

Research on a PIR motion sensor

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Abstract:

For motion detection applications ranging from automated lighting to security systems, passive infrared (PIR) sensors are essential. Using a series of controlled trials, this research assesses multiple parameters to analyze a PIR sensor's performance. Determining the sensor's dependability, sensitivity and accuracy was a primary goal. The sensor successfully prioritizes motion over static heat sources, as seen by the data, which showed neither false positives nor false negatives. Reliable detection was only found up to 1.5 meters, which is less than the datasheet's detection range. In contrast to the indicated 120°, the angle sensitivity detected motion up to 150°, exceeding data-sheet values. These results imply that while PIR sensors are quite good at distinguishing motion from ambient heat, their angular precision and range may change based on environmental conditions. This study cleared out important knowledge on the sensor's usefulness and practical constraints, especially regarding automation and security systems.

I. INTRODUCTION AND BACKGROUND

In recent years, the significance of home security has escalated, with a notable rise in burglary incidents across the UK. Recent data indicates that 9% of UK residents reported being burgled in the past year, with an average loss of £3,896 per incident [1]. Such trends highlight the crucial need for effective motion detection systems to safeguard residential and commercial properties.

Motion detection technology serves as a cornerstone in modern security systems, enabling the identification of unauthorised movements within a designated area. These systems are also vital to other applications, such as automated lighting and industrial automation. Among the diverse technologies employed for motion detection such as ultrasonic, microwave, and tomographic sensors, Passive Infrared (PIR) sensors have appeared as a preferred choice due to their low costs, minimal power consumption, and reliability. PIR sensors operate by detecting infrared radiation emitted by warm objects, for example human bodies. They consist of three primary components: the Fresnel lens which focuses infrared radiation onto the sensor elements, expanding the detection area, a pyroelectric sensor, which generates electrical signals in response to changes in infrared radiation, effectively sensing motion, and the electronic circuitry which processes the signals from the sensor, filtering noise and converting them into discrete outputs for triggering alarms or other responses.

The effectiveness of PIR sensors can be influenced by various factors, including environmental conditions and potential hardware issues. Studies have highlighted that lens obstructions, such as dust accumulation, can diminish sensor performance. Additionally, environmental factors like humidity and temperature fluctuations can affect the pyroelectric elements, leading to false readings. Ensuring the integrity of the electronic components is also essential for our research, as hardware failures can affect the sensor's functionality [2].

In this research project, we focus on the TruSens HC-SR505 Mini PIR Motion Sensor. Our objective is to evaluate

its performance through a series of controlled experiments conducted on King's College London's campus, specifically in 'The Quad' and the outdoor bike storage. These experiments will assess the sensor's performance across detection distance, angle of coverage, and responsiveness to temperature variations. By analysing the sensor's performance in the real world, we aim to provide insights into its suitability for enhancing security measures, explore potential ways for optimisation, to contribute to the development of more robust and reliable motion detection systems, and address the growing need for effective security solutions in both residential and commercial backgrounds.

II. LITERATURE REVIEW

There is vast research on motion sensors. Previous research conducted by Verma et al., 2021, included a sensitivity enhancement of a PIR sensor for motion detection, where a mathematical model was created to analyse the performance of the sensor, with the goal of making it more receptive and achieving better sensitivity. The model investigated the rate of absorption of infrared; the simulation results of voltage output of the model were compared considering these parameters, and specific values were concluded which gave the best sensitivity value. The experiment also showed that enhanced sensitivity increases the efficacy of the PIR system [3]. Another paper, by Yun & Lee, 2014, presented a study of human movement detection and identification using a set of PIR sensors. Three PIR-based modules were placed in a hallway for monitoring people, one on the ceiling and two on opposite walls facing each other. A data set from eight subjects were collected when walking in three different conditions: two directions, three distance intervals and three speed levels. Their findings showed that with the raw data set captured from a single PIR sensor of each of the three modules, more than 92% accuracy was achieved in classifying the direction and speed of movement, the distance interval and identifying subjects [4]. The paper conducted by Kannan, Kumar and Sr, aimed to utilize IoT and PIR sensor technology to create an automatic door control system that offered convenience, security and energy efficiency. The automatic door control system consisted of detecting human presence by opening the door when someone approached it, and closing it once they have passed [5].

