Design and development of a motion detector based on Arduino

Wang Junchi

Vicente Traver Salcedo

Cotutor: Antonio Martinez Millana

Bachelor's Thesis presented at Escuela Técnica Superior de Ingenieros de Telecomunicación of Universitat Politècnica de València,

Academic Year 2019-2020

Valencia, 5 de March de 2020

Escuela Técnica Superior de Ingeniería de Telecomunicación
Universitat Politècnica de València
Edificio 4D. Camino de Vera, s/n, 46022 Valencia
Tel. +34 96 387 71 90, ext. 77190
www.etsit.upv.es

Abstract

Studies reveal that the aging tendency of the population in current society is getting increasingly serious. An increase in the number of seniors leads to the problem of the lack of appropriate care for this group. Under this situation, systems must adopt new technologies that make them capable of covering larger groups of populations in efficient and effective ways,

A recent paradigm for new healthcare systems is to prevent and treat patients at home. One of the possible variables to collect is the movements of seniors at home, as they can be an indicator of serious health problems. Among the sensors with trace function, the PIR sensor is a passive sensor to detect the motion of humans by infrared radiation. This kind of sensor has the advantage of low cost and fewer privacy issues.

In the project, we conducted a series of experiments systematically to characterize the PIR sensor, Bluetooth module, and Wi-Fi module. With the experiment results, we designed and developed a detector system based on the PIR sensor, using Arduino as the CPU and transmitting the data by Bluetooth and WIFI. The data from the detectors were collected by a gateway and presented the position of the user on a dashboard.

According to the tests, the system can provide a relatively accurate trajectory of the human in the house, and can eliminate the influence of the air condition, instantaneous movement and overlapping positive signal due to the positive signal delay.

Index

Capítulo 1. Introduction

1.1 Motivation and background

1.1.1 Growth of the quantity of the seniors

In current society, the aging tendency of the population is getting increasingly obvious. According to the World Population Prospects 2019, one in 11 people in the world is over age 65, and this number will increase to one in 6 in 2050. Besides, there are 143 million persons aged 80 years or over in the world, and this number is projected to triple to 426 million in 2050.[1]

The expanding quantity of seniors leads to the problem of lacking care for them. In the United States, nearly 30% of the 46 million older people who live in the community (as opposed to an institution, such as a nursing home) live alone[2]. In China, statistics show that in 2016, the number of elderly people living alone in China was 20 million, and it is predicted that the number of elderly people living alone in China will reach 30 million by 2020[3]. The problem in Japan is also serious. According to the record, there were 6.25 million households leads by seniors with only 1 member, which consisted of 11.7% of all the households.

1.1.2 Dementia and wandering

Dementia is a broad category of brain diseases that cause a long-term and often gradual decrease in the ability to think and remember that is severe enough to affect daily functioning. Worldwide, around 50 million people have dementia, and there are nearly 10 million new cases every year. [4]

Wandering, in people with dementia, is a common behavior that can cause great risk for the person, and is often the major priority (and concern) for caregivers. It is estimated to be the most common form of disruption from people with dementia within institutions.[5] It may result in severe consequences for the patient who may get lost, become exhausted, and suffer from traumas. It also represents a burden for the patient's family and care providers, especially in case of running away.

1.2 State of art

1.2.1 Wondering detection

Though with serious harm, the risk of wandering can be decreased by a reliable caring system.

In [6], the author designed a novel system of electronic tagging in patients, and two incidences of external wandering were successfully detected. [7] proposed a real-time method for wandering detection based on individuals' GPS traces. By representing wandering traces as loops, the problem of wandering detection was transformed into detecting loops in elders' mobility trajectories. In [8], they used Process mining to detect the abnormal activity of the seniors.

In this project, we also want to design a trajectory system.

1.2.2 Trajectory

The trajectory of the seniors can not only provide rough behaviors for the caregivers, but it can also detect the wandering of seniors with dementia. In this part, we will introduce some technologies of trajectory.

Overview of trajectory technology

All kinds of devices are utilized in the indoor trace, including the figure, Wi-Fi, smartphone, radial frequency, and PIR sensor. And there are a lot of technologies devoted to providing the function of the trace.

Figure and video are utilized widely in the trajectory. In place a device called “Omni-directional Vision Sensor (ODVS)” in the center of the house to learn the routine of activities adaptively, and detect and predict the abnormal activities of the elder through detecting the significant deviations of the activity data in spatial and temporal aspects.[9]

In [10], Channel state information is employed. The paper proposed an algorithm that used discrete wavelet transform and quadratic discriminant analysis to determine the location of the human.

In [11], the team designed a portable frequency-modulated continuous-wave (FMCW) radar prototype. And their experimental results for a walking person in a highly-cluttered indoor environment confirm the suitability of the low-cost radar prototype for indoor healthcare applications.

Trajectory by PIR sensors

PIR sensor is a passive sensor with the advantage of low cost and fewer privacy issues. So, it is welcomed in the indoor trajectory.

In [12], the team put several PIR sensors in a house, and multiplex masks with the binary PIR sensors to obtain a compressed overlapping structure. And they show how to circumvent the problem of structure induces ambiguity during transitions between zones by using a novel localization algorithm based on the transferable belief model TBM.

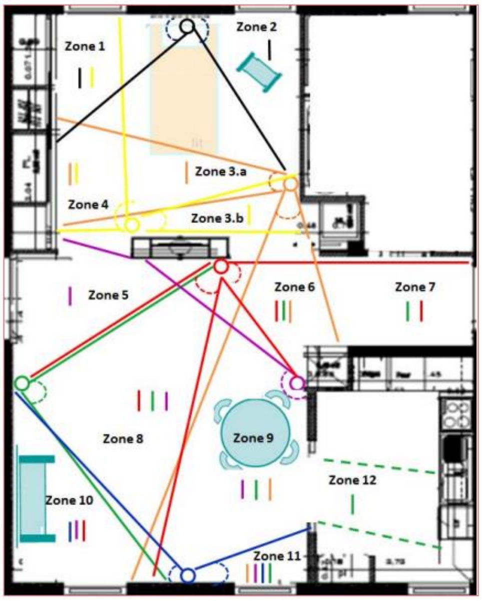

Figure 1. Picture in [12]

[13] also used PIR sensors in the house, and used a deep convolutional neural network to detect the early stage of dementia. As a result, the random forest and DCNN yielded the best classification accuracies of 94.48% and 97.84%, respectively.

In [14], the team provides a high accuracy of the single target trace by Kalman filtering. They put two sensor nodes in a room and each node with 14 PIR sensors.

In [15], they used a self-made PIR sensor to achieve a scalable, reconfigurable multi-agent system (MAS), which consists of sensing, action, decision, and database agents, for human tracking and self-calibration.

The PIR sensor is not only installed in the horizontal angle. In [16], several PIR sensors are set at the roof of the room to provide an accurate trajectory in a small area.

In the larger scale, [17] developed a geometric algebra (GA)-based approach to generate all possible human trajectories from the PIR sensor network data. The project bases on the MERL sensor database published by the Mitsubishi Electric Research Labs.[18]

Capítulo 2. Objectives

This project wants to design a motion detector system based on Arduino to detect human trajectory at home when seniors live. The system should be able to track the users in a house model with one living room, two bedrooms, a kitchen, and common furniture. The position of the users should be presented on an internet dashboard.

PIR sensor is the main sensing element in a motion detector. To utilize the PIR sensor better and avoid the wrong signal, this project will design and implement a series of tests to understand the basic characters and parameters of the PIR sensor.

The positions and poses to set the detectors will be considered in the project. We are going to set different quantities of detectors at different heights and positions with different angles in the room. The effects will be tested systematically to provide the choice with the best performance.

Various kinds of structures with different Arduino boards and transmission modules can both achieve the target. The project will discuss the various kinds of structures considering the cost, efficiency, effectiveness, and so on to find the best solution.

The project will design and develop the detector system synthesizing the results from the research. With the complete system, the project will design a set of systematic tests to measure the specific performance of the system.

Capítulo 3. Materials and methods

3.1 Materials

In this part, we will briefly introduce the components and platforms used in the project, including the basic characters and parameters.

3.1.1 Arduino

Arduino is an open-source electronics platform based on easy-to-use hardware and software. It's intended for anyone making interactive projects. It senses the environment by receiving inputs from many sensors and affects its surroundings by controlling lights, motors, and other actuators. The Arduino board can be controlled by writing code in the Arduino programming language and using the Arduino development environment.

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x). It lacks only a DC power jack and works with a Mini-B USB cable instead of a standard one. In the project, the Arduino nano clone is used as the CPU of the sensor nodes due to its low cost, using CH340 as the converter to the mini USB port. [19]

Arduino MKR1000 has been designed to offer a practical and cost-effective solution for makers seeking to add Wi-Fi connectivity to their projects with minimal previous experience in networking. It is based on the Atmel ATSAMW25 SoC (System on Chip), which is part of the SmartConnect family of Atmel Wireless devices, specifically designed for IoT projects and devices.

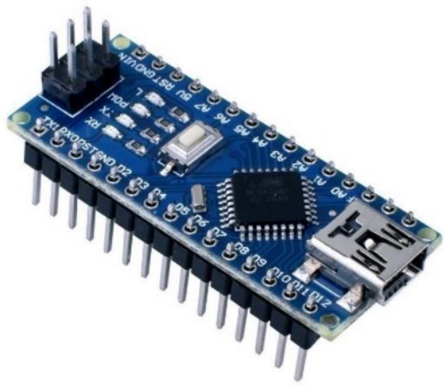

Figure 2. Arduino nano

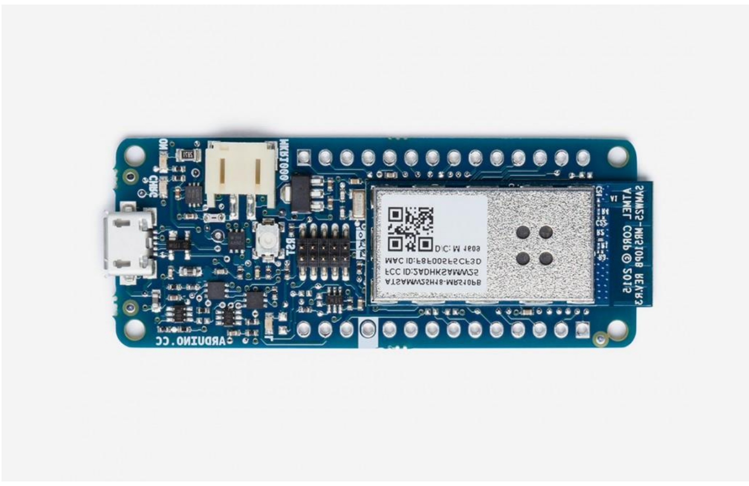

Figure 3. Arduino MKR1000

3.1.2 PIR sensor

The kernel of the motion detector is the PIR sensor, in which there is a pyroelectric sensor and a Fresnel sensor.

Figure 4. PIR sensor

Pyroelectric sensors are made of crystalline materials and generate surface charges when exposed to heat in the form of infrared radiation. When the amount of radiation irradiated on the crystal changes, the amount of charge also changes, which can then be measured by a sensitive field-effect transistor (FET) device built into the sensor.

