Title	SEATEC : a vacancy monitor system for a small restaurant
Sub Title	
Author	徐, 心(Xu, Xin) 加藤, 朗(Kato, Akira)
Publisher	慶應義塾大学大学院メディアデザイン研究科
Publication year	2017
Jtitle	
JaLC DOI	
Abstract	
Notes	修士学位論文. 2017年度メディアデザイン学 第604号
Genre	Thesis or Dissertation
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40001001-00002017-0604

Master's Thesis
Academic Year 2017

SEATEC: A Vacancy Monitor System for a Small Restaurant

Keio University
Graduate School of Media Design

Xin Xu

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
MASTER of Media Design

Xin Xu

Thesis Committee:

Professor Akira Kato	(Supervisor)
Associate Professor Kazunori Sugiura	(Co-supervisor)
Professor Hiro Kishi	(Member)

Abstract of Master's Thesis of Academic Year 2017

SEATEC: A Vacancy Monitor System for a Small Restaurant

Category: Science / Engineering

Summary

Vacancy monitor systems are widely used in many fields. As for restaurants, usually only fine dining ones are using such internet-based systems, costly both in labor and money. Most of the others, small restaurants commonly just use paper, pen and manpower. There are always a lot of delicious and popular small restaurants, sometimes we may walk up long steep stairs ended up with no vacant seats.

Subsequent to this, a lightweight vacancy monitor system is necessary for small restaurants. The most important problem to build such system is to find out a way to sense and count customers enter and exit restaurants, or sense the vacancy seats in restaurants, and this way should lower the barriers of entry for both supply and demand side.

This thesis will focus on one way to detect the vacancy situation of chairs, and will discuss its capability and limitation.

Keywords:

Human Detection, IoT, Expense, Picture Analysis, Distance Sensor

Keio University Graduate School of Media Design

Xin Xu

Acknowledgements

I feel much indebted to many people who have instructed and favored me during those time writing this paper. Firstly I owe my greatest debt of gratitude to my tutor, also my supervisor, Professor Akira Kato, who has given me his constant help, read the draft with great care and offered me invaluable advice and informative suggestions. I am also indebt to Professor Kato for not only guiding me about my research but with many aspects of my life as well. Without his help, encouragement and guidance, I could not have completed this paper.

My thanks also go to all the professors, teachers and schoolmates who have taught me and communicate with me during the past two years, who have helped me enrich and broaden my knowledge. Especially for Professor Uhyo and Professor Kishi, for their warm-heart encouragement and most valuable advice, and the most important aspect is their insightful comments and suggestions on the draft of this paper.

My thanks go to all the staff of the reference library of our school as well, who are always kind and patient in helping me to search for useful materials relevant to my study.

Last but not least, I would like to express my thanks to my family and my friends for their valuable encouragement and spiritual support during my study.

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Chapter 1
Introduction

Nowadays, the pace of life has been keeping speeding up with the time flies. When searching for how to reduce time wasters, you will find large amounts of sites tell you the effective ways to stop wasting time at work. On the contrary, our rest time is also limited and more precious to us. So some researchers and companies just try everything to decrease wasting of time. As a result, many kinds of vacancy monitor systems appeared, they are widely used in many fields, such as Border Force at airports, free space in offices [41], checkout counters in supermarkets, toilets [11], etc.. Such systems are built to help people from both supply and demand side to be more economical of time and energy.

As for restaurants, usually only fine dining ones are using such internet-based systems, costly both on labour and money. In such restaurants, normally there would be a pointed staff keep observing if there are customers about to entering the shop, some of them just use a list-book at the entrance for customers to write the member state and seats they required, and restaurant staff would need to check the vacancy situation in the restaurant by looking around the whole shop from time to time, and those staff need to compare the vacancy situation with the requirements written in the list-book to guide customers waiting for seats. Of course, some automatic and online systems have already been developed nowadays, but those systems also have lots of problems.

For example, the most common vacancy management system of restaurants in China, customers could input their requirements of seats to a number machine to get their waiting number and wait for calling. Some of such systems even use register system that would need customers to provide their phone number and names. So far, from all those introduction and observation on such systems, they only got automatic functions for the customer side, as for the restaurants side, or we say the supply side, such system still needs staff to count the vacancy situation and input the data into the system to complete the waiting and guiding function. On the other hands, for most of the other restaurants, which we call small restaurants commonly just use paper, pen and manpower to manage vacancy seats and customers. There are always a lot of delicious and popular small restaurants; sometimes we may walk up long steep stairs ended up with no vacant seats. As a result, a lightweight vacancy monitor system is necessary for small restaurants.

Current vacancy monitor systems of restaurants are mostly related to their booking system; it's usually used in the situation of no vacancy tables. In this case, usually customers need to go to the restaurant, get a number card or something like that to wait for seats. There are rarely related research about such system, and it's not suitable for most small restaurant, but we could use this as a reference.

There's a system that is very close to what would be discussed in this thesis, which called flavor-concentration system from Ichiran Ramen, a Japanese ramen food-service business specializing in tonkotsu ramen. This system is very popular in many customers mostly because people could eat ramen without having to worry about their surroundings. This system focuses on the environment excludes the cook, the other staff and other customers with fabric dividers installed between the customers' table and the kitchen, and partition boards that separate one's seat from the next. For they find that customers could enjoy the flavour of ramen more when they are in such environment. But my concentration of the system is its Vacancy Seat Guide board, which shows the vacancy situation in the restaurant and seemed like would change with the situation in real time.

