설치가 간편한 IR 적외선 센서를 활용한 출입문 유동인구 계측 방법

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Counting People Walking Through Doorway using Easy-to-Install IR Infrared Sensors

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요 약

대부분의 비즈니스에서는 고객의 움직임에 대한 의미 있는 정보를 얻어낼 수 있는 유동인구 계측 데이터가 매우 중요하게 작용한다. 슈퍼마켓의 경우, 손님들의 수에 따라 계산대 수를 늘리거나 줄일 수 있다. 스마트 빌딩 또한, 각 객실의 수용 인원에 따라 냉난방 시스템을 제어하는 스마트 컨트롤러 같이 다양하게 적용될 수 있다. 카메라 기반 유동인구 계측 시스템과 같이 첨단 기술을 활용하여 보다 정확한 결과를 얻을 수도 있지만, 가격이 비싸고, 현장 설치가 어려우며, 사생활 침해의 문제가 발생하기도 한다. 본 논문에서는 특정 통로 혹은 IR 적외선 센서가 설치된 출입구의 유동인구 계측 방법을 제시한다. 나아가, 사람과 다른 물체를 구분하여 인식하는 방법을 제시하는데, 해당 솔루션은 저렴하고, 설치가 간편하며, 무엇보다 실시간 계측이 가능하다. 우리의 유동인구 계측 솔루션은 약 95%의 정확도를 보이고 있다.

ABSTRACT

People counting data is crucial for most business owners, since they can derive meaningful information about customers movement within their businesses. For example, owners of the supermarkets can increase or decrease the number of checkouts counters depending on number of occupants. Also, it has many applications in smart buildings, too. Where it can be used as a smart controller to control heating and cooling systems depending on a number of occupants in each room. There are advanced technologies like camera-based people counting system, which can give more accurate counting result. But they are expensive, hard to deploy and privacy invasive. In this paper, we propose a method and a hardware sensor for counting people passing through a passage or an entrance using IR Infrared sensors. Proposed sensor operates at low voltage, so low power consumption ensure long duration on batteries. Moreover, we propose a new method that distinguishes human body and other objects. Proposed method is inexpensive, easy to install and most importantly, it is real-time. The evaluation of our proposed method showed that when counting people passing one by one without overlapping, recall was 96% and when people carrying handbag like objects, the precision was 88%. Our proposed method outperforms IR Infrared based people counting systems in term of counting accuracy.

키워드

IR Infrared sensors, People Counting, Indoor Counting, Port Manipulation, Arduino

Ⅰ. Introduction

IoT technologies are growing rapidly and being applied in various fields starting from medical to

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smart buildings and farming. IoT devices assist humans to ease their task and improve work efficiency. Among many IoT devices, people counting sensors have attracted many industries and researchers by its importance. Knowing the number of people at the certain space can help businesses to improve service quality, or when it is combined with other IoT devices it can be used as a smart electronic controller for a power efficiency, too.

According to some researches, only less than 8% retailers know about their conversion rate, which is not enough to determine your business success. Having a people counter system at your store to get customers conversion rate is crucial to know about your store's overall performance. People counting also helps with optimizing staff scheduling which can result in decreasing labor cost and increasing customer satisfaction. Most retailers over hire or under hire staffs since they do not have enough foot traffic and peak hours data for staff scheduling. So far, much research has been done to build people counting system using diverse sensors, such as thermal sensors, cameras, ToF sensors, Wi-Fi sniffers and Beacon sensors. Most of the people counting systems built based on these sensors have disadvantages like capturing personal information or poor accuracy which makes it unsuitable for people counting. In this paper, we propose a new IR Infrared based people counting sensor. Rather than just counting, proposed sensor is able to distinguish human and other small objects. Our people counting sensor is simple, low cost, easy to install and has a high accuracy.

Throughout this study, for ease of explanation, the word person is used interchangeably with object.

Ⅱ. Related work

Recently, various technologies have been combined with the concept of Internet of Things (IoT) [1]. Among them, people counting which has attracted many researches and studied for at least few decades using different technologies. In [2], [3] camera-based people counting system has been studied. Camera based people counting system may have the highest accuracy, but due to the privacy issues it has a limit of installation. Other than camera, IR-UWB radar sensor also drawing attention as an intelligent sensor that can be applied to people counting application easily with a simple hardware configuration [4], [5]. However, IR-UWB is expensive so it is not affordable by everyone. In [6], PIR is used to count number of people at the entrances, but this method requires multiple sensors to be installed for a single entrance and sensors should always remain connected to the power which makes it hard for anyone who wants to install it. Until we came across [7], our sensors operated same way in which sensors must be connected to the sustainable power all the time. In [7], by exploiting the real-world data streams from hundreds of digital LED integrated passive infrared (PIR) occupancy sensors they were able to reduce load about 30% across lightning fixtures.