Figure 5. Structure of the PIR sensor

Over the pyroelectric sensor, there is a Fresnel lens. Fresnel lenses are mostly thin sheets made of polyolefin material. One side of the lens is smooth and the other side is marked with concentric circles from small to large. Fresnel lenses are in many cases similar to the infrared and visible convex lenses, the effect is better, but the cost is much lower than ordinary convex lenses. There are three effects of using a Fresnel lens in the PIR sensors: Firstly, it can focus the infra-red radiation from the body on the pyroelectric sensor. Secondly, it can limit the peak frequency of the incident light to 10 μ m, which is the peak frequency of the infrared radiation from the human body. At last, the Fresnel lens used the special optical principle of the lens to produce an alternating "blind area" and "highly sensitive area" in front of the detector to improve the sensitivity of its detection reception. When someone passes in front of the lens, the infrared ray emitted by the human body will constantly alternate from the "blind area" to the "highly sensitive area", so that the received infrared signal is input in the form of pulses of suddenly strong and suddenly weak, thus strengthening its energy amplitude.

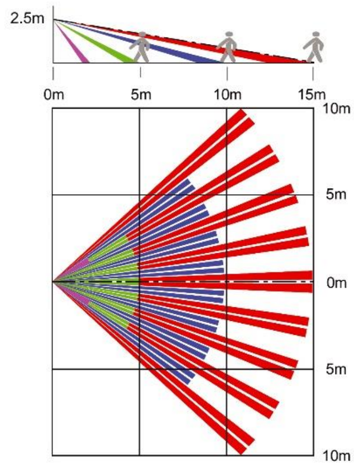

Figure 6. Principle of the PIR sensor

The delay time and detect distance can be changed by adjusting the screw at the back of the PIR sensor. According to the specification file, for the screw of sensing distance, the clockwise adjustment means longer distance, and anticlockwise adjustment means shorter distance. For the screw of output duration, clockwise means longer duration, and anticlockwise means shorter.

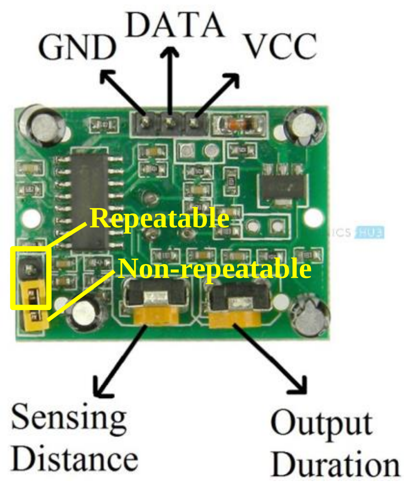

Figure 7. Modes and pin of PIR sensor

3.1.3 Bluetooth module

As a small-range wireless connection technology, Bluetooth can realize convenient, fast, flexible, safe, low-cost, and low-power data communication and voice communication between devices. Therefore, it is one of the mainstream technologies for wireless personal area network communication.

FSC-BT836 V1.3

FSC-BT836 module is chosen in the project. It's a dual-mode Bluetooth 4.2 data transceiver module from Feasycom. It supports many profiles including SPP (master-slave), HID, GATT, etc. Provide customers with modules (standard firmware), applications, SDKs, and programming examples. In SPP mode, it can have 10 connections at most at the same time. In the project, we use AT command to control it.

2.2.2 Establish SPP Connection

Format: AT+SPPCONN=Param
Param: MAC address of target device (12 Bytes ASCII)

Figure 8. The AT command to establish SPP connection

3.2.7 SPP Received Data

Format: +SPPDATA=Param1, Param2, Param3
Param1: SPP Channel
Param2: Payload length
Param3: Payload

Example: Received data "1234567890" from remote device via SPP
<<   *+SPPDATA=1,10,1234567890*

Figure 9. The format of data received from different channels

FSC-BT826 V1.2

FSC-BT826 has a similar function with FSC-BT826, except the one-to-many connection. In the project, this module has to only transmit the data as the slave module.

3.1.4 WIFI module

ESP8266

ESP8266 is a wireless WIFI module launched by ai-thinker. It is specially designed for mobile devices, wearable electronic products, and IoT applications. It can be configured through AT commands, communicate with the serial port on the single-chip computer, and use WIFI for data transmission.

3.1.5 Demonstrator house

Most of the tests are done in a demonstrator house. Down here is the approximate layout of the house. The height of the house is 310 cm. The toilet is omitted in the figure.

Figure 10. The approximate layout of the house

3.2 Method

This section will introduce the method used in the project to know the characters and parameters of each component. All the test was done in the normal indoor temperature of 20-26℃.

3.2.1 PIR sensor

maximal detection angle of the PIR sensor

To know the maximal angle of view of the PIR sensor, we dug a sensor shape hole on a KT board. We chose the surface of the Pyroelectric sensor inside the PIR sensor as the center and marked the angles from the mid perpendicular. Considering the maximal angle recorded on the specification is 100° (50° from the mid perpendicular on each side), we marked the angle from 50° and selected 10-20° as the interval.

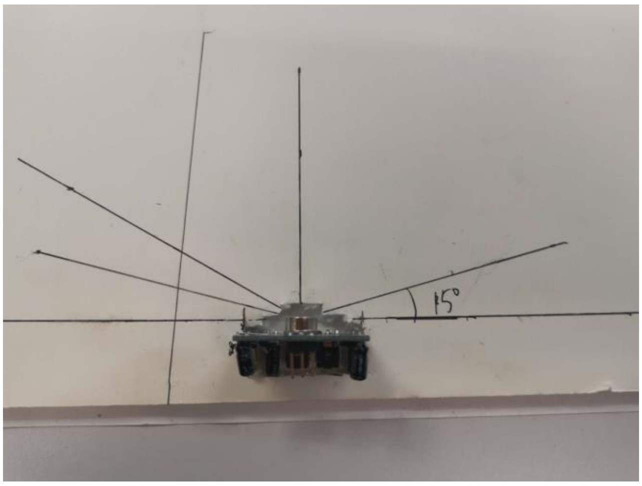

Figure 11. The center of the angles

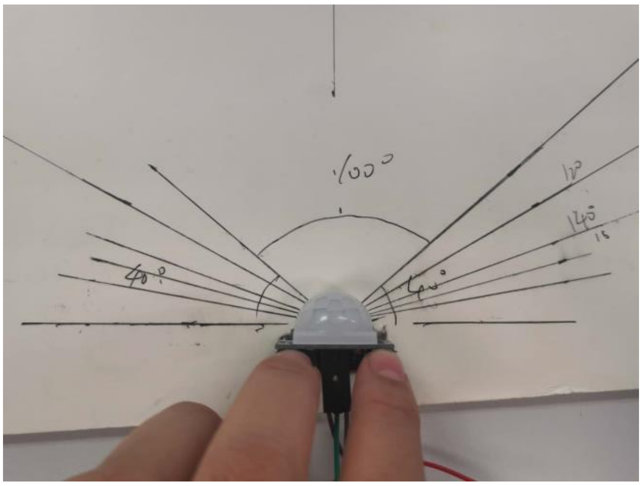

Figure 12. The angles marked on the KT board

First, we set the PIR sensor to the repeatable model with minimal duration and longest distance. Then, we fixed the PIR sensor on the board and try to know if the sensor can detect the motion of shaking the hand at a certain angle. The tester shook the hands at the outside and inside at each angle and recorded the status of the sensor. For avoiding the effect of the delay, the test started from the 80° to 50° from the mid perpendicular. The tests were implemented on both sides of the mid perpendicular to eliminate the influence of offset. 3 sensors were chosen randomly as the samples and tested in order.

Detection range

This test was designed to know the maximal detection distance at each angle, so the KT board in the last test was utilized again. The maximal mode was used by default for better performance. According to the principle, at the distance, the motion could only be detected if the motion was large enough. Thus, we investigated the maximal detection distance by shaking the body by a meter. To avoid the effect from the delay, we did the test from long distance to short and recorded the distance when the PIR sensor first detected the motion. Considering the maximal length of the diagonal of the test site was about 5.78 meters when the distance was larger than this number, we marked "out" to represent the distance in this angle is large enough. 3 sensors were chosen randomly as the samples and tested in order.

Minimal duration

Though the duration time of the positive signal of the PIR sensor can be adjusted, there is still an unavoidable duration time of the positive signal, which will affect the accuracy of the system. Plus, the duration time triggered by different kinds of movement is different. This test is to know the different duration times of the positive signal. So that in the design we can try to eliminate the effect from it.

In the test, we programmed the Arduino board to scan the PIR sensor every 0.5 seconds, and presented the result on the serial monitor. We faced the PIR sensor toward the wall, swung the hand rapidly for once, and counted the amount of the positive signal. Multiply the number of the signal by 2 is the minimum duration time of the signal in seconds. To know the effects of the present time of the user, we swung the hand with two speeds. In one speed, the hand was exposed to the PIR sensor for less than 1 second. In another one, the explosion time was longer than 2 seconds. 3 sensors were chosen randomly as the samples and tested in order. We did the 10 times on each sensor.

Delay of the signal

When the motion stop, the positive signal will not stop immediately. There will be a delay after the motion disappear. This test is to know the length of the delay.

This test used the same program and environment as the test of duration time. in this test, the test swung the hand in front of the PIR sensor for a random time and recorded the quantity of the signal after the hand left the detection area. 3 sensors were chosen randomly as the samples and tested in order. We did the test 10 times on each sensor.

Pet

Pets are common in the current family. Although the Fresnel lens can filter most of the infrared from the environment, the pets with similar body temperature may lead to a positive signal. By this test, we want to know if the system with the PIR sensor as the center is impervious to the pet.

In the test, we chose a pet dog with a height of 40 cm length of 60 cm as the sample. We put the PIR sensor on the floor, and let the dog move in front of the PIR sensor, and monitor the status of the sensor.

Air condition

Air-condition is necessary for the current family. We considered two modes of the air condition (swing or not) and 3 positions of the PIR sensor. The sensor was faced with the air condition at 1 meter away to know the original effect of the equipment. And then put it at the same corner, opposite corner and side corner of the AC. The output signal and the length of the signal are recorded. Every observation lasts 60 seconds.

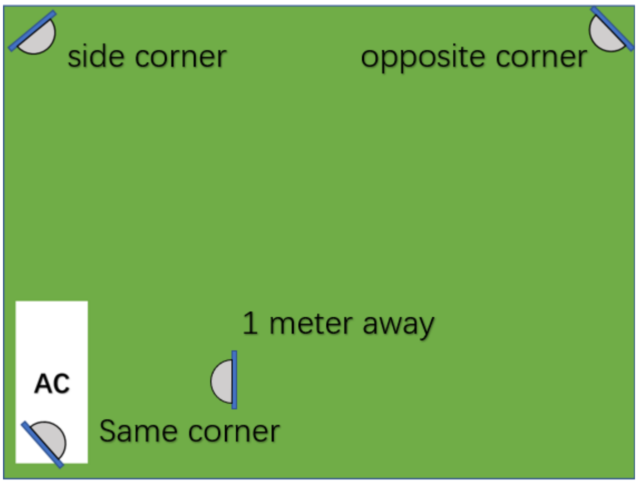

Figure 13. Position of test

Furniture

In the house, there is some furniture has the function of heating, which may affect the infrared radiation of the environment. We designed this test to know the influence of heating furniture. these kinds of furniture are discussed in the project: a screen of the television, gas stove, and microwave oven.

We faced the PIR sensor to the target, let the target furniture work, and observe the status of the sensor.

3.2.2 Wireless module

The Bluetooth module and WIFI module are compared in the project.