Although these papers conducted in depth research on motion sensors, there were areas where there wasn't any research, or we wanted to further examine specific parameters. One parameter that was focused on was the dead time (also known as the blocking time or delay time). Measuring the dead time is important because depending on the sensor's use, the dead time can be modified to make the sensor more efficient. For example a short dead time would be beneficial for an automated door system, for security and energy saving reasons. False positives and false negatives were also an area of interest, since it was important to analyse if the sensor prioritizes motion detection over heat sources. It was also important to further investigate and analyse the distance and angle, since these two are the most important parameters for the functionality and use of the sensor.

III. OBJECTIVES AND QUESTIONS TO BE ADDRESSED

The objective of this report is to measure, verify, and evaluate the performance of a PIR sensor through different experiments, and compare it to the values stated in the datasheet. The key questions to address:

1. How far can the PIR sensor detect motion?
2. What is the angular detection range of the PIR sensor?
3. What is the sensor's dead time before it can detect another motion?
4. How does the sensor's performance vary in hot vs cold environments?
5. Is the motion sensor accurate when the already existing infrared radiation of the environment is relatively high?

IV. METHODOLOGY

Below is a picture of the setup of the sensor for the experiments.

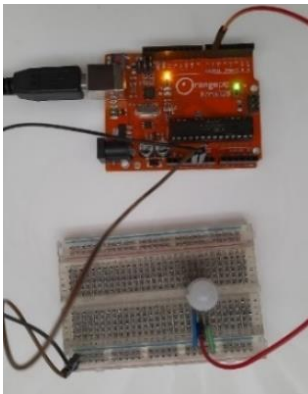


Figure 1: Setup of the sensor

The sensor is connected to an Orangepip Kona328 (which is an Arduino IDE compatible board). Via jumper wires, the sensor's VCC pin connects to the Arduino's 5V output pin, the output pin of the sensor is connected to the board's D6 pin, and the ground pin is connected to the Arduino's GND (ground). The reason why the sensor was placed into the breadboard was to ensure the sensor was stable, for consistency throughout the experiments. The yellow LED on the board indicates that motion was detected. The code below was uploaded to the Arduino for the sensor to detect motion.

```
# define LED 13
int motion;

void setup() {
  Serial.begin(9600);
  pinMode(6, INPUT);
  pinMode(LED, OUTPUT);
  digitalWrite(6, LOW);
  digitalWrite(LED, LOW);
}

void loop() {
  if(digitalRead(6) == HIGH) {
    digitalWrite(LED, HIGH);
    if(motion == 1 && digitalRead(6) == HIGH) {
      Serial.println("Motion detected");
    }
    motion = 0;
  }
  else {
    digitalWrite(LED, LOW);
    if(motion == 0 && digitalRead(6) == LOW) {
      Serial.println("No motion detected");
    }
    motion = 1;
  }
}
```

Figure 2: Motion detection code

Below is Table 1, the specifications of the sensor taken from the datasheet [6].

| Parameter | Value(s) |
|-------------------------|----------------------------|
| Operating voltage range | DC 4.5 - 20V |
| Level output | High 3.3V / Low 0V |
| Trigger | Reusable trigger (default) |
| Delay Time | 8 s \pm 30% |
| Induction angle | <100 degrees cone angle |
| Sensing distance | 3 m |

Table 1: Sensor specifications

A. Dead time

The dead time is the time after each motion detection during which the system is not able to record another detection. To measure this value, the code below was uploaded to the Arduino.

```
unsigned long tStart;

void setup() {
  Serial.begin(9600);
  pinMode(6, INPUT);
}

void loop () {
  if (digitalRead(6) == LOW) {
    tStart = millis();
  }
  else {
    Serial.print("Dead time: ");
    Serial.print(millis() - tStart);
    Serial.println(" ms");
  }
}
```