Ichiran has already applied for a patent of its flavor-concentration system. According to the description and claims of its patent(JP4267981B2), field work in one of its shops and interviews with actual staff from Ichiran shops, some specific information are got about how the system works to display the real-time vacancy state of all seats. It turned out that entering/leaving detection sensors are set at the entrance/exit, seating /unseating detection sensor set under every single table, a contact switch for customer to send intention to the staff side and two buttons for staff to confirm the seat situation, and the guide board mentioned before would display the vacancy situation of each seat based on the input result from the contact switch and the seat information input switch. The interview of the staff revealed that the system is still based on man-power mostly, and the staff listed a series of typical situations, such as when the customer leaves the seat temporally for toilet or other intends, the sensor would detect and display the seat as vacant, then staff should judge the actual state and if its temporal vacant, the staff should push button that displays the seat as occupied. In a word, this is still a manual system, and the template of the shops should also be concerned, which its seats are all at a counter, and its seats are all settled and unmovable.

As a result, such low-cost, easy to set/installed online vacancy management system is not yet been developed or apparently is still rare in this field for small restaurants. Hence, the theme problem of this thesis is still deserved to be discussed. If this system is built and designed successfully at last and verified to be working well in small restaurants, it could be improved to develop more functions like the help the restaurants to calculate conversion rates, busy time and vacant time and many other data that could help the restaurants improve their service.

1.1 Research Question

The most important problem to build such system is how to define the vacancy state, which means we need to find out a way to sense and count customers enter and exit restaurants, or sense the vacancy seats in restaurants, and this way should lower the barriers of entry for both supply and demand side. To sense and count customers enter and exit restaurants, most such systems would use cameras set at the entrance, and infrared sensor, camera or human detection system would help count. To sense the vacancy seats in restaurants, pressure sensors or distance sensors are mostly used ones. Those tools and solutions would be introduced in detail in the next chapter.

Subsequent to this, there are also an amount of boundary conditions need to be defined. We need to confirm the definition of a small restaurant first, using the amount of available seats and tables, usable space and area or other definition; we need to configure different templates of chairs and tables in restaurants and confirm if there are movable chairs and tables, those would all affect the system construction; we also need to confirm the architectural construction of restaurants as this would affect if such system can be built naturally and easily. There are lots of other situations need to be considered, but the most important one is to control the cost to as low as possible so that restaurant side can bear, and it needs to fulfill its function at the same time.

1.2 Contribution

In this thesis, possible tools and devices that could be used to solve the core problem of the theme will be introduced and discussed, which are those that could sense and count customers enter and exit restaurants, or sense the vacancy seats in restaurants, and those which are usable but not suitable in some way. Those would be introduced in the second chapter which would talk about those related works. Then to find out at least one available way to implement core part of the system proposed, which would be introduced in the third chapter to discuss the most suitable tool, and also the core part for the SEATEC system.

Lastly, the contribution of the contents of this thesis is summarized as follows:

- Search for related works and analyze the constructions, goals, how they execute, budgets and every other details that should be concerned in those works.
- Introduce and discuss suitable tools and devices that could be used to sense and count customers enter and exit restaurants, or sense the vacancy seats in restaurants. Screen out those has disadvantages in power consumption, complexity to install, security level and of course the price.
- Experiments and researches on testing, verifying and checking the selected tools and devices' capability, and build up the whole system.
- Test the system built up to check if its capable for actual small restaurants and list up the weakness and problems to solve.
- Execute the conclusion and find out what should be done for future research and system building.

Chapter 2
Related Works

To clear the contributions of SEATEC system, those existing research, products and systems that are solving the same or similar problems to the research will be summarized and introduced in this chapter. As we all known, there are commonly two kinds of solution, one is to detect human or objects from pictures or videos through appearance and motion of them, such as the open-source library of programming functions mainly aimed at real-time computer vision called openCV [27], and the other one is to use sensors to detect human or object, or could even count the number of human such as infrared sensor, pressure sensor and so on.

How those researches that already exist relate to SEATEC system, the features, weakness and strong points and the characteristics that would be affected if used in the system proposed by this thesis will be introduced, and of course the reason of why those existed works are different from SEATEC system will be given at the end of each part.

2.1 Camera

The origin of human detection may come from pattern recognition. There are many types of research on the object, face [40], pedestrian and other kinds of detection [24,30]. Such detection always build a detector through a great amount of training examples using machine learning [42].

At the same time, there's another way to detect human, using the thermographic camera, also called infrared camera. It's used in a large range of fields, mostly used in medical and architectonic fields [7,15].

Those two ways are almost totally different from each other, but the only similarity is that they both need to use the camera to work.

2.1.1 Feature Detection and Description

The very first using of pattern recognition that has been put to practical use is face recognition. Also there are lots of different companies and products can fulfill this function, such as Google Vision API, Amazon Rekognition, Face++, OpenCV, etc... But most of them are provided to researchers or business, which means would cost a large amount of money. This is one of the problems need to concern.

It's well-known that human motion's pattern is readily distinguishable from other sorts of motion. Recently many researches have used motion to detect human. [17,25,26] Those approaches are very different from the face and pedestrian detection mentioned above. They literally track moving objects from amounts of frames and analyze the motion to find out the periodicity or other clues.

To detect human through video or picture, thousands of detection windows should be evaluated every second. The first step is to train a detector through every usable detection window in every frame of videos as illustrated in Figure 2.1. What people wear always affect their appearance, and focus on gradient-based features could solve this problem.