Power consumption

To know the power consumption of two modules, a power bank with a screen to show the percentage of remaining electricity was used to quantify the consumption. The tested module was connected to the Arduino nano board. After connecting the board to the power bank, we recorded the time and the percentage of remaining power. After 4 hours, we recorded the remaining electricity and got the change. we tested two modes, one downloaded an empty program to the Arduino, and another mode with a sample program. The output of the power bank if

Transmission distance

We connected the Bluetooth module to the Arduino, let it send a number “1” out every second. Then, we connected to the Bluetooth by the mobile phone, left the module slowly, and observed the signal. When the signal stopped, recorded the signal.

The comparison of the other characters based on the information on the internet.

3.2.3 Position of the sensor

To elevate the performance of the system, the best position to set a single sensor and double sensors need to be discussed. To quantify the ability of detection, we defined 10 test routes (marked from a to j) and 7 test nodes (marked from 1 to 7) and monitored the status of the sensor when the tester moving through the test routes or taking some activities at the nodes.

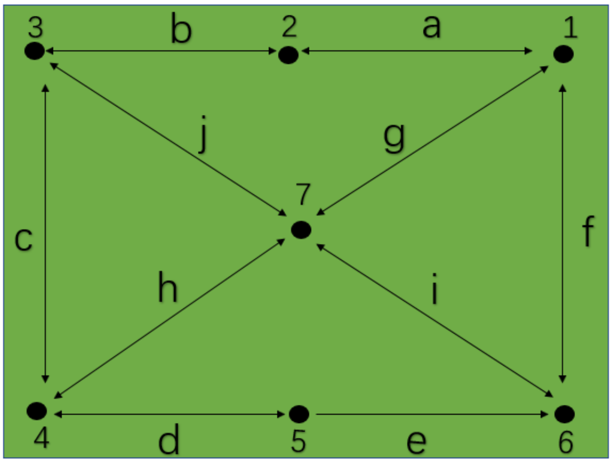

Figure 14. Test nodes and routes

Three activities with different level of amplitudes were tested at the nodes, they are:

A. Center the elbow and wave your arm across your chest
B. Without moving, move the arms around your body
C. Shake the body without change of position.

The same program as the duration time tests was used in this test. The tester could connect the Bluetooth module by the test app to monitor the signal. The behaviors were done 5 times at each route and nodes. Each behavior started after the status return to nobody. We recorded the results from the sensors.

To make the result more comprehensible, the result would be summarized in figure form. For the test routes, if all of the activities on one route were detected, the route would be marked as a "sensitive route". Otherwise, the route would be "insensitive route". For the test nodes, if all the behaviors at a node were detected, the node would be marked as "sensitive node". If activity B and C could be detected only, the node would be marked as "medium sensitive nodes". If only activity C can be detected, it would be marked as "less sensitive node". If all the three activities could not be detected, the node could be marked as "insensitive nodes". These would be marked by color according to the chart below:

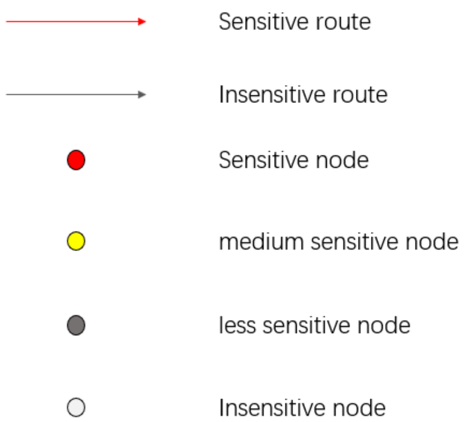

Figure 15. Marks of the sensibility

3.2.4 Wia dashboard

Wia is a cloud platform that aims to provide developers with a scalable and powerful backend for their Internet of Things (IoT) solutions. It aims to solve the complexity and cost behind developing a real-time Internet of Things platform.[22]

The address of the Wia is https://dashboard.wia.io/spaces. After registering and login in, the users can create their own space and device. Each device has a unique identification code. In the dashboard, the users can create the widget connecting the events that can be triggered by the actual device. Wia provided the sample codes for the Arduino MKR 1000.

In the use of the dashboard, the users can omit the detail of the internet protocol. They need just change the content in the "root["name"]" to the event they created in the dashboard, and put what they want to present in the "root["data"]". After using the function "postToWia()", the data would be transmitted to the dashboard.

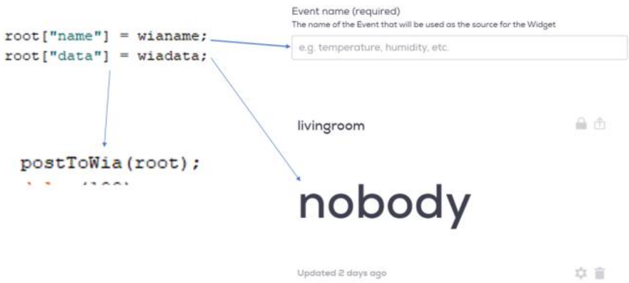

Figure 16. Use of the dashboard

3.2.5 System testing

This section will describe the methods to test the design of the project.

Anti-interference performance

To know the anti-interference performance of the design, we designed a test to compare them. The detector with normal design to transmit the data on time and the design from the project was put together facing the target. A program that can receive the data from 2 detectors and put them in the same figure was utilized to do the comparison. The targets included the normal moving, instantaneous motion, the pet dog, air condition, and gas stove. While maintaining the original functionality, the program of the new design was modified in some detail to make the results observable.

Wrong signal avoidance

From the result of the delay test, we speculated that when the user leaving a room and enter a new one, there may be a wrong signal from the old room because of the positive signal delay. In this test, we put the two sensors in two adjoining rooms and monitored there output when they were both in normal design and both in the new design. Similar programs from the last test were used after accommodation.

Accuracy of the system

This part is the test of the whole system.

To know the accuracy of the whole system, we defined a route in the house to traverse all the rooms. The tester would walk through the routes in two modes. In one mode, the tester would move though the route directly without stopping. In another one, the tester would stop the movement in each room for 5 seconds (including the living room when passing by). Each route was tested in the speed is 1m/s, which is the normal speed for the older adults without disabling [24]. Each situation would be tested for 5 times. The trajectory of the movement from the dashboard would be recorded.

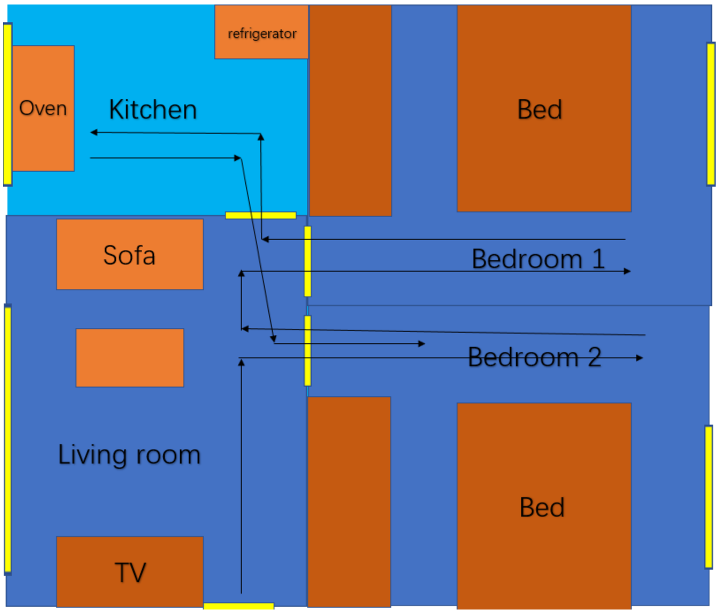

Figure 17. test route in the house

Capítulo 4. Results

4.1 Characterization of the PIR sensor

4.1.1 Modes of the PIR sensor

The PIR sensors have two modes. In the non-repetitive triggering mode, after the induction output high level, the output will automatically change from high level to low level as soon as the delay time ends. Repeatable triggering mode: after the sensor outputs a high level, during the delay period, if a human body moves within its sensing range, its output will remain at a high level, and the delay will not be high until the person leaves The level changes to a low level (the sensor module automatically delays a delay period after each activity of the human body is detected, and the time of the last activity is the starting point of the delay time). The repeatable triggering mode with the continuous signal meets the needs better in the project.

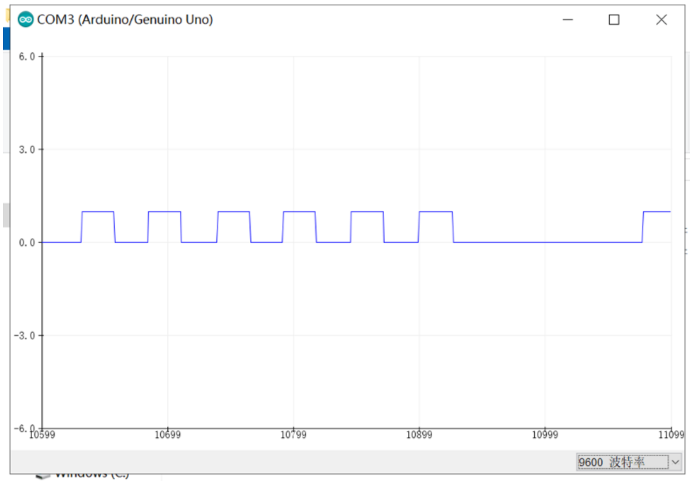

Figure 18. Non-repeatable mode

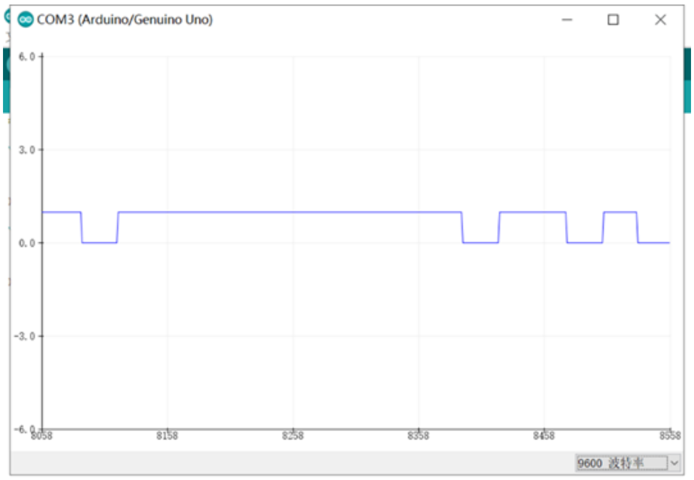

Figure 19. Repeatable mode

4.1.2 Scope of the PIR sensor

There are two characters to define the area that can be detected by the PIR sensor: angle and the detection distance

Angle

The result for the test of the angle is below

angle	50°	60°	70°	75°	80°
Sensor1	1:1 / 1:1	1:1 / 1:1	1:1 / 1:1	0:1 / 0:1	0:0 / 0:0
Sensor2	1:1 / 1:1	1:1 / 1:1	1:1 / 1:1	0:1 / 0:1	0:0 / 0:0
Sensor3	1:1 / 1:1	1:1 / 1:1	1:1 / 1:1	0:1 / 0:1	0:0 / 0:0

Table 1. Result for the test of angle

In the chart, the data means: outside the left line: inside the left line/outside the right line: inside the right line

In the chart, we can observe that the change of the signal happens when the hand moves across the line of 75° . According to the results, the maximal detection angle will be regarded as 150° in the project instead of 100° from the specification.