Our work is distinct from previous works by its simplicity, affordability and high accuracy.

Ⅲ. IR infrared sensors-based people counting

3.1 IR Infrared sensors

IR Infrared sensors are mainly used in electronic devices' remotes, like TV remote controllers. There are two types of IR Infrared sensors, namely, IR Transmitter and IR Receiver. IR transmitters are similar to normal LEDs, but it emits invisible infrared lights. On the other hand, IR Receiver receives the modulated infrared waves and changes its outputs.

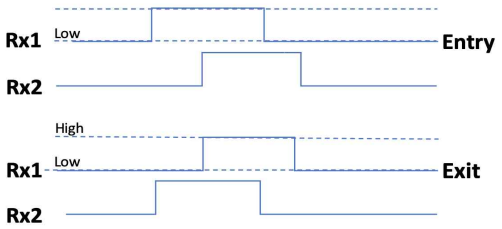
3.2 Algorithm

Counting algorithm validates the count when the certain states occur in certain order. Which means sensors should detect the obstacle in certain order to determine the count and the direction.

3.3 Detecting an object and determining movement direction

IR Transmitter (Tx) sends a short burst of a 38Khz carrier signal continuously and two IR Receivers (Rx) sensors read it. When an object crosses between Tx and Rx, it blocks the signal transmitted from Tx to Rxs, so the sensor detects the object.

It is possible to determine moving direction of a person, depending on which Rx has been blocked first, as shown in the Figure 1 below. In order to determine the moving direction of a person and counting, we located a Tx sensor on one side and two Rxs on the other side of the entrance.



***High**- blocked, **Low**- no obstacle.*

Noise free signal	states	**00111111111111111111000**
Noise signal	states	**00111110011111110011000**

Figure 1. Person counting chronogram

3.4 Power efficiency

In order our sensor to be able to run on a battery for long time, we have to consider the power efficiency. As mentioned earlier Tx sends out a 38Khz carrier signal continuously which consumes power all the time. On the other side, Rxs run all time to sense IR infrared rays whether Tx sends infrared rays out or not. To prevent our sensors from consuming power during idle state, we use Passive Infrared (PIR) sensor. The idea is that, when motion is detected by PIR sensor, it triggers Tx and Rx sensors and so Tx starts sending infrared rays where Rx sensors start sensing it. But, different PIR sensors have different sensitivity and also they have time delay of 1~3 seconds which may make it unsuitable for our project. If a PIR sensor is less sensitive, an object might passes the designated place before IR sensors are activated by the PIR, as a result IR sensors miss the object. To ackle this problem, in the following experiment, we compare several PIR sensors to find the most suitable PIR sensor for Rx and Tx activation.

First, we set up three PIR sensors, namely SR505, SIS612P and SEN050135 with LED attached to each of them for ease of observation. LED goes HIGH (ON) when motion is detected, so we can notice the time delay difference between PIRs easily. We observed that, sensor SR505 has always was to sense passing people first, SlS612P was second and SEN050135 was the last.

Second, to compare the sensitivity of PIR sensors, how sensitive to motion, we placed all three PIR sensors on the same desk near where people work and logged output of every PIR sensor separately during 328 seconds. The output is 1 if motion detected, 0 otherwise. The result of the experiment is shown in Table 1

Table 1. PIR comparison

Model name	Detection count	Duration
SR505	306	328sec
SIS612P	216	328sec
SEN050135	187	328sec

We chose SR505 PIR sensor which has the shortest, 1 second time delay and is the most sensitive among three.

3.5 IR receiver noise filtration

Noise signal have huge impact on counting accuracy. The problem was that, Rxs sense IR rays even Tx is blocked by passing human, which means it was sensing a noise signal. IR rays emitted from Tx is deflected when encountered with other objects. IR rays can produce secondary wavelets when it collides with any obstacles in its path. When IR rays gets emitted from LED, it moves in the direction it is angled. When any obstacle interferes in the path, the IR rays get cut and it produces secondary wavelets which propagates mostly in return direction or in a direction opposite to that of the primary waves, which produces the net result like reflection of IR rays. When we block IR LED the IR Receiver often senses deflected IR Rays which we consider it as noise signal. Deflected IR rays, which is considered as a noise signal has negative effect on people counting accuracy. So, those noise should be filtered out. Since, we are using Rxs and Tx for people counting Rx should not be able to receive any IR rays when Tx is blocked. As a solution to this problem, when reading the state of the sensor from the source, the state must be constant for a certain of time in a row to be considered as a true, directly received signal as shown below.

