Machine Learning-Based Object Detection System Using PIR Sensor

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***Summary*—An intrusion prevention system using a digital Pyroelectric Infra-Red (PIR) sensor produces an error with an object, not a human. To solve this error, this research suggests an analog PIR sensor and an object detection system using machine learning. The analog PIR sensor provides an output based on various voltage scales within a certain area rather than producing binary outputs using a threshold value. From samples of an analog signal attained by using an analog PIR sensor, a Fast Fourier Transform (FFT) processed frequency is produced and used as a feature vector of the Artificial Convolutional Neural Network (CNN). The artificial CNN then studies the signal patterns of human motion and animal motion and detects whether it is a human or animal that intruded.**

Keywords—machine learning; object detection system; PIR sensor

I. INTRODUCTION

A Pyroelectric Infra-Red (PIR) sensor uses the pyroelectric effect of electromotive forces that occur when it absorbs infrared rays and polarization changes result in electronic charges abandoned. The PIR sensor then detects an object that has a temperature differential with surrounding environments and produces signals. Using these signals, the sensor can detect human or animal motion [1].

In security systems, there are a number of ray detection machines developed that prevent intrusion and give an alarm using a PIR based motion sensor [1][2]. However, the PIR based motion detection sensor that works with a temperature differential between objects and surrounding environments is highly sensitive when the object moves closer to the sensor; hence, it is radically less sensitive when the object is close enough to warm up the surrounding environment, which presents a problem [3]. Therefore, during the summer, when the ambient temperature is closer to the temperature of the human body, the sensor will experience more problems than would occur in the winter. In addition, even if a human body is moving slowly or has a cover to block the heat, the sensor has a propensity to decrease in sensitivity. For example, if a person is holding an umbrella or wearing a raincoat, his or her umbrella or raincoat blocks the heat generated by their body, and the PIR sensor has difficulty detecting motion. Sunlight has various rays that the PIR sensor can detect and which have motion; therefore, the sensor will have problems if the sunlight touches it.

The existing intrusion prevention system detects motions based on the threshold values of the PIR sensors. If the digital logic values go above the fixed threshold value, they produce a HIGH, which is considered an intrusion; otherwise they produce a LOW, which is not considered an intrusion. The threshold values vary by objects and situations; therefore, they can only identify whether there is an object [3].

This research suggests a new form of PIR sensor and machine learning based object detection algorithm to identify a human and an object. First, the paper describes the extraction of a range of signals attained from PIR sensors and the technique by which PIR data are processed into signals and frequency components of the signals are extracted into feature vectors. This research is still underway; therefore, this paper only covers the learning method through an Artificial Convolutional Neural Network (CNN) that is a machine learning algorithm and the design of a classification method after the learning.

II. GATHERING SENSOR AND CNN LAYERS

In this section, we describe the signal acquisition process using PIR and the operation process of CNN.

A. Gathering sensor data

To collect infrared lights in pyroelectric devices, a Fresnel lens was used. The advantage of using a Fresnel lens is that owing to its extremely thin construction it behaves exactly like a convex lens.

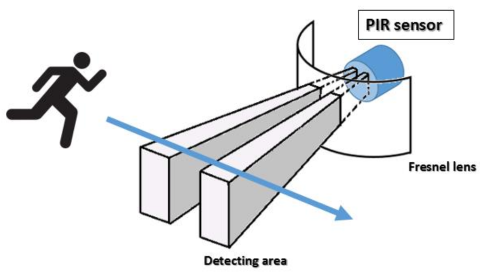

Figure 1. Concept of recognizing an object using PIR sensor and Fresnel lens[5]

The infrared lights detection area is separated into two parts, as seen in Figure 1, which are the detection area and non-detection area. The detection area describes a distance wherein a human can be detected, while the non-detection area describes a distance wherein a human cannot be detected; however, the movement of an object smaller than a human, which has a heat source higher in temperature than that of a human's body temperature, can be detected. Generally, the detection distance of an infrared detection sensor means the distance to the detection area [4]. However, when the infrared detection system is being installed, the non-detection area should be considered.