Distance

The result of the test of the distance is below.

	75°	60°	45°	30°	0
Sensor1	1.2m	2.6m	out	out	out
Sensor2	1m	2.3m	out	out	out
Sensor3	1.2m	1.6m	4m	out	out

Table 2. Result for the test of distance

In the chart, we found that though the PIR sensor can detect the motion at 75° from the mid perpendicular, the detection distance at this angle was limited. The sensor can detect the motion at 75° and 60° only in a short distance less than 3 meters, which is not large enough to cover the room in the project. And the distance increases rapidly when it got close to the mid perpendicular. In the scope of 45° , the distance is longer than the diagonal, which means the detection can reach the farthest place in the room.

From the tests, we found the maximal detection angle of the PIR sensor is about 150° . However, not all the angles are useful for the project. According to the result, the distance at 90° can completely meet our needs.

4.1.3 The minimal duration of the signal

The result for the minimal duration time is below:

time	1	2	3	4	5	6	7	8	9	10
Sensor1	8	6	6	8	7	6	8	6	7	7
Sensor2	5	5	7	8	9	9	7	11	9	6
Sensor3	10	11	6	6	6	7	6	7	6	6

Table 3. Fast motion duration time

time	1	2	3	4	5	6	7	8	9	10
Sensor1	15	16	15	15	16	17	17	16	18	17
Sensor2	16	16	16	17	16	14	15	14	15	17
Sensor3	14	14	15	14	15	15	16	16	17	14

Table 4. Slow-motion duration time

Observing the results, we could find the distinction between every test. The duration time for an instantaneous varied from 2.5s-5.5s and the time for slow-motion were from 7-9s. The differences depended on the actual speed and moving amplitude. Thus, in the practical situation, the PIR sensor will produce a positive signal for 5.5 seconds at most after an instantaneous trigger. For a continuous motion longer than 2 seconds, the positive signal from the sensor will be longer than 7 seconds.

4.1.4 Delay of the signal

The delay of the positive signal after the motion stop is below:

time	1	2	3	4	5	6	7	8	9	10
Sensor1	8	9	7	6	6	10	8	7	6	6
Sensor2	7	8	6	8	7	9	7	6	7	7
Sensor3	8	7	7	9	9	8	7	8	7	8

Table 5. Delay of the signal

From the result, there will be a positive signal for 3-5 seconds after the motion stop, which means the PIR sensor will generate extra positive for 5 seconds at most after the user leaving the room.

4.1.5 Pet

In the test, we found the PIR sensor would respond to the sample pet dog.

4.1.6 Air condition

The result for the test of the PIR sensor is below:

Position	1 meter	Same corner	Side corner	Opposite corner
Not swing	0	0	0	0
Swing	1	1	0	0

Table 6. Result for the test of air condition

When we let the air condition work without a swing and faced the PIR sensor to the air condition at 1 meter away, the PIR sensor could detect nothing at all the test positions. When the air condition was changed to the swing mode, the sensor-generated some positive signals at the 1 meter away and the same corner. And the duration of each positive signal was no longer than 4 seconds. In the side corner and opposite side, nothing was detected. This trigger is from the remarkable temperature change caused by the swing of the air condition leaves. When the PIR sensor is far away from the equipment, the change is not strong enough to be detected.

4.1.7 Furniture

Gas stove

In the test, the PIR sensor produced the positive signal intermittently. The waggle of the fire and the temperature change from it leads to these positive signals. In the design, the PIR sensor will avoid facing the gas stove.

Microwave oven

In the test, the microwave oven at work didn’t trigger the PIR sensor. The temperature change was blocked in the microwave oven. In the design, the position of the oven can be ignored.

Screen

From the result, the screen of the television cannot trigger the PIR sensor.

4.6.3 *Position of the sensor*

This section discusses which scheme to set the single or PIR sensor can achieve better performance in the system.

5 positions to set the sensor are considered in this section.

A: at the center of the roof

B: in the corner of the room at the height of 1.2-1.6 meters with a horizontal angle of view

C: in the middle of the room at the height of 1.2-1.6 meters with a horizontal angle of view

D: in the corner of the room at the height of 2.0-3.0 meters with an inclined angle of view

E: in the middle of the room at the height of 2.0-3.0 meters with an inclined angle of view

Position A

A part of products based on the PIR sensor was installed at the center of the roof. Though from the data we collected, the detection area of a PIR sensor that was set in the center of the roof can cover the whole room, in our project, the center of the roof in all the rooms is covered with the ceiling lamp or fan. The occlusion from the fan may lead to unstable signal and security issues. We got corresponding results in the simple tests. And the ceiling lamp leads to the offset of the position to set the PIR sensor, which results in the offset of the detection area. And these designs are common in the current house. Due to these influences, considering the practical situation, we think this scheme is not suitable for our project.

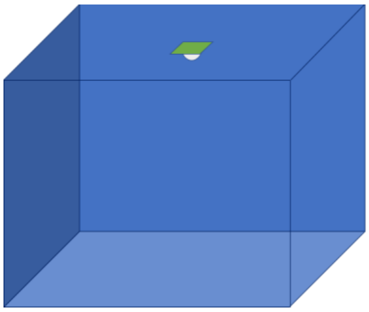

Figure 20. Position A

Position B

Considering that the detection distances within 90 degrees are longer than the longest side of the room, in this situation, the detection area can cover the whole room theoretically. From the result, we can see that the PIR sensor at position B has an insensitive route in its opposite corner. This is because the PIR sensor is sensitive to the radial movement. And in other routes, the movement through the routes can be detected. But motion with small amplitude can only be detected at the nodes in front of the sensor. There is an insensitive node in the opposite corner.

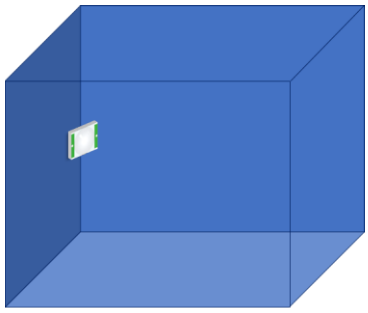

Figure 21. Position B

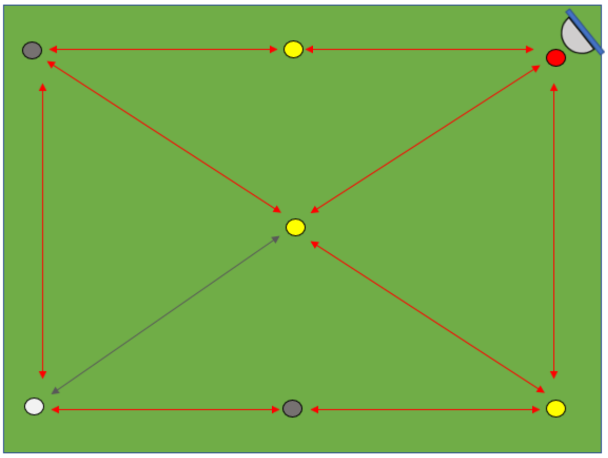

Figure 22. Result of position B

Position C

From the preceding result, we know that the maximal angle of the PIR sensor is 150° . So, there must be an insensitive area out of this angle. We got a coincident result from the test. From the resulting figure, we can find that the sensor at this position cannot detect the motion or activity on the side.

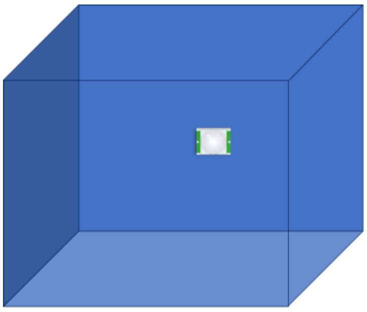

Figure 23. Position C

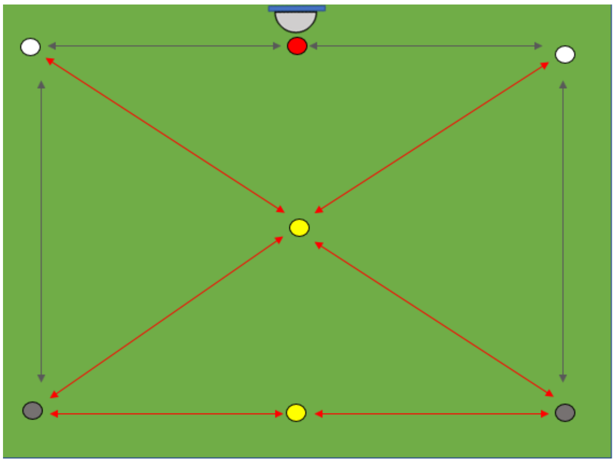

Figure 24. Result of position C

Position D

In the test of the PIR sensor at position B, we got a similar result as the sensor at position B.

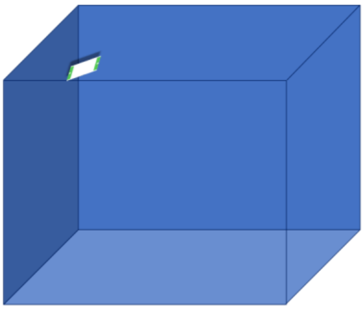

Figure 25. Position D

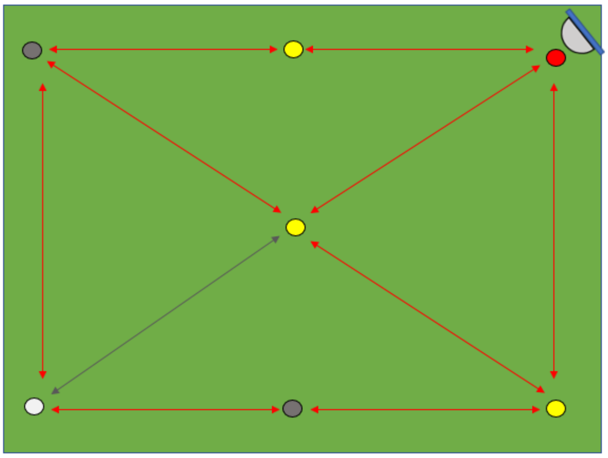

Figure 26. Result of position D

Position E

From the figure, we can see that the sensor performs better than the sensor at position C. However, there are still 2 insensitive routes at the side.

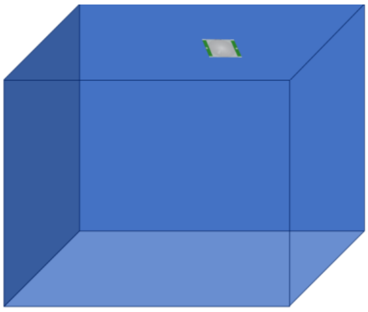

Figure 27. Position E

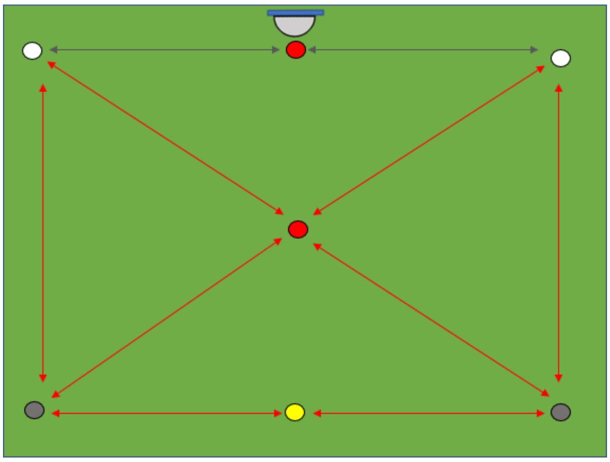

Figure 28. Result of position E

From the results, the PIR sensor at all the positions has an insensitive area. Relatively, the sensor installed in the corner has a large sensitive area. For the motion, the behavior with a small amplitude can only be detected in a small area for all the positions.