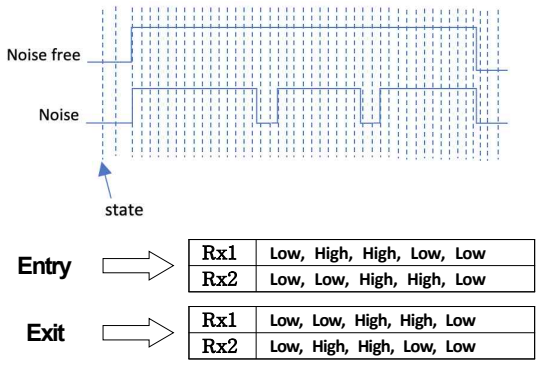


Figure 2. Noise signal distinguishing

3.6 Distinguishing a hand and a body

When a person walks swinging his hands or

holding a cup, and if a hand or a cup blocks the IR sensors before the body blocks them, one person is counted as two. Our goal is to make the gate to be able to distinguish a hand/cup or other objects and a body, and count when the IR sensors are blocked only by body.

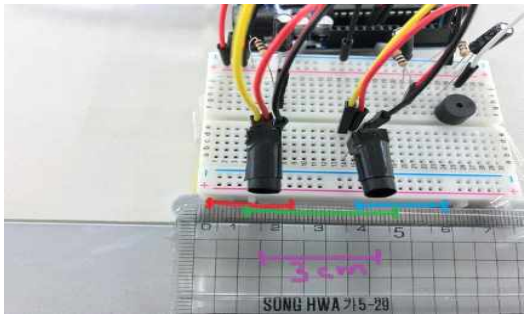


Figure 3. Rx sensors positioning

As we can see in Figure 3, IR sensors are located 3cm apart from each other. And there are three different sections as we have labeled them using red, green and blue colors. Red section is when only the first IR sensor is blocked from the left. If two sensors are blocked at the same time that it is the green section, and finally if the only second sensor on the right is blocked it is blue.

When a person crosses through three sections, sensors input are as follow:

- When a person is in red section: (Sensor_1: HIGH, Sensor_2: LOW)
- When a person is in green section: (Sensor_1: HIGH, Sensor_2: HIGH)
- When a person is in blue section: (Sensor_1: LOW, Sensor_2: HIGH)

How long does each section last depends on object's size and moving speed of it. Humans tend to walk at about 1.4 meter per second although capable of walking even at higher speed. Let's assume that sensor in Figure 3 is installed at the average person's hip hight and a person passing by sensor has a hip size of about 18cm from the side, including clothes. If the person walks Figure 4 at average speed of 1.4 m/s, the red section will last only about 20 milliseconds, the green will last about 100 milliseconds and so the blue will last as same as red, 20 milliseconds. At the same setting, when the hand, wide open size of about 10cm is swung at the speed of 1.4m/s as shown in Figure 5, the red and blue sections both will last same as before which is about 20 milliseconds, but the green will last about 50 milliseconds. As we can see, size of the object has no effect on the duration of red and blue but green. Based on our experiment result, it can be concluded as, considering the size of hip in range of 18~30cm from size, passing object to be considered as a human green section should last at least six times and at most nine times longer than red and blue sections.