B. *Convolutional Neural Network (CNN)*

A Convolutional Neural Network (CNN) that was firstly proposed by Yann Lecun in 1998 is an artificial neural network modeling the training process for recognizing cursive writing [6]. CNN has contributed to simplifying the complex calculation structure of existing Multi-Layer Perceptron (MLP) by adding a convolutional layer. Henceforth, the CNN has been studied in many researches by proving its high performance for studying image [7].

1) *Convolutional Layer*

The big difference between MLP and CNN is the convolutional layer. For the existing MLP, every neuron is connected to those of next layer when every layer is transferred to the next one. For example, assume that we perform training having an image as inputs. When the size of input image is 32x32x3 (32 wide, 32 high, 3 color channels), the number of neuron of first input layer becomes 3,072 by 32x32x3 = 3,072. The number of neuron of second hidden layer is 120,000 by 200x200x3 = 120,000. If every neuron of input and hidden layer is connected then the total becomes 368,640,000 by 3,072x120,000 = 368,640,000. Accordingly, every layer has a quite complex structure, which requires huge amount of calculation. In other words, investigating every pixel when recognizing image is not possible and even a waste of time. Recognizing an image requires a method of extracting features of various pixels. The convolutional layer is used in this method. The calculation of convolutional layer is shown in Figure 2.

2) *Pooling Layer*

A pooling layer takes the role of reducing width, height and size, which in turn reduces the amount of calculation of neural network and the number of parameter and controls the overfitting.

The left side of Figure 3 shows the result volume of pooling layer. It shows that 224*224*64 size volume decreased to 112*112*64 volume. The right side of Figure shows the example of Max Pooling process that results in the maximum value in every area. If the result value has the average value of filters, then it is called an average pooling.

3) *Fully Connected Layer*

A fully connected layer has the same structure of MLP that was previously explained. Every neurons of each layer is connected and the results go through the activation function; therefore it has the same structure with the one of MLP.

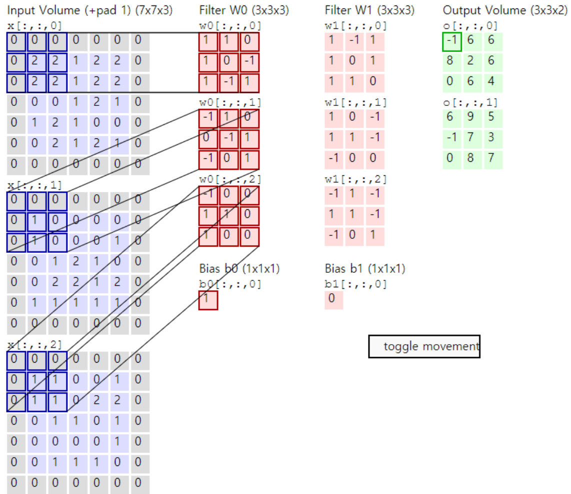

Figure 2. Calculation process of convolutional layer

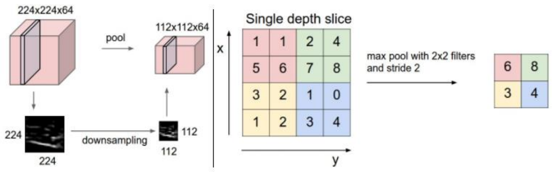

Figure 3. Example of Pooling Layer

4) *ReLU Function*

$f(x) = \tanh(x)$ and $f(x) = (1 + e^{-x})^{-1}$ have been widely used after passing through the neural network. However, looking at the function from the calculation of training process using gradient descent, the training process is quite slow because of nonlinear aspect. Therefore, to improve the calculating speed, $f(x) = \max(0, x)$ is used. Rectified Linear Units (ReLU) has much faster calculating speed than hyper tangent or sigmoid function which were referred when training Deep Convolutional Neural Networks (DCNN).

III. SUGGESTED PIR SENSOR-BASED HUMAN AND OBJECT DETECTION SYSTEM

In this section, we propose a PIR sensor based human and object detection system.