The learning algorithm chooses from a heterogeneous set of filters during every round of training [10], including the appearance filters, the motion direction filters, etc.. The significant aspect of the resulting classifier is that it mixes motion and appearance features. It balances intensity and motion information in order to maximize detection rates. As a single classifier for face detection needs too many features and would be too slow for the real-time experiment. Cascade architecture could possibly make the detector efficient. Here's an example pf Cascade architecture [42]: pass the first classifier with the conclusion of there are pedestrian or not(true or false). False would halt further computation and causes the detector to return false. True would pass the input along to the next classifier in the cascade. If all classifiers vote true, then the input is classified as a true.

There is still another problem for pedestrian detection, as introduced above, most techniques have been succeeded in distinguishing isolated people, but they often failed when it's crowded or when the situation is very complicated. Clearly, the problem is how to get accurate object detection, especially under crowded situations. For human detection in small restaurants, it would be even harder, as the appearances and motion of people in the room would be rather complicated and harder to be detected.

(Source: Detecting pedestrians using patterns of motion and appearance. [42])

Figure 2.1: A small sample of positive training examples. A pair of image patterns comprise a single example for training.

2.1.2 People Counting Camera

Today camera-based people counting tools are growing quickly, they offer retailers and other service industries a way to capture and analyze customer data from their locations. The reason they choose camera is that cameras are typically placed above the area where the demand side want to count the people that enter or in the place. Two kinds of them will be introduced in this subsection. 3D-ToF Camera and Network Camera System.

3D-ToF Camera

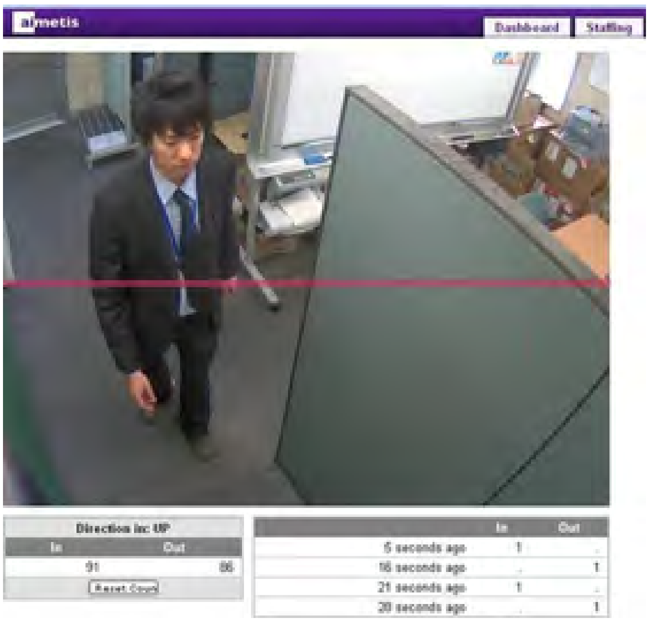
Three dimensional time-of-flight(3D-ToF) camera [14] is becoming a popular alternative to the stereo vision which generally uses two cameras separated by a distance, in a physical arrangement similar to the human eyes. The 3D-ToF camera is a range imaging camera system that capture distance based on the known speed of light, measuring the ToF of a light signal between the camera and the subject for each point of images. To make it simple, it works by illuminating the scene with a modulated light source, and observing the reflected light. It is a class of scannerless LIDAR, in which the entire scene is captured with each laser or light pulse, as opposed to point-by-point with a laser beam such as in scanning LIDAR systems. [13, 34]

(Source: Hitach website [1])

Figure 2.2: 3D LiDAR (TOF) Motion Sensor from HLS-LFOM Seriesof Hitach company.

Compared to 3D laser scanning methods for capturing 3D images, TOF cameras operate very quickly, providing up to 160 images per second. It consists of illumination unit, optics, image sensor, driver electronics and computation or interface. Its ranging technique does not make out range data without shadow effects that are incomplete, for the reason that illumination and observation directions can be col-linear. Compare to the other 3D imaging technologies, stereo vision and structured-light, the advantage of ToF is its low software complexity and medium material cost(although the cost of stereo vision is the lowest among them). On the other side, It's good for simplicity, efficient distance algorithm and speed, it operates very quickly, providing up to 160 images per second. In the meantime it's short at background light, interference and multiple reflections.

There are already amounts of products on the market that using 3D-ToF camera system, such as 3D LiDAR (Light Detection And Ranging) ToF Motion Sensor as illustrated in Figure 2.2 from HLS-LFOM Series of Hitachi company, but it is still very expensive so far, a single one would cost about ten thousands Japanese Yen.



(Source: SystemK website [5])

Figure 2.3: The people counter system from a Japanese company called SystemK Corporation.

Network Camera System

There are already lots of people counting camera systems [22] that based on network camera system which are provided as products, they are usually used for the purpose of security. I'll introduce a people counter system as illustrated in Figure 2.3 from a Japanese company called SystemK Corporation[1] as an example. This system could use some kinds of network camera that are promoted and software provided by this company, with such composition, the system could be able to count the amount of people from both directions in respect to the camera. There's no introduction to be particular about the software, as it's introduced as could detect and draw out the face data of several people at the same time, and could also detect age and gender of people we can assume that it uses face detection or object detection technology. As the specific design of the system has not been published, through its characteristic that could count people divided by entering and exiting the room, we can assume that it may set the count sensor whose array is parallel to the moving direction of people pass by. [12] This system costs at least seventy thousand Japanese Yen without cameras.