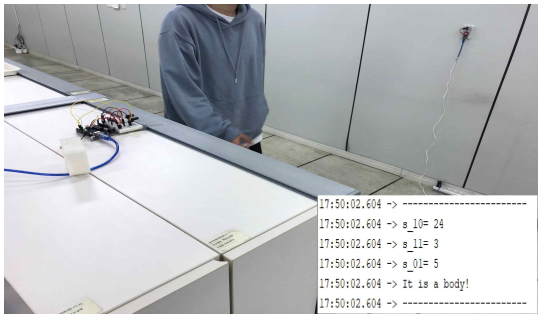


Figure 4. Person passing by sensor

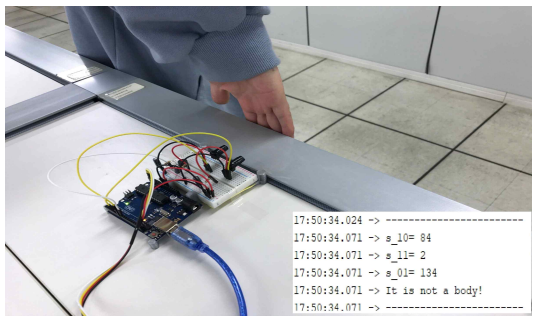


Figure 5. Hand swung by sensor

3.7 Speed up algorithm using Port Manipulation

As we have mentioned and seen in previous sections, our people counting sensor's Rx side consists of two Rxs, namely IRx_1 and IRx_2 which are located only 3cm away from each other. Our people counting algorithm runs on a board where Rx is installed and the algorithm has three phases. The first phase is when passing object blocks only the IRx_1 and the phase two is when both IRx_1 and IRx_2 are blocked at the same time and the last, third phase is when the only IRx_3 blocked. If a person walks at high speed of about 3 meters per second, section red in Figure 3 will last only 10 milliseconds. But since, it is only a high walking speed, the sensor's input has to be read even faster, roughly in every less than 1 millisecond to be able to catch the passing object in running speed. In reality people do not just walk but run, too. But, most of the time these sensors are used on arduino boards where digitalRead() is used to read sensor's input. When digitalRead() is used it takes a while to execute. So, it makes our algorithm run slow and miss the passing person in

high speed. In order to speed up our algorithm to tackle slugishing problem we used port registration. Port registers allow for lower-level and faster manipulation of the i/o pins of the micro controller on an Arduino board. Chips used in Arduino board has three ports.

- B (digital pin 8 to 13)
- C (analog input pins)
- D (digital pins 0 to 7)

Each port is controlled by three registers, which are also defined variables in the Arduino language. The DDR register, determines whether the pin is an INPUT or OUTPUT. The PORT register controls whether the pin is HIGH or LOW, and the PIN register reads the state of INPUT pins set to input with pinMode().

For instance:

- DDRD = B11111110 - sets Arduino pins 1 to 7 as outputs, pin 0 as input
- PORTD = B10101000 - sets digital pins 7,5,3 HIGH
- value = (PIND >> 6 & B01000000 >> 6)

which is equal to value = digitalRead(pin6)

Before port manipulation, Arduino board was able to read IRx input using digitalRead() about 115114 times per second, after port manipulation it was able to read about 588361 times per second, which is about 5 times faster.

Ⅳ. Experiment

In this section we evaluate the performance of the proposed method for people counting.

4.1 Experiment Setup

For experiment we chose our workplace and installed the people counting sensors at the main entrance Figure 6, Figure 7. This place has only one entrance and there are always people entering and leaving which is ideal place to test proposed method.

Figure 6. Inspecting sensors beforehand

Figure 7. Adjusting Tx and Rxs

For people counting sensor we used following parts:

- Two Arduino Uno boards
- Two IR Receivers - KSM-913TE5N
- One IR Transmitter - SI5312-H
- Two LEDs for count indication
- Two 200 Ohm resistors
- Two 10uf capacitors
- One small buzzer for count indication.

Metrics: To evaluate the performance of the proposed people counting method, e.g., how accurately our sensors can count passing people, we use recall and precision metrics Formula 1.

$$Precision = \frac{TP}{TP+FP}$$

$$Recall = \frac{TP}{TP+FN}$$

Formula 1. Metrics

We assume that proposed sensor may count one person as two or more when the person is carrying a hand bag or other objects. In this case we use precision metric for evaluation. In contrast, it may count only one person when more than one person is passing. To evaluate this type of cases we use recall metric.

4.2 Performance

First, five people entered and exited the room 20 times each, in total 100 times. People did not overlapped with each other while entering and exiting the room. Out of 100 times, sensor was able to detect and count 96 times. Recall of this experiment would be 96%.

Second, with the same setting as first, but people carrying a hand bag and boxes in different size entered and exited the room 100 times in total. In this scenario, proposed sensor counted as 113 people passed by, where the actual number of

passed by people was 100. Precision of second experiment is 88%.

According to the experiment results, proposed people counting method performs better in places where people do not overlap at the entrances, and enter and exit one by one.

Ⅴ. Conclusion

Using simple sensors we demonstrated people counting system that is able to handle complicated tasks. To the best of our knowledge, it is the first work that used IR Infrared sensors to distinguish objects, such as human body and other objects according to their size. To exploit the IR Infrared sensors for counting and distinguishing objects we tested and resized the distance between two IR sensors to find the best size that yields the desired people counting sensor size and counting accuracy. Below Figure 8 is our finalized hardware which runs on four AA batteries.

Figure 8. Finalized PCB

For future work, we have several interesting research directions:

(1) Counting overlapped people based on different states read from IR sensors.
(2) Distinguishing person carrying an object.

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