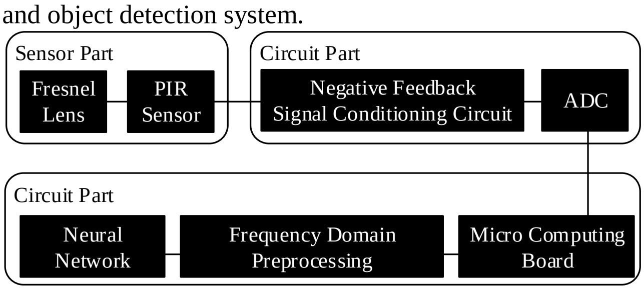

Figure 4. Construction of PIR sensor-based human and object detection system

Figure 4 is used to represent the entire data processing part. The overall data processing structure is divided into a sensor part, circuit part, and processor part. The sensor part has a role in extracting signals from an external stimulus. The circuit part amplifies and transforms the signals that came from the sensor part up to the dynamic

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range. Additionally, it transforms the analog signals into digital signals so that they can be processed in the processor part. The processing part transforms the signals of the digital time area that came from the circuit part into signals of the frequency area so that they can be easily classified into machine learning class. The signals transformed into the frequency area go through the artificial CNN and are classified by models that study newly given inputs.

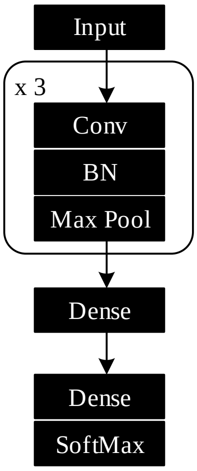

Figure 5. CNN based human and object detection algorithm

This research uses a five-layered structure that consists of input and output layers and three CONV LAYERs, while each input layer uses its own feature information. The output layers consist of two nodes that are the criteria for distinguishing between a human and a pet. Figure 5 describes the structure of the artificial CNN that was used.

IV. IMPLEMENTATION

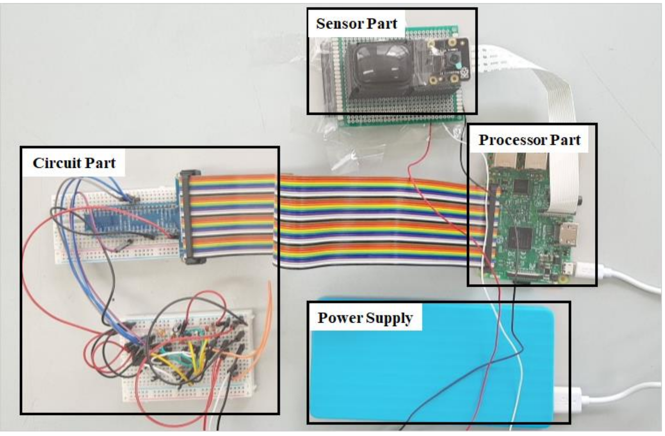

Figure 6. Object detection part of the realized PIR sensor-based human and object detection system

The circuit part of the suggested system amplifies the signal by 69 dB through a non-inverting two-stage amplifier. This filtered the low and high frequency noise that could have led to incorrect detection. Thus, the direct current components were removed. After confirming that the input signals in the analog-to-digital converter (ADC) were ranging from 0 to 3020, the reference voltage was set to 0.37 times the maximum voltage.

An LHI-878 was used as a PIR sensor in the sensor part and a PD23-6020 was used for the Fresnel lens. A Raspberry Pi 3 Model B was used in the processor part. To check object detection, a Raspberry Pi NoIR Camera V3 module was connected to the process. Figure 6 shows the actual equipment of proposed system.

The software development tool of machine learning used keras library-based deep learning studio, CPU used Intel®Core(i)i5-6600 and GPU used Geforce GTX 1050 Ti.

V. EXPERIMENTS AND EVALUATION

We had conducted experiments based on several factors that affect the amount of ambient infrared that PIR sensor detects.

In Figure 7, the *t* represents the number of samples and the sample rate is equal to 14.5 ksps; f(t) describes values ranging from 0 to 5 v in quantization rate of 3020. Data from the PIR sensor were collected when a human was at a distance of 1 m, 2 m, and 5 m and in different positions. Additionally, data were collected when a dog at a distance of 2 m was in motion. These data were Fast Fourier Transform (FFT) processed to detect whether the object was human or animal using an artificial CNN.