As introduced above, the two kinds of people counting camera, 3D-ToF camera and Network Camera System could count the amount of people in a limited space, which seem to be suitable for vacancy monitor in small restaurants, but as those cameras could only count the amount of people, but can't distinguish customers and staff, so it would be another problem to find out the number of vacancy seats according to the amount of people in restaurants, also the camera would not be able to sense the luggage of customers on the seats.

2.2 Sensor

Another way to detect human is using sensors. There are many kinds of them, for example, infrared sensor [43], laser sensor, Radar sensor [39], 3D scanner, ultrasonic sensor and so on. As infrared camera and distance sensor were used in part of the experiment, only pressure sensor will be introduced in this section.

1 SystemK Corporation (`https://systemk-camera.jp/`)

2.2.1 Pressure Sensor

A pressure sensor is a device for pressure measurement of gases, solid or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated regarding force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed, such a signal is electrical.

There's a research about seat-interface pressure [37], and the conclusion is that gender has no big affect, and the research also find out that there's no significant difference between body mass index (BMI), height, weight or maximum pressure. BMI is defined as the body mass divided by the square of the body height, and is universally expressed in units of kg/m2, resulting from a mass in kilograms and height in metres.

If we set a pressure sensor on a chair, when someone sits on or something is put on it, pressure would be converted into the voltage value by the sensor. It causes less noise and occlusion problems compared to other sensors such as infrared sensors and ultrasonic sensors [20]. Pressure sensor could detect the weight of human, but it could detect the weight of baggage or something else at the same time, it's hard to distinguish [33] them in such situation.

Of course, we're sure that we could use pressure sensor to detect if there's someone or something on the chair now, but if we use it to manage the vacancy situation in restaurants, that means each chair need a sensor and a transmitter receiver set, it may be dangerous and easy to be broken. Also there already exist such product, such as KeyValue Company produced a smart seat sheet which use pressure sensor and iBeacon to detect the vacancy situation of chair. iBeacon is based on Bluetooth low energy proximity sensing by transmitting a universally unique identifier[4] picked up by a compatible app or operating system.

2.2.2 Distance Sensor

Distance sensors are generally divided into two kinds, which are triangulation sensors for the close-up range and time-of-flight sensors for long distances, the second kind is which we have already introduced People Counting Camera. Distance sensor is a kind of fast and accurate measurement which could get precise position of objects and detect a wide range of materials. The advantage and disadvantage and other details of distance sensor would be introduced in the next chapter.

Chapter 3
SEATEC System

I propose a vacancy management system for a small restaurant in this thesis, and this system was named as SEATEC. Here the small restaurant points to restaurants that have a capacity of under twenty people. As the template of restaurants would need to be defined in some case, some typical example will be introduced in this chapter.

As the most important problem to solve is the way to sense and count customers enter and exit restaurants, or sense the vacancy seats in restaurants. some experiment will be showed and that would tell the suitable tool to solve the problem and explain why.

3.1 Approach

As introduced in the chapter Related Works, there are two kinds of solution, to use camera or sensor. The experiments were designed in both ways and there are the process and conclusion below.

3.1.1 Infrared Camera

The experiment using infrared camera take advantage of no need to consider the template or conditions of restaurants or chairs and tables in restaurants. In this experiment, Raspberry Pi 3 Model B, Raspberry Pi NoIR Camera Board and four Infrared cut-off filters were used to find out if those low-cost and easy-installed tools could detect human in restaurants.

- Raspberry Pi 3 Model B
- Raspberry Pi NoIR Camera Board
- Infrared cut-off filters (720, 760, 850, 950)

- Micro SD card with NOOBS
- Micro USB power supply (2.1 A)
- HDMI cable, monitor, keyboard

I'd like to introduce the tools be used first. The Raspberry Pi 3 Model B is a single-board computer with wireless LAN and Bluetooth connectivity. The infrared Camera Module v2 (Pi NoIR) [4] has a Sony IMX219 8-megapixel sensor (compared to the 5-megapixel OmniVision OV5647 sensor of the original camera). The Camera Module can be used to take high-definition video, as well as still photographs. It could be used for time-lapse, slow-motion, and other video cleverness. However, it does not employ an infrared filter. (NoIR = No Infrared.) This means that pictures took by daylight will look decidedly curious, but relatively it has the ability to see in the dark with infrared lighting. Its a leap forward in image quality, colour fidelity, and low-light performance. It supports 1080p30, 720p60 and VGA90 video modes, as well as still capture. It attaches via a 15cm ribbon cable to the CSI port on the Raspberry Pi. The camera works with all models of Raspberry Pi 1, 2, and 3. It can be accessed through the MMAL and V4L APIs, and there are numerous third-party libraries built for it, including the Picamera Python library. The camera module is very popular in home security applications, and in wildlife camera traps.

The camera is essentially identical to the normal camera but it has no infrared filter, meaning that it lets in infrared light. This camera, combined with an infrared light source, will give you night vision. As we all know, the wavelength of light that human can see by eyes is restricted to 400-700 nanometres. The infrared radiation generated by human is strongest at a wavelength of 9.4 micrometres, and human skin is in the wavelength range of 1000nm 14000nm [36]. As it was aiming to detect human by this camera, so infrared cut-off filters were needed mentioned above to cut off the wavelength beyond human body to get the data of human amount.

Firstly I'd like to introduce what an infrared cut-off filter is. It is sometimes called IR filter or heat-absorbing filter, it's designed to reflect or block mid-infrared wavelengths while passing visible light, often used in devices with bright incandescent light bulbs to prevent unwanted heating. There are also filters which are used in solid state (CCD or CMOS) video cameras to block IR due to the high sensitivity of many camera sensors to near-infrared light, which is similar to my

Figure 3.1: Photo took with IR950 filter.