4.2 Comparison of the wireless modules

The results for the test of power consumption are below:

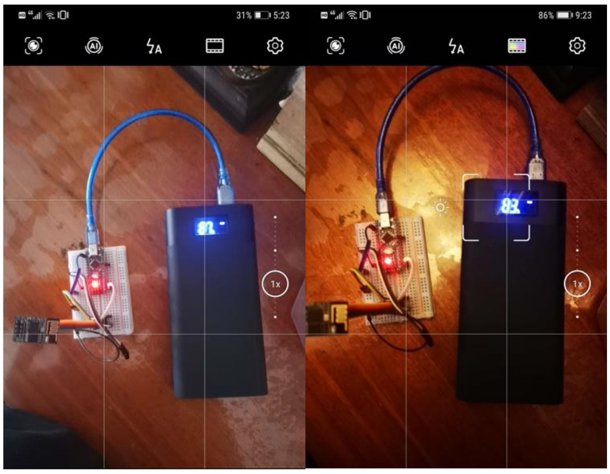

Figure 29. Wi-Fi module (empty mode)

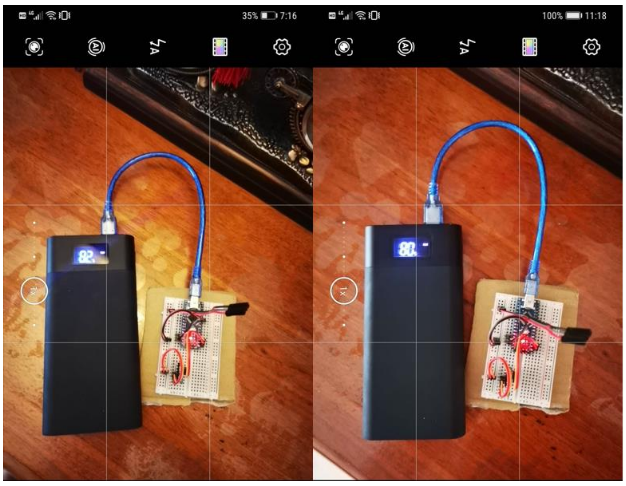

Figure 30. Bluetooth module (empty mode)

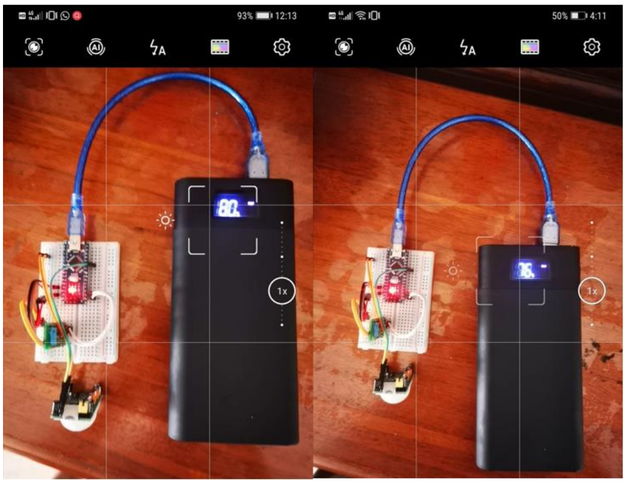

Figure 31. Bluetooth module (working mode)

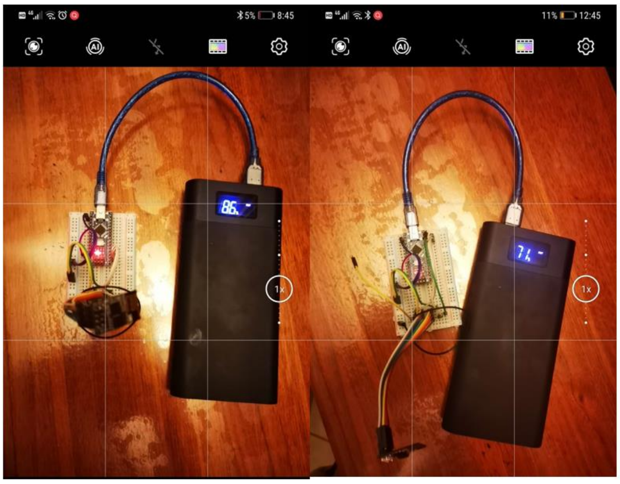

Figure 32. Wi-Fi module (working mode)

	Bluetooth	Wi-Fi
Protocol	IEEE802.11	IEEE802.11.X
Frequency	2.4GHz	2.4GHz
Bandwidth	Low (800 Kbps)	High (11 Mbps)
Specifications authority	Bluetooth SIG	IEEE, WECA
Power consumption (empty mode)	2%	4%
Power consumption (working mode)	4%	15%
Detection distance	longer than 10 meters (5-30m from the information)	With 802.11b/g the typical range is 32 meters indoors and 95 meters (300 ft) outdoors. 802.11n has a greater range. 2.5GHz Wi-Fi communication has a greater range than 5GHz. Antennas can also increase range.
Maximum devices	10 (infinite in BLE mode)	Infinite
Other devices requirement	A gateway as a center to connect to the internet	Router
Difficulty in process data	Low (program at Arduino MKR 1000 by C/C++)	High (At Wia dashboard by dashboard)
Cost	Low	High
Ease of use	Fairly simple to use. It is easy to switch between devices or find and connect to any device.	It is more complex and requires the configuration of hardware and software.

Table 7. Chart of comparison between Wi-Fi and Bluetooth [23]

According to the chart, Wi-Fi has the advantage of high speed, long-distance, and high expandability. Bluetooth has the advantage of low power consumption, low cost, and ease of use, and data processing. Consider the need for the project and the practical situation, the Bluetooth module can completely meet the needs with ease to design and maintain, which is more suitable in the project.

4.3 Design of the system

In this chapter, we will introduce the design of our system, including the hardware design, software design, and dashboard design. This is the structure of the system:

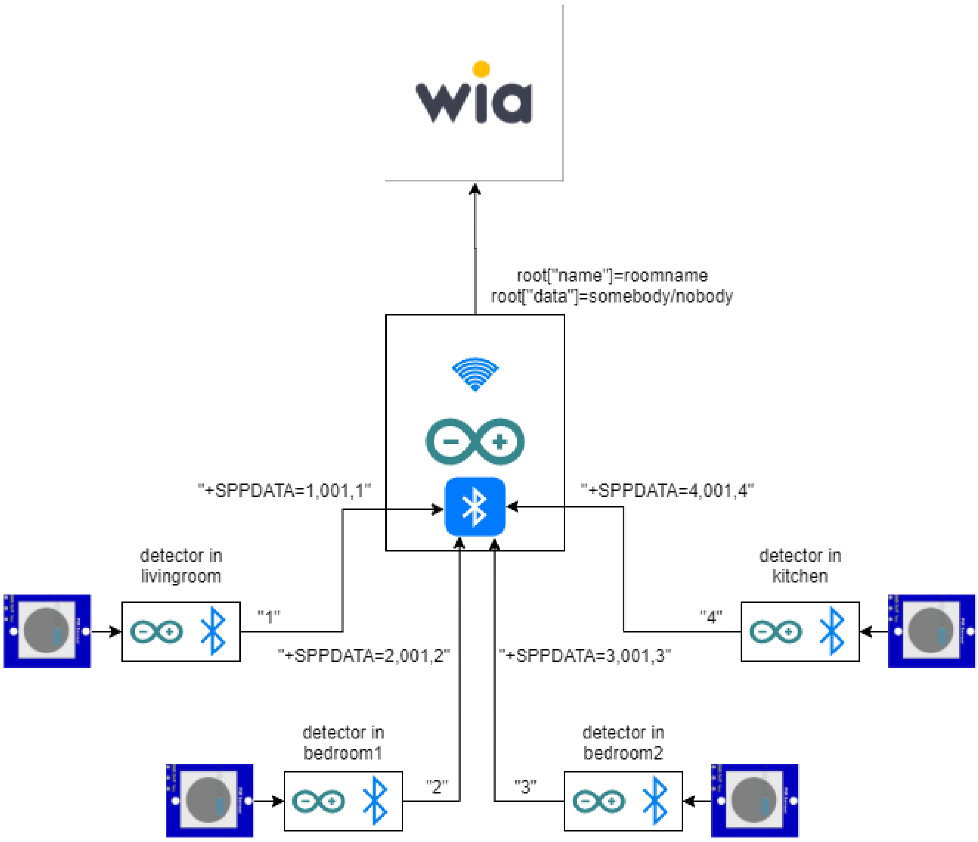

Figure 34. Structure of the system

From the tests of the position, the sensor installed at the corner has better performance. Considering the influence of the barriers, to get less overlapping area and fast response time, the PIR sensor in this system will be installed at the corner near the door, at the height of 2.5 meters. The positions in the demonstrator house are below:

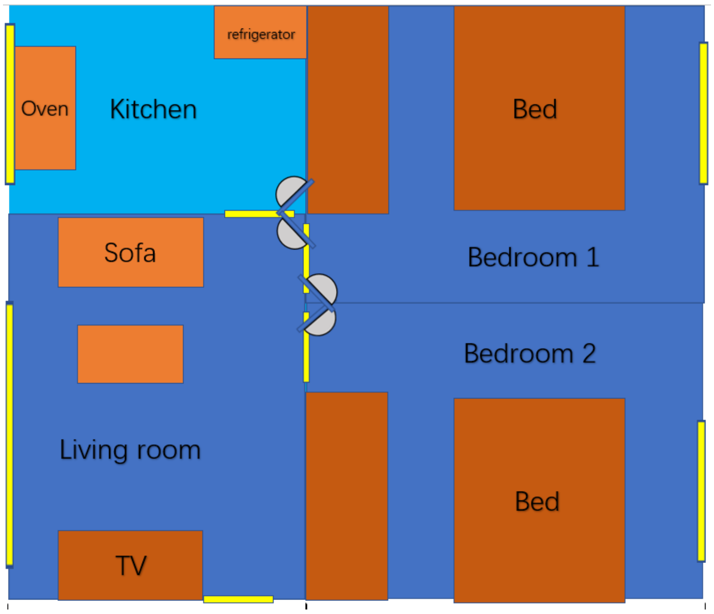

Figure 35. Position of the sensors

4.3.1 hardware design

There are 2 parts in the motion detector system: the detector part and the gateway.