Figure 3: Code to calculate dead time

To briefly explain the code, when the sensor's output goes low, it stores the current time using millis(). This marks the start of the "dead" period, meaning the sensor is inactive and won't detect new motion. As soon as the sensor goes high again (meaning it can detect motion again), the code calculates: dead time = current time - start time. The result is printed to the Arduino IDE's serial monitor, showing how long the sensor remained high.

Motion was introduced by moving a hand in front of the sensor at a consistent distance of approximately 10 cm, and then it was waited for the time to be printed in the serial monitor to be recorded.

B. Angle Sensing

The aim of this experiment is to validate the angle detection range of the sensor and compare it with the stated value of 100° in the datasheet. Firstly, the sensor was positioned in a fixed and aligned position – on a marked out schematic for angle measuring. The distance was set and controlled at 20 cm from the sensor. The angle at which motion occurred varied with 15° intervals starting with 0° and ending at 180°. The human hand, and its motion was controlled, to ensure an accurate experiment. We repeated the experiment at 40 and 60 cm distances from the sensor, conducting 3 trials at each distance. As the motion was inputted, if the sensor detected it, the LED on the Arduino board would light up. Data was collected and recorded in a table, a value of 1 was assigned if motion was detected, and 0 if the sensor didn't sense motion.

C. Distance

The experiment was first conducted in the Quad. Two tables were joined with double sided tape to reduce noise

from vibrations/accidental impacts. A tape measure was laid perpendicular to the sensor and markings were made every 25cm. A protractor and double-sided tape were used to ensure that the tape measure is perpendicular and remains unaffected by motions that we may not detect, such as if the tables get knocked. See Figure 4 for the experimental setup. A person stood at the intervals and would then move. For the sake of accuracy in measurement, it was important that they didn't move vertically relative to the sensor. Movements were performed 5 times at every interval. For the environment temperature experiment, we moved to the outdoor bike storage area, where the temperature was 6°C, providing a strong contrast to the indoor conditions. The setup remained consistent. There were 10 movements per interval.



Figure 4: The set-up of the Distance experiment, which was similar to the Angle Coverage experiment

D. False Positives and False Negatives

The aim of this experiment was to test the sensor's response in the presence of a strong heat source - a metal kettle with boiling water inside. The test was conducted to determine whether the sensor will reliably detect human motion while a boiling kettle was placed within the module's field of view. The hypothesis was that a kettle is hotter (up to 63°C) than a hand and may mask its heat signature. The test also investigated the cause of the shorter detection range than the data sheet value – see section VC.

The setup consisted of a boiling kettle placed in front of the sensor at two distances - 10cm and 50cm. Motions of two types were performed: hand movement next to and in front of the kettle and full-body motion around it. This test determined if false positives (sensor detecting motion when none is present) can be caused by the heat emitted from the kettle (near 100°C), and false negatives (sensor failing to detect actual movement) can be a result of the interference of the heat source and strong IR emissions. This is particularly important to understand if the module sensitivity may vary with distance, particularly given the previously noted limited detection range. If the sensor distinguishes motion from heat increases, there should be no false detection of movement. This experiment highlighted potential limits of real life uses of the sensor; in applications where heat sources may be found.