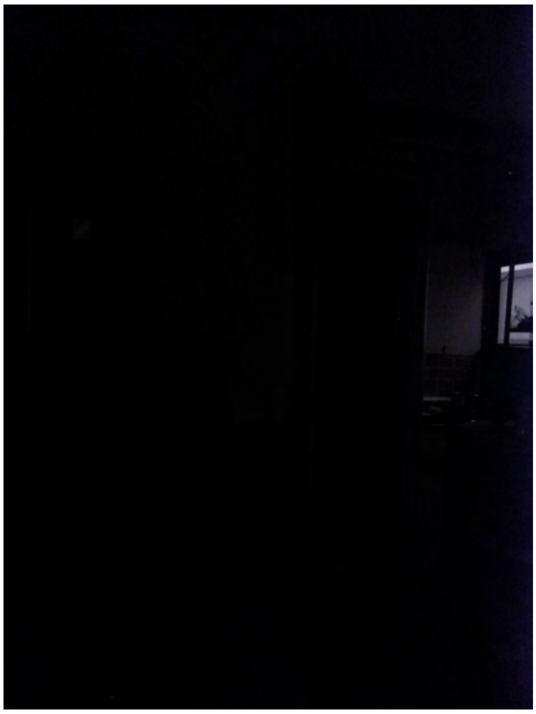


Figure 3.2: Photo took without IR filter covered.

Figure 3.3: Photos took by Raspberry Pi NoIR Camera covered with four kinds of IR filters.

goal. These filters typically have a blue hue to them as they also sometimes block some of the light from the longer red wavelengths.

Based on the wavelength of human skin, which is between 1000 nanometres to 14000 nanometres, used four kinds of IR filter were used to complete my experiment. They could separately cut off wavelength less than 720 nanometres, 760 nanometres, 850 nanometres and 950 nanometres. After set up all the hardware, the camera settings were configured to the longest shutter speed and the biggest Sensitivity ISO to make sure the camera could be in the best situation of taking photos. Then the first photo was took without IR filter at seven in the evening, standing in front of the camera, in a room with all lights off. From that photo as illustrated in Figure 3.2, we could only see a little bit of a small window as there was moonlight went through it. Then the IR filters were put to cover on the camera separately and took four photos under exactly same settings as above. Figure 3.3 is photos took with those IR filters.

Time 19:00 (dark)

Shutter Speed 5 second (longest)

Sensitivity ISO 800 (biggest)

I was standing right in front of the camera when taking those photos. But according to those photos above, we could see nothing but black. So the conclusion of this experiment is that inexpensive infrared-capable camera is unusable.

3.1.2 Distance Sensor

Since the way to use camera can't solve the problem need to be solved in this research, here is another experiment of another solution, the distance sensor.

The sensor used for the experiment is GP2Y0E03, a distance sensor made by Sharp Corporation. GP2Y0E03 [3] is a distance measuring sensor unit, it measures the distance from its lens to objects by detecting the light spot position of reflection on the detector. It could measure the distance with high accuracy by the adoption of CMOS image sensor. As it adopts the triangulation method, the distance detection is not easily influenced by the environment, such as the variety of objects' reflectivity, temperature and the operating duration. GP2Y0E03 could output both the voltage corresponding to the detected distance and digital(I^2C)

data, which means it could output in the form of I^2C or analog. As a result, it could also be used as a proximity sensor. Figure 3.4 is the schematic of the sensor.

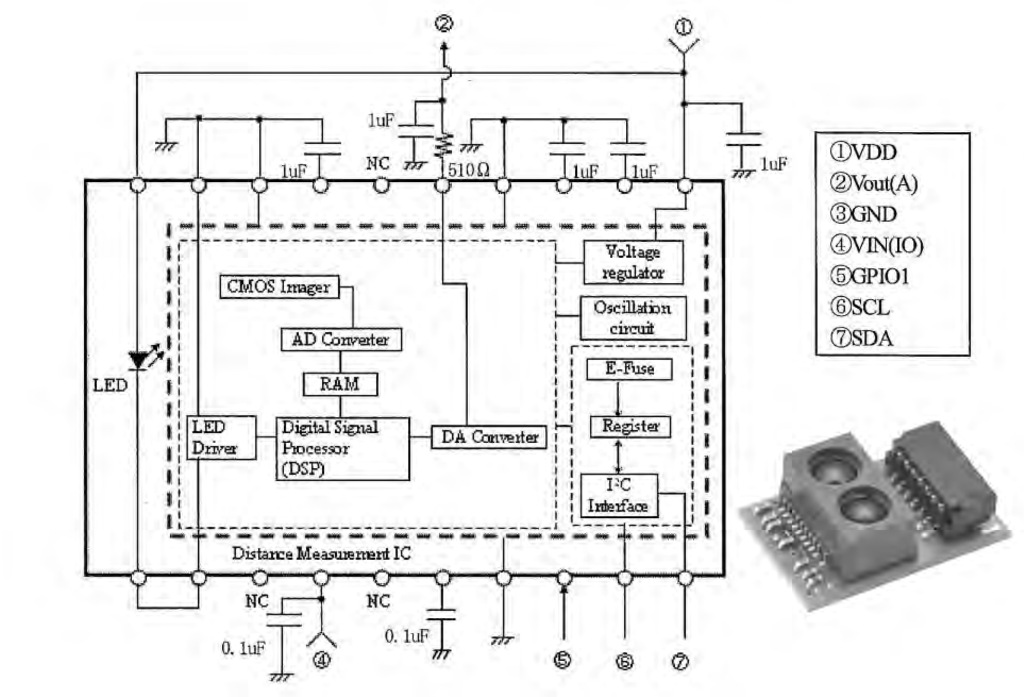
According to the data-sheet of GP2Y0E03, the sensor is able to detect the distance from 4 cm(2.2V) at minimum to 50 cm(0.5V) at maximum, and the reflectance of reflective objects from low to high. According to this, we could get the formula of the relation between voltage and detected distance, which is formula 5.2 [38] below. As the output time of the first distance value would be changed by the condition of reflective object, for the reason that when the auto-adjustment function is operating it will take time, on the contrary the sensor would output the measured distance value after its first measurement. So the response time to is defined by the maximum time of auto-adjustment operating. What was used in this experiment is its digital output, and digital output (I^2C bus) keeps maximum distance of output(64cm).