Detector hardware design

For the detector part, the hardware design is below:

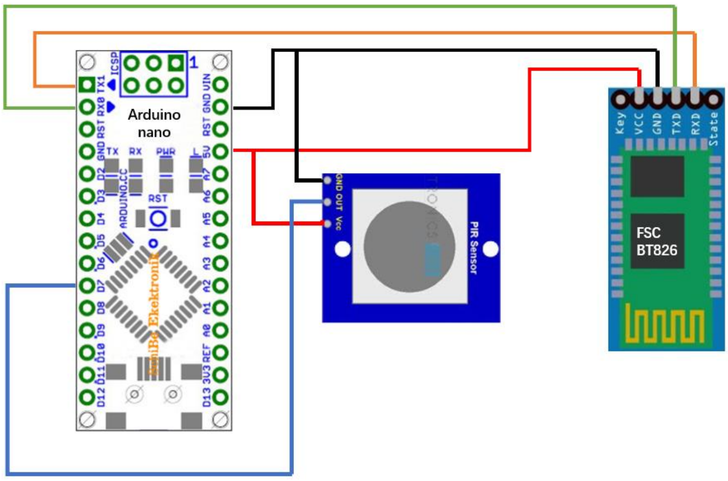

Figure 36. Hardware design of the detector

There are 3 components: Arduino nano board, PIR sensor, and FSC-BT836 module. The connection should be like the chart below:

Arduino	FSC-BT8266	PIR sensor
+5V	+5V	+5V
GND	GND	GND
RX0	TXD	
TX1	RXD	
D7		OUT

Table 8. Connection chart

Gateway hardware design

The hardware design of the gateway is below:

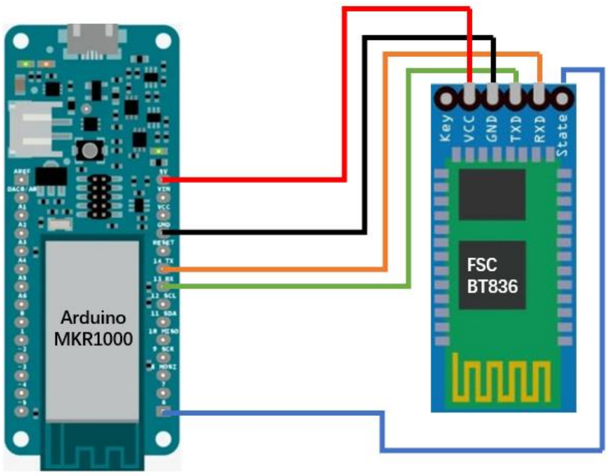

Figure 37. Hardware design of the gateway

There should be 2 components: Arduino MKR 1000 and FSC-BT836. The connection chart should like below:

Arduino MKR 1000	FSC-BT836

+5V	+5V
GND	GND
TX	RXD
RX	TXD
6	state

Table 9. Connection chart

4.3.2 software design

Detector software design

According to the previous research, all the wrong signals caused by the air condition and instantaneous motion can last for several seconds, which will lead to the obvious unintended activation. From the result of our research, most of the duration time of these signals is shorter than 5.5 seconds. Considering the motion speed of the seniors are always not momentary and will stay in a house for longer than 2 seconds, we set a “check time” of 6 seconds to avoid the influence of these environmental noises. This time is between the maximal duration time for an instantaneous trigger of 5.5 seconds and the minimal duration time for the normal motion of 7 seconds. When the detector detects motion, it will wait for 6 seconds, and check the status of the PIR sensor again. If the PIR sensor still has a positive output, the Arduino will send the data to the gateway formally.

This “check time” can also avoid the influence of the delay time. In the normal design, when the user leaves a room and enters a new room, the sensor in the last room will still have a positive signal due to the delay. So, there will be a wrong signal to show the user goes back to the preceding room. With the “check time”, the positive signal from the detector in the preceding room will have stopped before the detector in the new room sending the signal. Thus, the system can show the correct position of the user.

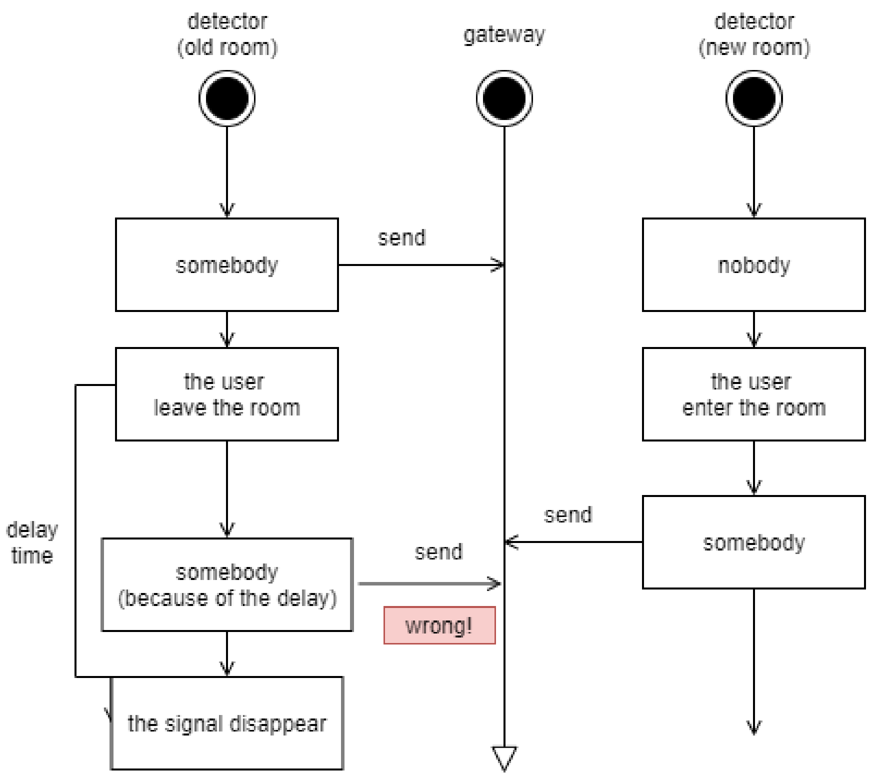

Figure 38. The wrong signal if no checking time

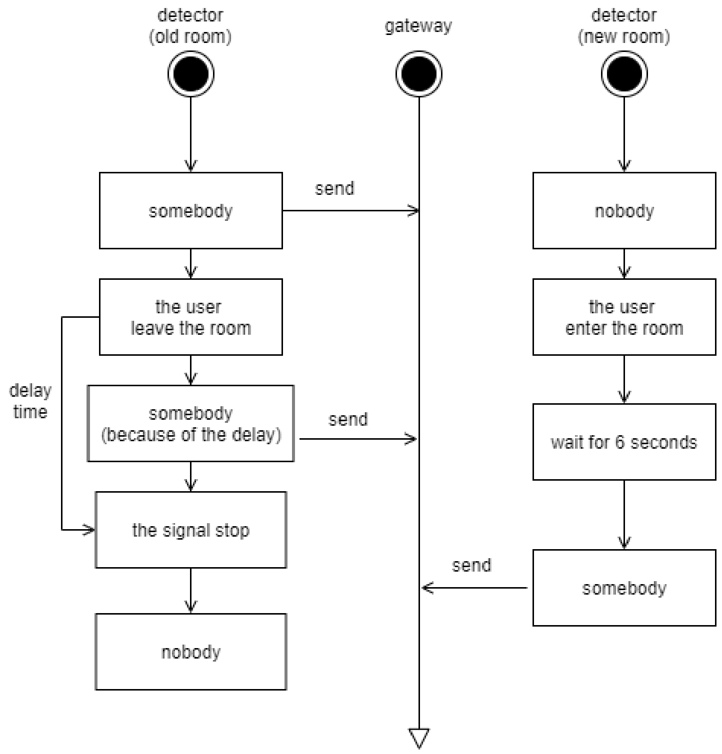

Figure 39. Correct signal

With the design logic, the flow chart is below:

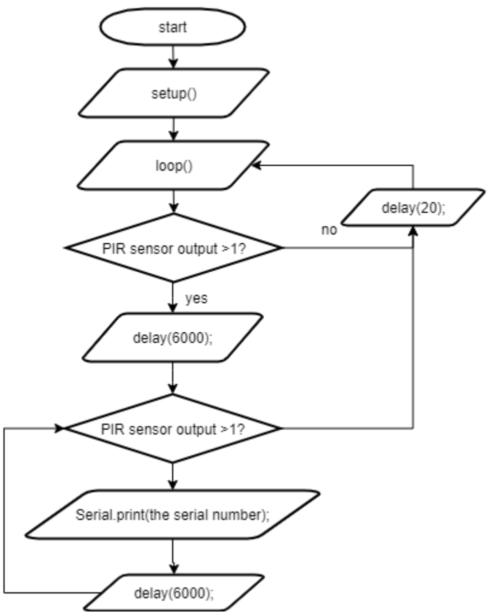

Figure 40. Flow chart of the detector

When entering the loop, the program will start to monitor the PIR sensor. After it detects the first motion, it will wait for 6 seconds, and check the status of the PIR sensor again. When the PIR sensor is still generating a positive signal, the Arduino nano sends the signal to the gateway. To let the gateway recognize the source of the data easier, the detector will send their serial number to the gateway.

Gateway software design

According to the research, the PIR sensor is insensitive to the small movement without body move. However, the seniors are always in this kind of movement instead of walking around the house. With this consideration, the "refresh mode" is used in the design of the system. When the gateway receives the signal from a detector, it will first judge if this signal is from a new room. If it is, the gateway will upload it to the Wia dashboard. Then, the gateway will also upload the data to set the status of the last room to "nobody". After that, the system will set the serial number of the new room to the "last room".

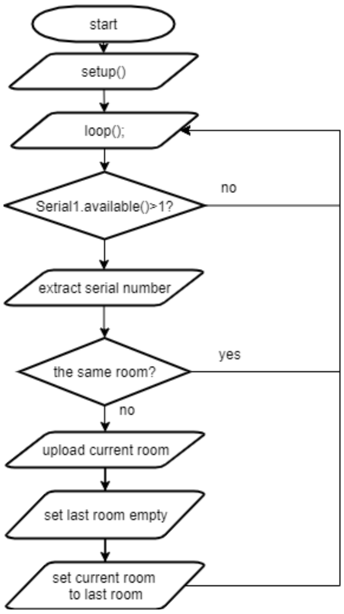

Figure 41. Flow chart of the gateway

4.3.3 Dashboard design

According to the need, there should be 5 widgets in the dashboard, four status widgets connect to 4 rooms and a widget to receive the message.

4.4 Implementation of the system

In this section, we will introduce the actual implementation of the system, including the picture of hardware and program.

4.4.1 Implementation of the hardware

Implementation of the detector

According to the design, the components are assembled on a breadboard. For easy installation and aesthetics, most of the components are packaged in a box except the PIR sensor. The PIR sensor is pasted on the outside corner of the box. The Bluetooth module was

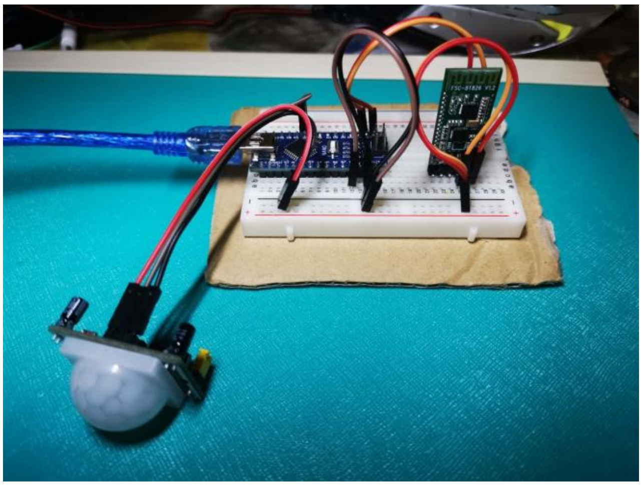

Figure 42. Implementation of the detector

Figure 43. Implementation of the detector (installed)

Implementation of the gateway

Based on the design, the gateway is assembled.