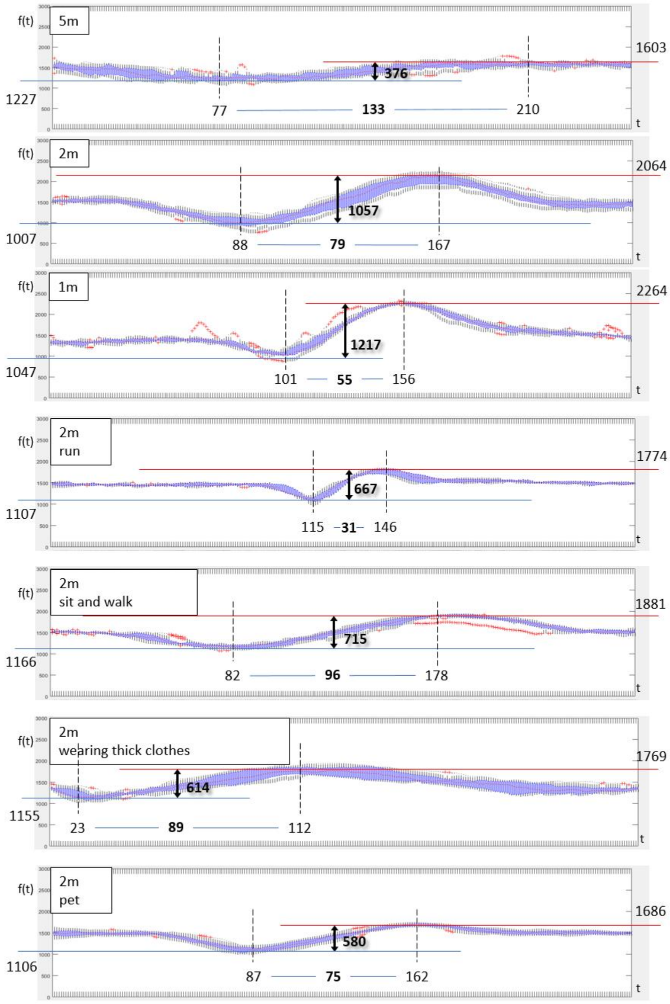

Figure 7. Distribution of PIR sensor values depending on distance of human and animal

TABLE I. TRAINING, VALIDATION, TEST DATA CONDITION

	Group	Human	Nothing
Training	A group	9,000	9,000
Validation		3,000	3,000
Test	B group	3,000	3,000
Total	-	15,000	15,000

By using the developed Object Detection System, data were collected by distinguishing between when there being a person and when there being none. The acquisition cycle was 1 second and was labeled with 1000 data per second. Table 1 shows the dataset configuration.

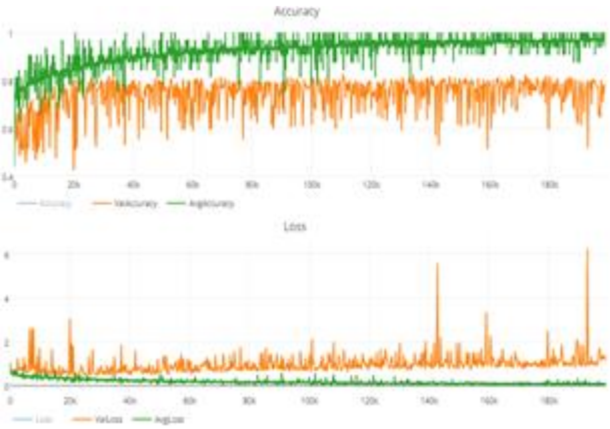

Figure 8. Accuracy and loss rate distribution toward each step

The accuracy and the loss rate were identified by distinguishing between when there being a person and when there being none toward the training, validation and test.

Training accuracy was 97.62%, validation accuracy was 80.5% and test accuracy was 72.8%. Figure 8 shows the accuracy and loss rate distribution toward the training, validation and test.

VI. CONCLUSION

This study designed a PIR signal process and CNN based learning algorithm using analog signals to improve a PIR sensor-based intrusion detection system. The signal processing algorithm was realized and used in experiments to distinguish between a human and an object in various situations.

In the future, this research will transform signals of a certain time range into a frequency range to express a certain frequency component of a human or an object as data. Thereafter, using this data as a parameter of the machine learning algorithm, the accuracy of an object detection system using a PIR sensor will be improved.

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