V. RESULTS AND DISCUSSION

A. Dead time

This experiment was run 10 times, and the results are shown in the Table 2.

| Iteration | Dead time (ms) | Dead time (s) |
|-----------|----------------|---------------|
| 1 | 8651 | 8.651 |
| 2 | 8252 | 8.252 |
| 3 | 8501 | 8.501 |
| 4 | 8477 | 8.477 |
| 5 | 8551 | 8.551 |
| 6 | 8477 | 8.477 |
| 7 | 7480 | 7.480 |
| 8 | 8526 | 8.526 |
| 9 | 8402 | 8.402 |
| 10 | 8227 | 8.227 |

Table 2: Results of dead time experiment

With these values, the mean is calculated to be 8.354 s, the sample variance is 0.111 s and the sample standard deviation is 0.334 s. The small variance and standard deviation show the consistency of the time values, and since the time delay of the sensor stated in the data sheet is $8 \text{ s} \pm 30\%$, the results can also be verified to be correct. A mean value of 8.354 s could be used in certain automatic lighting systems, but it does present limitations because it wouldn't be long enough or short enough to be ideal for the previous sensor usage examples, so it would need either modifying or using a different sensor in general. Using the mean and standard deviation, the normal distribution can be plotted below.

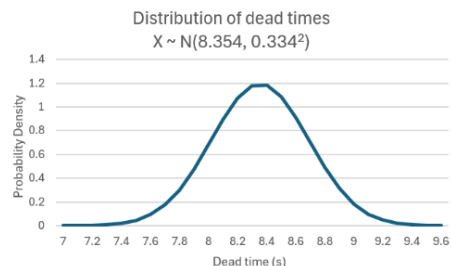


Figure 5: Normal distribution plot of dead time results

The bell-shaped curve indicates the results follow a Gaussian distribution. The graph also shows that the results are not skewed, and most dead time values (95%) are ± 2 standard deviations from the mean, in this case, this is 0.668, leading to the range of values being 7.686 to 9.022. A statistical test can also be performed to test whether the data can be normally distributed. For this data, the Kolmogorov-Smirnov test was performed, and a K-S test statistic (D) of 0.260 was computed, and since this value is less than the p-value of 0.41 for an α value of 0.05, we can assume that the data of the dead times are normally distributed.

B. Angle Sensing

The results for the experiments at distances of 20 cm, 40 cm, and 60 cm are shown in Figure 6. For 20 cm and 40 cm, the detection range was observed to be 30° to 150° (120° conical range), which is wider than the 40° to 140° range stated in the datasheet. This error may have occurred due to factors such as increased sensitivity at closer distances, slight misalignment of the sensor, or other IR sources interfering. However, at 60 cm, the detection range was 40° to 140°, aligning with the datasheet value. This result showed that at a larger distance, the sensor detects motion more accurately, potentially due to lower sensitivity. The experiment was conducted three times for each distance and showed consistent results across all trials. Throughout the experimental process, occasional detections occurred outside

the expected range, likely due to random interferences, such as accidental movement from nearby hands or arms.

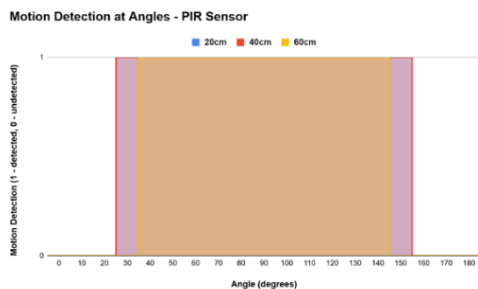


Figure 6: The angular range in which motion was detected

C. Distance

The sensor did not detect distances up to 3 m and thus contradicts the data sheet [6]. See Figure 7 below:

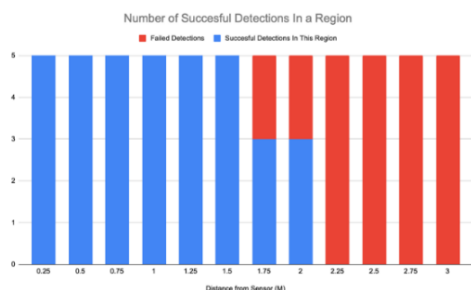


Figure 7: A chart shows the sensor was accurate up to 1.5 m indoors

As seen, the sensor struggled to accurately detect movements beyond 1.5 m. This contrasts with the data sheet: movement can be detected up to 3m. From 1.75m to 2m, the sensor activated for 3 out of 5 trials. Past 2 m, no motion was detected. This could be due to dust in the module or similarity in the temperature of the human and the ambient temperature.