$$Distance(cm) = -270.6 \times Voltage(V) + 635.3 \quad (3.1)$$

Therefore an experiment was designed using Arduino and this sensor as listed below, to do a series of tests to find out if we could use distance sensor to define the vacancy situation of seats. In this experiment, the sensor was set under the table and forms a right angle with the table line right in front of the chair. In this experiment, the table is fixed at the same place, and the chair is movable. The data collected from the sensor with the series of movement of people pulling out the chair, sitting and leaving are observed, to see if the distance data is related to the movement. If it is, then this sensor could be used to check the vacancy situations of chairs.

- Arduino Uno
- Windows 7 PC
- Sharp Distance Sensor GP2Y0E03

Throughout the series of tests in this experiment, the distance that this sensor could detect is actually from 2 cm to 60 cm. When the object or human in front of the sensor is out of its detectable range, which means the object or human is too close or too far away from the sensor, or deviated from right in front of the sensor, the data it provides is 61 cm. To avoid the problem that object or human too close to the sensor, the most efficient solution is to just set the sensor 2 cm back to the front table line, and as the biggest detectable distance is 60 cm, far longer



(Source: GP2Y0E03 Datasheet [3])

Figure 3.4: Sharp Distance Sensor GP2Y0E03

that when there is an object or a human sit on the chair, the distance between them and the sensor would definitely be in the detectable range. For the problem that object or human deviated from right in front of the sensor, my solution is to set the sensor at the position that right in the middle of the table line.

Hence, the goal of this experiment is to find out if there's a rule that could define the vacancy situation of chairs, which means no matter the figure of human is fat or thin, the size of object(customers' luggage like backpacks or shopping bags) is big or small, when there is someone or something sit on the chair, the distance to the sensor would be in a general range. The concept of the experiment is as we can see from Figure 3.5, the distance sensor is set under the table at the right middle line and right in front of the chair.

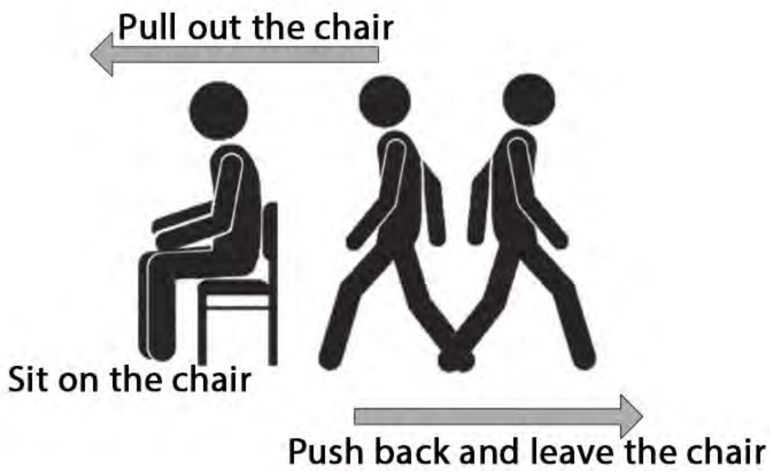


Figure 3.5: Concept of distance sensors' usage.

To find out the rule, dozens of research participants have helped with the series of tests in this experiment. After collecting the data of all participants and the movements of them to make comparisons with the data, those data are collected and modified into line charts. In Figure 3.8 are two illustrates from two typical research participants. The first illustrate up here is from a participant whose height is 175 cm, weight is 81 kg. The second one down here is from a participant whose height is 150 cm, weight is 42 kg.

As we could see from the illustrates, it's clearly that there's actually a rule among those data, which appears that discipline which could help us define if there is someone or something one the chair is actually existing. As the movements of

