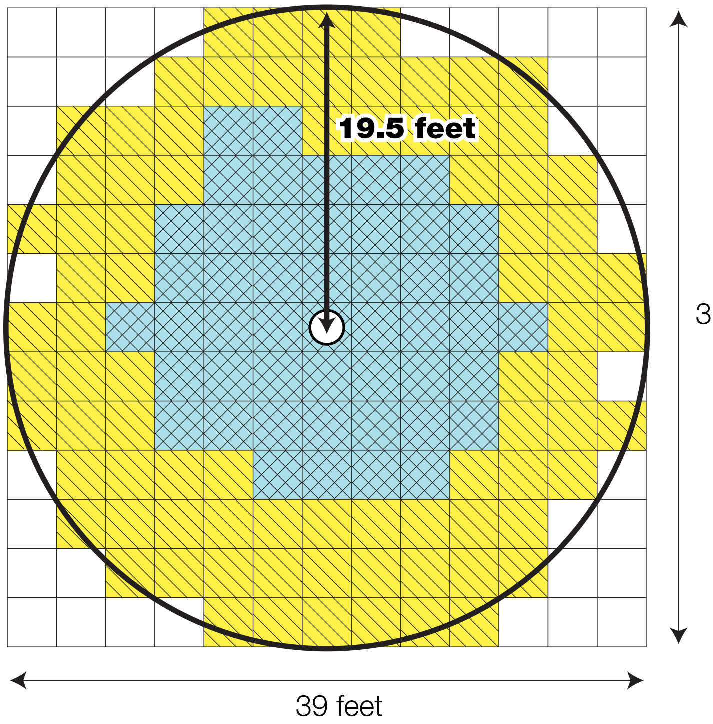

Figure 6. Major motion (yellow / hatched) and minor motion (blue / cross-hatched) test results for the LRFx-OCRB-P sensor.

Unfortunately, the NEMA tests are not adequate to discern the differences in the performance of sensors used in real world applications. The NEMA minor motion test does not adequately test the fine motion often exhibited by humans.

The New Fine Motion Test

NEMA's prescribed tests are not sensitive enough to accurately demonstrate the performance of sensors. The tests in the NEMA guideline produce large signals that are easily detected.

A test was required to accurately evaluate the sensor performance in the presence of fine motion. Taking into account the physics of the detector, Lutron developed a new test that more accurately demonstrates the increased sensitivity required for detecting real human motion.

The NEMA test for minor motion uses a robotic arm with a cross-sectional area of 3". by 15". (45 in^2). The robot arm is heated to 95° F and moved in a 90° motion at 90° per second. This represents an arm wave; for example, a person taking a drink from a cup of coffee.

The **new** Lutron test uses a robot with a much smaller cross-section — 4" by 6" (24 in^2). This size represents a hand and has a cross-section that is just 53% the size of the robot arm. The hand is heated to 90° F (somewhat cooler than the NEMA test) and moved in a 90° motion at 90° per second (same as in the NEMA test). **This new test is referred to as the fine motion test and represents a hand moving; for example, a person typing on a computer.**

Figure 7 shows fine motion test results for a sensor (LRFx-OCRB-P) using the Lutron XCT algorithms. As can be seen, fine motion is detected well out to a 9' radius. Also included in Figure 7 are results for the same test conducted using a sensor without signal processing technology. As illustrated, the fine motion sensitivity improves greatly through the use of the XCT algorithm.

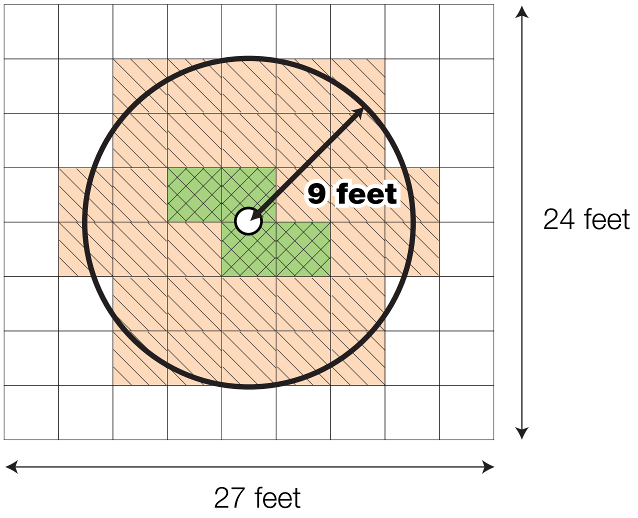

Figure 7. Fine motion test results for the LRFx-OCRB-P sensor with XCT technology (orange / hatched) and for a sensor that is not using signal processing (green / cross-hatched).