For the environment temperature experiment, there was an improved distance detection, where the sensor detected motion between 2.0 and 2.5 m across 10 trials, but was not able to exceed 2.5 m. The angle performance did remain the same whereas the blind spots at extreme angles did not improve. Nevertheless, this experiment demonstrates that colder outdoor conditions improve motion detection distance, mainly due to a stronger infrared contrast between the human body and the cooler background.

D. False Positives and False Negatives

Motion detection was evaluated at two distances with movement occurring both next to and in front of the kettle. The results in which 10 iterations have been done for each case are: for 10 cm distance from sensor, hand motion next to kettle and hand motion in front of kettle led to 0 false positives and 0 false negatives, and for 50 cm distance from sensor, full body motion next to kettle and hand motion in front of kettle led to 0 false positives and 0 false negatives.

The findings indicate the PIR sensor operated consistently, ensuring precise motion detection despite a nearby heat source. No false positive detection means that the sensor didn't interpret the stationary intense IR as movement. Moreover, the lack of false negatives proves that the module maintained its responsiveness to motion, even when a high-

temperature object partially blocked the field of view. The results show that the PIR sensor is better at finding motion than specific temperature readings, meaning that it can distinguish the effect of stationary heat sources. This fits with how it works, since it uses differences in infrared radiation instead of static heat sources to find motion. The results show that the apparent range limitations may be caused by changes in the surroundings, the placement of the sensors, or changes in their sensitivity, rather than a basic problem with the module itself. This test shows that the PIR sensor is suitable for detecting motion, even with thermal noise. This makes it perfect for real life cases where heat sources are present and motion should be detected while that heat source is stationary or moving in the range of the sensor.

VI. CONCLUSION & FUTURE WORK

This report verified the sensor's congruence to datasheet values and its suitability in industrial applications.

Regarding the data sheet values, there was mixed success. The delay time was confirmed within the stated error, but the angle coverage disputed the data sheet. The sensor was triggered by movements up to 10° wider per side than stated in the data sheet. In the distance experiment, accurate measurements were only taken up to 1.5 m away from the sensor - detection occurred for up to 60% of movements beyond this. Due to deviation from data sheet values, it cannot be used in security applications. Its inability to reliably turn on beyond 1.5 m makes it a risk to a customer - it allows a criminal to operate in the stated range. Perhaps it could be used when there is no risk to human life or expensive goods. Its apparent detection outside the stated coverage angles allows for the possibility of false positives, inconveniencing a customer if a response is triggered. The 8.354s dead time makes it too slow to react in lots of crimes. Many ceilings are not so tall that the distance from them to a human is greater than 3 m. Detection within 1.5 m is acceptable if a door motor is fast enough to respond. It's possible that there was an issue with our sensor (perhaps dust) so in future the experiments can be done with a fresh one, otherwise another sensor should be used, e.g. the WPSE314 with a range of up to 7 m and a detection angle of 120° [7].

Both temperature experiments were a success for industrial applications: in the presence of a hot kettle, motion was detected accurately; when sensing objects outside, it was more accurate at distances for which it was inaccurate indoors - it was able to accurately record movement up to 2.5 m. This can be due to the greater difference between the ambient temperature and a human when outside compared to inside.

The angle experiment shouldn't be repeated on the floor. It's possible that footsteps introduced noise. This could explain why it detected movement outside the stated range. In future, it could be placed on foam to reduce vibration. Another experiment can be done: a kettle (ambient temperature) can be placed a distance from the sensor. A thermometer should be attached to the kettle. It should be turned on and the temperature will increase rapidly and if the sensor goes off, it is a better indication of the effect that temperature has on false detections. Kettles can be placed at different distances from the sensor and more information can be gathered: the temperature and distance of false readings can correlate.

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