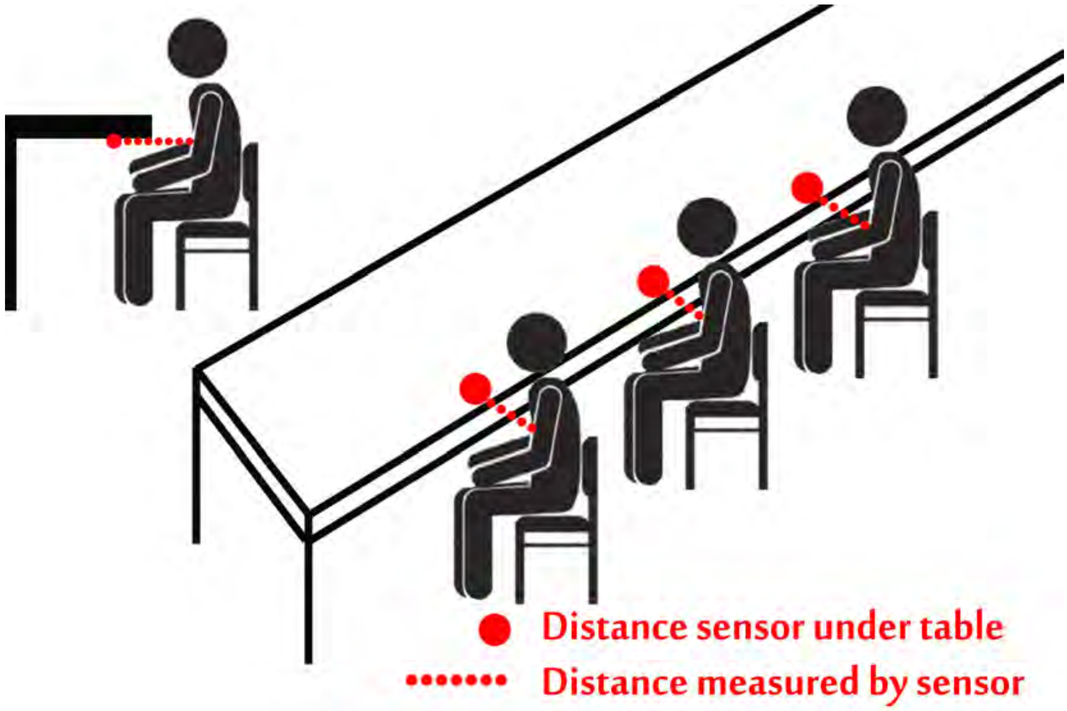


Figure 3.6: The distance that sensor measured.

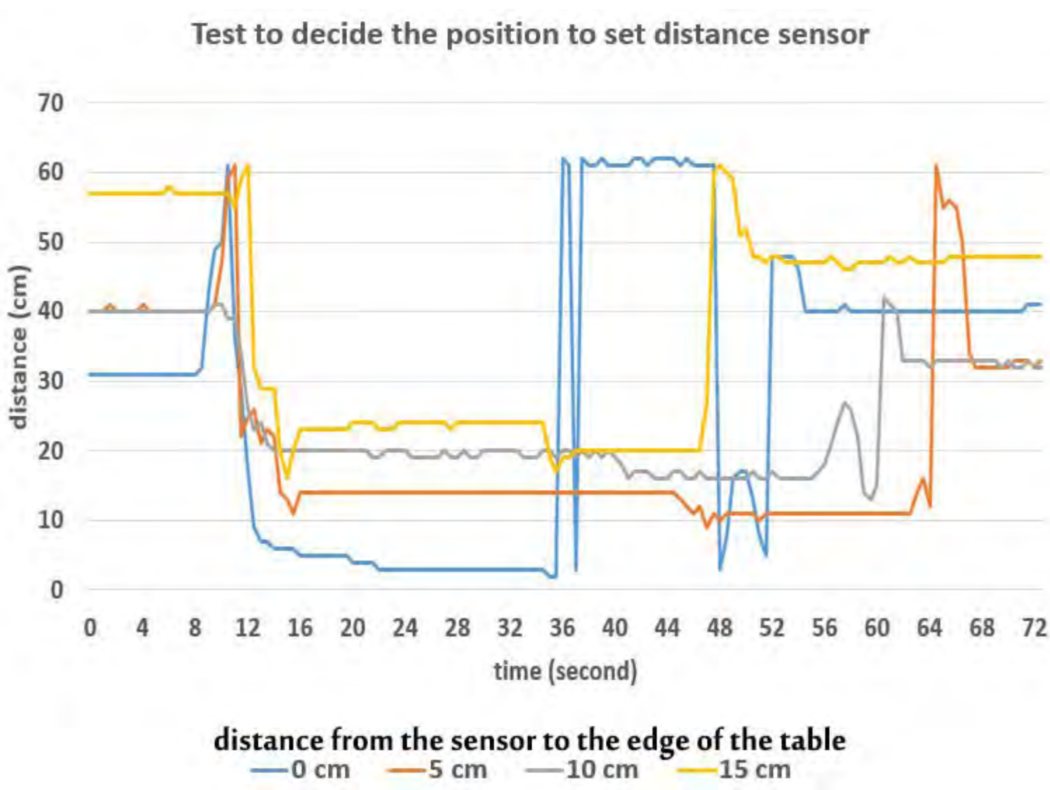


Figure 3.7: Test to decide the position to set distance sensor.