Benefits

Having a sensor that does not “false trip” while still being able to detect fine motion makes using sensors more attractive. Typically, 39% of the electrical energy usage in a building is due to lighting (as shown in Figure 8). Since the estimated savings from using occupancy sensors range between 25% and 40%, depending on the space, one can easily understand the importance of using occupancy sensors, see reference [5]. As a result of their inherent energy-saving benefits there is a growing trend for energy codes to require occupancy (or vacancy) sensors in buildings. Sensors that accurately and reliably detect motion in all cases (i.e. fine motion as well as major and minor motion) will help encourage the acceptance of such codes. In an increasingly green-conscious society, the energy and environmental advantages of occupancy sensors can truly help save the planet.

Save energy. Save money. Save the planet.

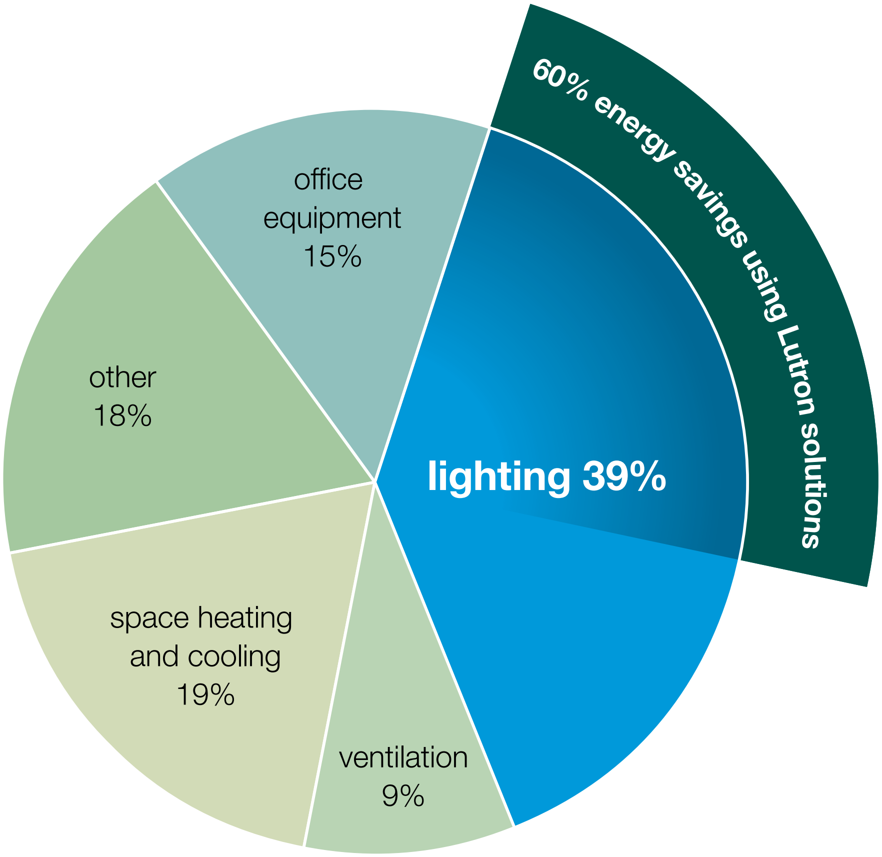

Figure 8. Electrical energy usage in a commercial office building.

Conclusion

The Lutron® XCT™ signal processing technology greatly enhances the performance of PIR sensors, enabling them to “see” fine motions that other sensors couldn’t previously detect. With the advent of this new technology, PIR sensors will find greater acceptance and more wide spread use.

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