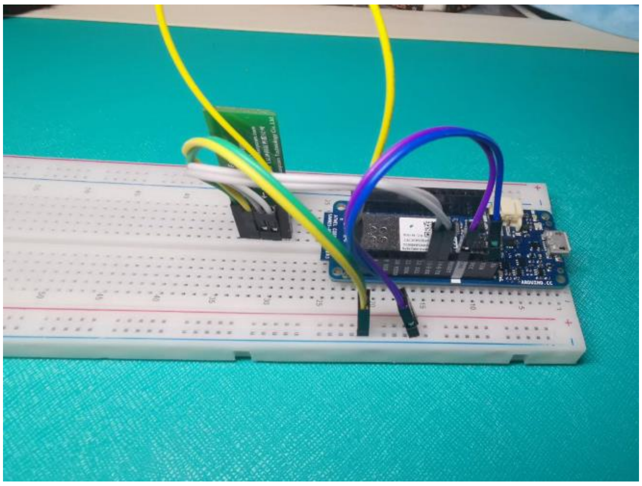

Figure 44. Implementation of the gateway

4.4.2 Implementation of the software

In this part, we will show the program in the system, introduce the function, and the logic.

Program for the detector

According to the flow chart, the program is below:

In the program, the baud rate is set to 115200, which is the default baud rate of the FSC-BT826 module. The detector sends the data without a line break because the gateway can read it independently.

Program for the gateway

The program is implemented according to the flow chart.

Most of the codes from the declaration part are obtained from the example to use the Wia dashboard by Arduino MKR 1000. The WIFI_SSID, WIFI_PASS, and device_secret_key are modified to suit the project and environment. Besides, there are three variables. "str" is to store the string from the detector. "lastroom" and "current" is to store corresponding data.

These two functions are used to upload the data to the dashboard. The function postToWia() is from the example. To let the uploading easier, we integrated the part to set the data.

A function messageWia() is to show some verbal content on the wia.

In the "setup()" part, the system has to use AT command to connect to all the detectors. The Bluetooth module will leave AT command mode after establishing the first connection. To establish more connection, the "status" pin on the module should be set to positive. After connecting to the WiFi, the program will reset all the widget to "nobody". And show the welcome message on the dashboard.

After receiving the data, the function "Serial1.readString()" is used to get the data string. Considering the format of string received from the Bluetooth will be "+SPPDATA = (SPPchannel), (payload length), (payload)\n", the codes below can extract the information. Then the program will judge if the signal is from a new room. If so, the program will upload the new position to the dashboard and set the preceding room empty. After these, it will set the "lastroom" to "current".

4.4.3 Implementation of the dashboard

The implementation of the dashboard is below:

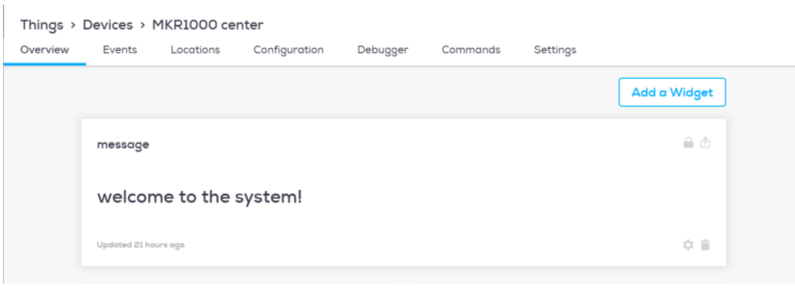

Figure 45. Widget of the message

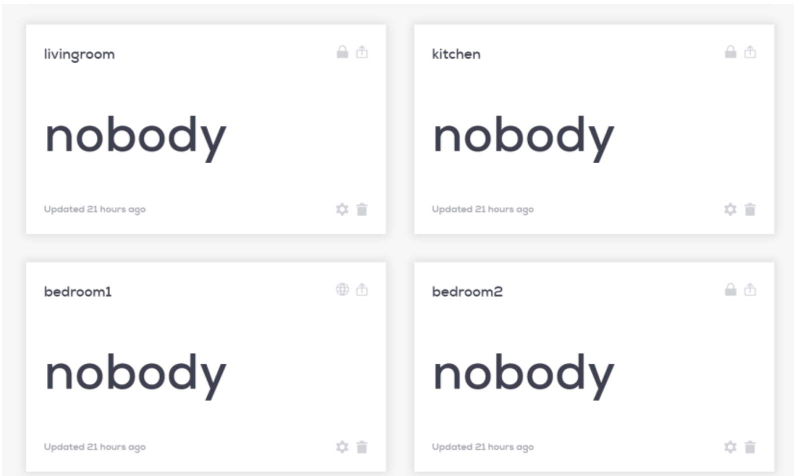

Figure 46. Widgets of the rooms

4.5 Test of the system

4.5.1 Test of the anti-interference performance

The figure of the normal moving presents the difference between the normal design and the new design. In the figure, the signal of the new design appears several seconds later than the normal design, which means there is a delay of the positive signal after the detector detects the moving.

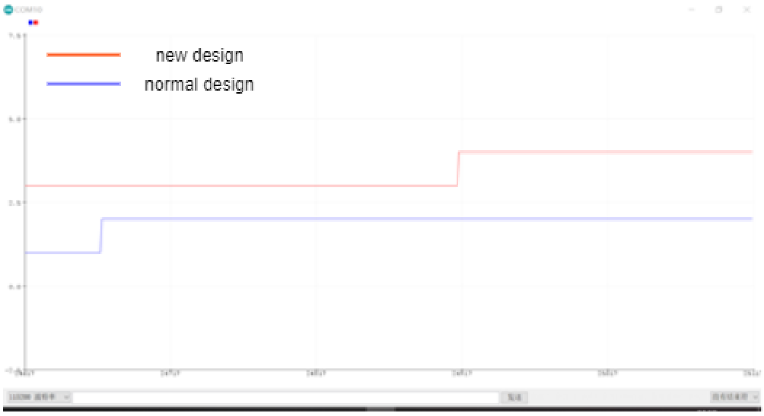

Figure 47. Normal moving

In the figure of the instantaneous motion, we can see the normal design is affected by the motion, and the detector with the new design can shield this kind of signal.

Figure 48. instantaneous motion

In the test of the air condition, we can observe the wrong signal produced by the air condition and the anti-interference ability of the new design.

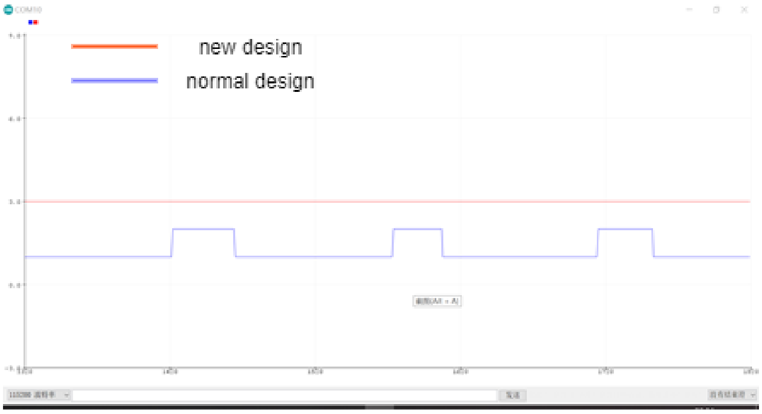

Figure 49. air condition

In the tests of the gas stove and the pet dog, we can see the wrong signal in both of the systems. So the system will still be affected by the stove and dog.

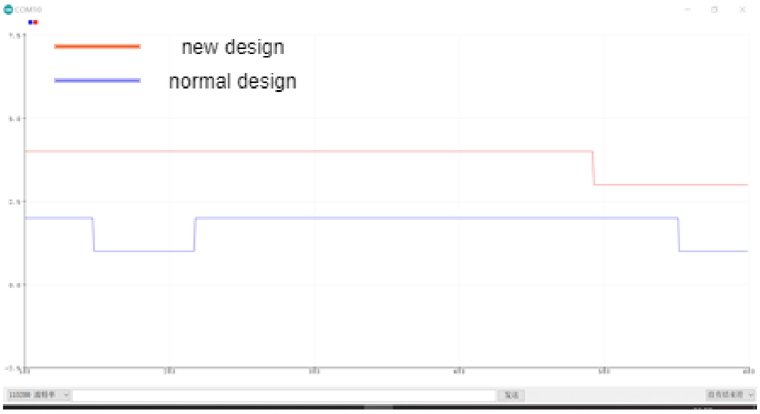

Figure 50. gas stove

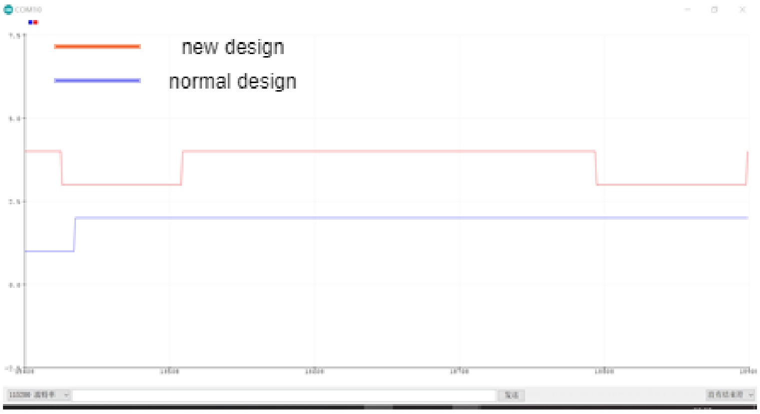

Figure 51. Dog

4.5.2 Tests of the wrong signal avoidance

From the results, we can see that, when the tester enters a new room, there are positive signals in both of the rooms at the same time. And this may lead to the mistake of the system. As a result of our design, there is an interval between the disappearance of the preceding positive signal and the start of the new one. So, the mistake of the system can be avoided.

Figure 52. Test of the normal design

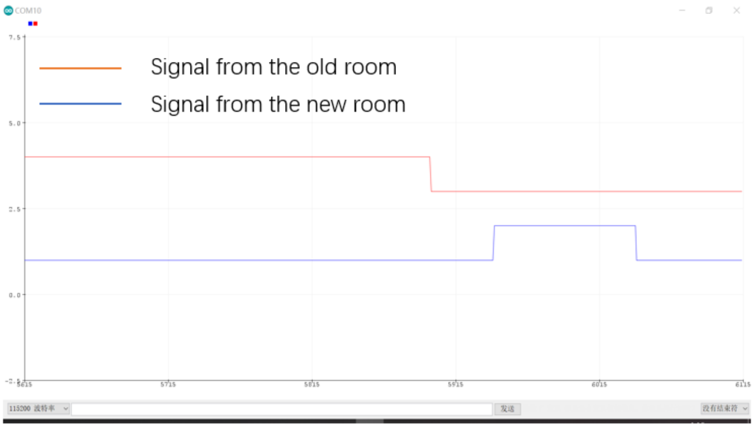

Figure 53. Test of the design with "check time"

4.6.3 *Test of the system*

The result of the test of the accuracy of the whole system is below:

Time	Trajectory
1	Nobody-livingroom-bedroom2-bedroom1-kitchen-livingroom-bedroom2
2	Nobody-livingroom-bedroom2-livingroom-bedroom1-kitchen-livingroom-bedroom2
3	Nobody-livingroom-bedroom2-livingroom-bedroom1-kitchen-livingroom-bedroom2
4	Nobody-livingroom-bedroom2-livingroom-bedroom1-kitchen-livingroom-bedroom2
5	Nobody-livingroom-bedroom2-bedroom1-kitchen-livingroom-bedroom2

Table 10. No-stop mode

Time	Trajectory
1	Nobody-livingroom-bedroom2-livingroom-bedroom1-livingroom-kitchen-livingroom-bedroom2
2	Nobody-livingroom-bedroom2-livingroom-bedroom1-livingroom-kitchen-livingroom-bedroom2
3	Nobody-livingroom-bedroom2-livingroom-bedroom1-livingroom-kitchen-livingroom-bedroom2
4	Nobody-livingroom-bedroom2-livingroom-bedroom1-livingroom-kitchen-livingroom-bedroom2
5	Nobody-livingroom-bedroom2-livingroom-bedroom1-livingroom-kitchen-livingroom-bedroom2

Table 11. Stop mode

From the results, we can find that, if the tester doesn't stop at all the rooms, the trajectory when passing by the living room for short distance may not be recognized. This is because of the short exposure duration from the PIR sensor in a short distance.

From the results of the stop mode, if the tester stays at every room for seconds, the system can provide a complete trajectory of the user.

During the observation, the system has a long delay after the movement, which is in accord with the design.

Capítulo 5. Discussion

There is a lot of researches based on the PIR sensor focused more on the study. These researches figured out all kinds of algorithms and used more and more PIR sensors to achieve high accuracy. The PIR sensor is utilized by them from a macroscopic angle. However, this project provides a microcosmic perspective on the details of the PIR sensor. It finds more precise data about the characteristics of the PIR sensor and finds the potential influence factors. Additionally, it proposes a method that can solve part of the problems it finds in the research. So that the system can provide a tracing system with higher accuracy for the seniors.

Though the angle of view on the specification file is 100°, we found its maximal angle of 150°. For the test of the distance, we defined the actual detection area. By the test of duration time and delay, the signal was considered in deeper detail in the project. We obtained the minimal duration time and the delay time of the signal.

We also considered more on the practical application. We investigated the influences of the common furniture including the air condition, gas stove, microwave oven, the screen of the television. These influences may be ignored in other researches. From the result, we can see that the screen and the microwave oven will not influence the PIR sensor.

According to the results of all the experiments, we finished our design. By the test, we found that our design of the “check time” can not only deal with the problem of the air condition and instantaneous unintended activation, it can also solve the problem of the wrong signal when entering a new room. So, we can ignore the position of the air condition when installing the sensor. The ability to avoid the instantaneous signal is helpful, because this kind of signal may come from plenty of influence factors. However, the system still cannot avoid the positive signal from the gas stove and dog. Maybe it’s dangerous to open the stove without people besides. But the dog can provide the single seniors better life.

For the position to install the detector, in this project, we choose to put it near the door to provide the signal immediately when someone enters the room. However, in our project, we define the detection area of the PIR sensor at several positions. Because of the refresh mode used in our system, the problem of the dead zone can be ignored. The PIR sensor can be installed at other places that can detect the entering person at once.

The system has a crucial feature of the delay of the whole system. This is a bargain between timeliness and accuracy. Considering the seniors are the group with low moving speeds and less movement, the system can provide the position and trajectory with higher accuracy may be better.

From the name of the projects, it seems easy to finish. but when I try to do it, too many problems appear. For a project, it’s insufficient to let the system “work”. I have to consider all of the details. How to design? Why design like this? What’s superiority? As a project concerning the hardware, there are always unpredictable problems. I tried to solve the problem of the connection with Arduino nano for about half a month. Finally, I solved it by using a new USB cable.

During the process of overcoming so many difficulties, I want to thank a lot of people. SABIEN provides the devices and environment of the project, and I got too much help from my supervisors and everyone in the laboratory, both on study and life. It was such an unforgettable experience to stay in a wonderful city. And of course, thanks to BUPT, QMUL, and UPV that provide the chance of the project.

For the next step. Our team will focus on several directions. On the one hand, our team will try to improve the reliability of the system, including the problem of the gas stove, pet dog, and the problem of passing by a room in a short distance. there is also more improvement be on the wireless module. in this project, we use the classical Bluetooth mode with SPP connection only. The BLE protocol can provide the service in low power consumption and doesn’t have the limit on the quantity of the devices in the system. For the ESP8266 Wi-Fi module, some low consumption solutions can be considered. Besides, we can consider the compatibility of more than two users in the room.

The other direction is about the service. In this program, the results can only be presented on the dashboard. But this can be expanded to a larger scale. The result can be presented on the other website or app on the mobile phone so that caregivers can see their status more convenient. Based on the results, more service can be introduced to help caregivers more. Such as the detection of the wandering or other abnormal activities. When the user stays in an abnormal room for a long time, send an alert to the caregiver.

Furthermore, this system can cooperate with other IoT devices. For example, when the user enters a new room, turn on or off the light automatically. When the user has left a room for a certain time, turn off the unnecessary furniture.

For the final vision, our team wants to design a whole system to improve the life quality of the seniors and help the caregivers take care of their families easier and better.

Capítulo 6. Conclusion

In this project, we finally designed a motion detector system that can track a single user in a house, and present his position and trajectory on the Wia dashboard.

From our tests of the PIR sensor, we obtained the time characteristic of the positive signal. The signal has a maximal delay of about 5 seconds, and the duration time of 5.5 seconds at most. With this data, we designed a "check time" for 6 seconds after the detector first detecting the motion. If there is still a positive signal, the detector will transmit the status to the gateway. If not, the detector will ignore the motion.

According to the experiments, in the common furniture that may lead to the infrared radiation change, microwave oven and screen will not affect the PIR sensor, and the air conditioner working in the swing mode, gas stove will result in unintended activation. So does the pet dog.

And we also got a result that it is hard for the detector to detect the movement in a small amplitude. So if the user stops moving, the signal will disappear. From this, we use the "refresh method" in our design. When the user stops the large motion, the system will keep his position in the room. Only when the detector from another room detects the motion, the new status will be upload, and the status will change.

With our design, the effect of the air conditioner can be eliminated. And the other factors that may lead to instantaneous signal, can also be avoided in the system. In addition, this design can solve the problem of the signal conflict when the user moving from one room to another.

In the tests of the whole system, we found that the system could provide a high degree of accuracy when the tester stayed for a moment in every room. But if the tester just passed by a room in a short distance, this part of the trajectory may be lost. For the real-time position, the system can present the position well but with a delay of 6 seconds.

REFERENCE

[1] UN DESA. (2019, June) World Population Prospects 2019: Highlights. Retrieved June 17, 2019, from United Nations Department of Economic and Social Affairs Web site: https://www.un.org/development/desa/publications/world-population-prospects-2019-highlights.html

[2] Barbara J. Berkman. (2019, May) *Older Adults Living Alone*. Retrieved May, 2019, from MSD MANUAL Consumer Version Web site: https://www.msdmanuals.com/home/older-people's-health-issues/social-issues-affecting-older-people/older-people-living-alone

[3] Suku. (2020, Febr) *银发经济行业数据分析：预测 2020 年中国独居老人数量为 0.3 亿人*. Retrieved Feb 13, 2020, from United Nations Department of Economic and Social Affairs Web site: https://www.iimedia.cn/c1061/68943.html

[4] https://en.wikipedia.org/wiki/Dementia

[5] https://www.who.int/news-room/fact-sheets/detail/dementia

[6] Frank Miskelly, A novel system of electronic tagging in patients with dementia and wandering, Age and Ageing, Volume 33, Issue 3, May 2004, Pages 304–306.

[7] Q. Lin, D. Zhang, X. Huang, H. Ni and X. Zhou, "Detecting wandering behavior based on GPS traces for elders with dementia," 2012 12th International Conference on Control Automation Robotics & Vision (ICARCV), Guangzhou, 2012, pp. 672-677

[8] Dogan, O.; Martinez-Millana, A.; Rojas, E.; Sepúlveda, M.; Munoz-Gama, J.; Traver, V.; Fernandez-Llatas, C. Individual Behavior Modeling with Sensors Using Process Mining. Electronics 2019, 8, 766.

[9] T. Yiping, J. Shunjing, Y. Zhongyuan and Y. Sisi, "Detection Elder Abnormal Activities by using Omni-directional Vision Sensor: Activity Data Collection and Modeling," 2006 SICE-ICASE International Joint Conference, Busan, 2006, pp. 3850-3853.

[10] H. Yu, B. Yang, J. Liu and G. Yu, "Passive Human Trajectory Tracking Study in Indoor Environment with CSI," 2018 International Conference on Networking and Network Applications (NaNA), Xi'an, China, 2018, pp. 372-377.

[11] Z. Peng, J. Muñoz-Ferreras, Y. Tang, R. Gómez-García and C. Li, "Portable coherent frequency-modulated continuous-wave radar for indoor human tracking," 2016 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS), Austin, TX, 2016, pp. 36-38.

[12] A. Hadj Henni, R. Ben Bachouch, O. Bennis and N. Ramdani, "Enhanced Multiplex Binary PIR Localization Using the Transferable Belief Model," in IEEE Sensors Journal, vol. 19, no. 18, pp. 8146-8159, 15 Sept.15, 2019.

[13] M. Gochoo, T. Tan, V. Velusamy, S. Liu, D. Bayanduuren and S. Huang, "Device-Free Non-Privacy Invasive Classification of Elderly Travel Patterns in a Smart House Using PIR Sensors and DCNN," in IEEE Sensors Journal, vol. 18, no. 1, pp. 390-400, 1 Jan.1, 2018.

[14] 李博雅. (0). 基于 PIR 传感器的目标跟踪系统的设计与实现. (Doctoral dissertation).

[15] J. Lu, J. Gong, Q. Hao and F. Hu, "Multi-agent based wireless pyroelectric infrared sensor networks for multi-human tracking and self-calibration," SENSORS, 2013 IEEE, Baltimore, MD, 2013, pp. 1-4.

[16] S. Lee, K. N. Ha and K. C. Lee, "A pyroelectric infrared sensor-based indoor location-aware system for the smart home," in IEEE Transactions on Consumer Electronics, vol. 52, no. 4, pp. 1311-1317, Nov. 2006.

[17] Yu, Z.; Yuan, L.; Luo, W.; Feng, L.; Lv, G. Spatio-Temporal Constrained Human Trajectory Generation from the PIR Motion Detector Sensor Network Data: A Geometric Algebra Approach. Sensors 2016, 16, 43

[18] Wren, C.R.; Ivanov, Y.A.; Leigh, D.; Westhues, J. The MERL motion detector dataset. In Proceedings of the 2007 Workshop on Massive Datasets, Nagoya, Japan, 12 November 2007; pp. 10–14.

[19] Arduino Studio. (2020, May) *Arduino nano.* Retrieved May 2020, from Arduino formal Web site: https://store.arduino.cc/usa/arduino-nano

[20] Arduino Studio. (2020, May) *Arduino MKR 1000.* Retrieved May, 2020, from Arduino formal Web site: https://store.arduino.cc/usa/arduino-mkr1000-with-headers-mounted
[21] https://www.cnblogs.com/BlueMountain-HaggenDazs/p/6056827.html
[22] https://developers.wia.io/things/mkr1000
[23] https://www.diffen.com/difference/Bluetooth_vs_Wifi
[24] Bendall MJ, Bassey EJ, Pearson MB. Factors affecting walking speed of elderly people. Age Ageing.1989;18:327-332.