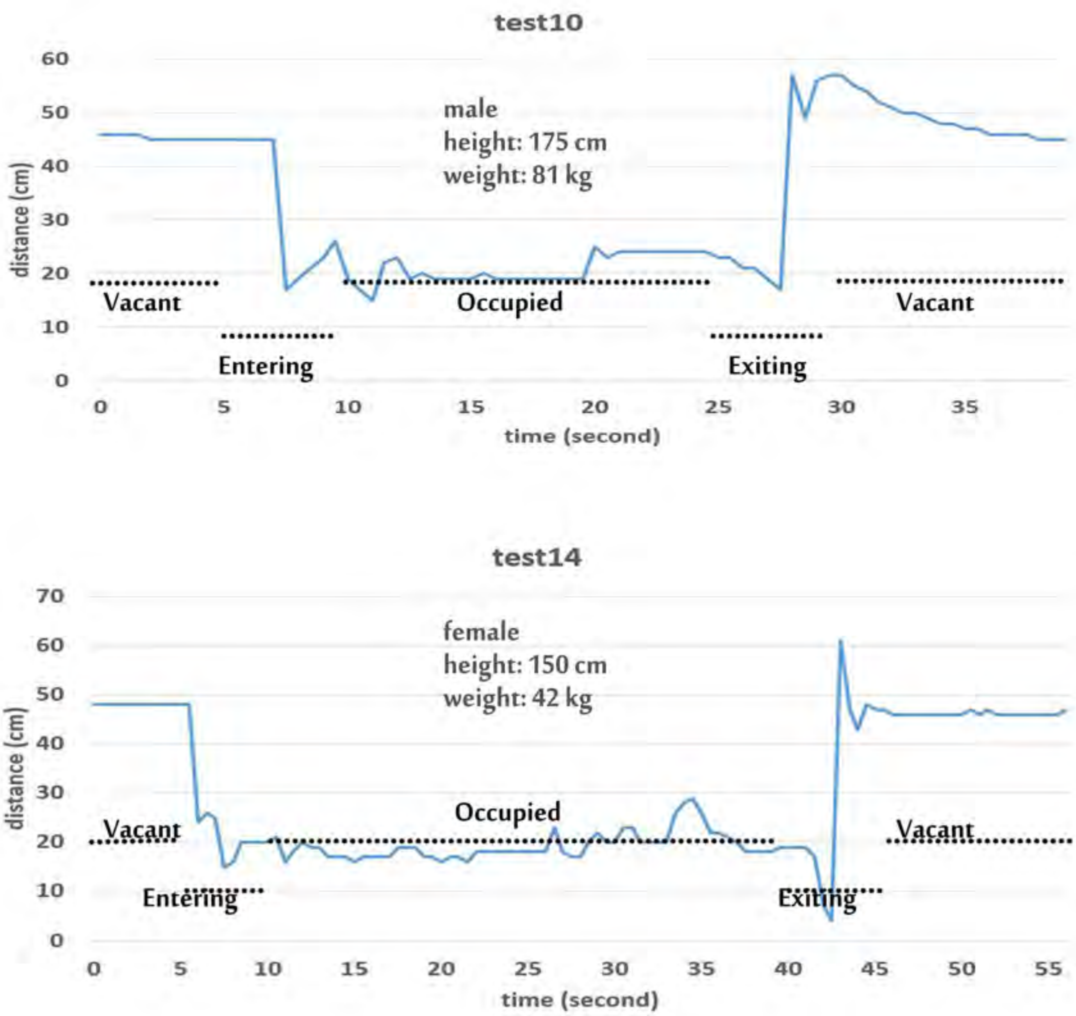


Figure 3.8: Two examples of research participants.

participants are analyzed by videos, their movement could be described according to their posture and other changes with the time goes in words.

In the chart of test 10, from the very first to the eight second, the straight line is when the chair stayed still, and the part of broken line is when the participant pulled out the chair. Then from the eighth second to the twenty-eighth second is when the participant stayed sitting on the chair, writing and chatting at the same time. The broken line after the twenty-eighth second is when the participant left the chair and after the chair returned to be vacant, the line returned to a stable straight line as well.

And in the chart of test 14, also from the very first to the eight second, the straight line is when the chair stayed still, and the part of broken line is when the participant pulled out the chair. Then from the eighth second to the forty-first second is when the participant stayed sitting on the chair, writing and chatting at the same time. The broken line after the forty-first second is when the participant left the chair and the broken line's changing range is bigger than the participant of test 10, because when this participant left the chair, this participant got close to the table(of course got close to the sensor at the same time) first and pulled out the chair to left in a big way. After the chair returned to be vacant, the line returned to a stable straight line as well.

From the two charts, the state of chair are generally the same before and after the participants sit on the chair, and from other charts of the other tests the same phenomena were found, even when there are different between the distance data of before and after, the biggest error is five cm, and among all the tests, ninety percent of this data is almost the same. Also after the participants are sitting and settled on the chair, the distance data would become stable as when the chair is vacant, and through the tests, the stable data is between ten to thirty cm, but among those tests, only one participant's data is under ten cm, but we could say that under the test situation, when the distance data is under thirty cm, the chair could be defined as occupied.

According to the charts and the movements changes at the same time, we could tell a few rules now. Firstly, when someone or something is sitting on the chair, the distance data is always shorter than which when the chair is vacant, of course the position of chair at first would also affect. Secondly, when the object or human has taken a seat and settled, the data would generally be stabled, which means the data would not easily be moved or disturbed. The stabled distance data is different for people with different figure characteristic.

It's also different when the human sit on the chair is talking to someone besides. But whatever the situation and the figure characteristic is, when the object or human is settled, and to be fair, most people rarely changed their position and posture when they settled down on the seat, which could also be observed from the tests before, so the distance data are generally stable.

3.2 System Scenario

As discussed in the first chapter, a lot of vacancy management systems have already existed, and most of them are based on manpower to record the vacancy situation in restaurants manually. The SEATEC system that this thesis proposes aims to be automatic, low cost and could be checked real-time online for both demand and supply side. The system also aims to build a database for the supply side, to help the restaurants to have the ability to get the data of busy time and spare time every day, and if possible, also help them analyze the data to help the supply side to arrange their supply, employee and other resources.

As the tests before proved that distance sensor could implement the function of defining the vacancy situation of chairs when the table is unmovable and the chair is movable. But as we all know, the template and seats constitute are always different in different restaurants. So that in which constitute this system could work and in other constitute how to configure this system to make it work or it just couldn't work, those situations should be defined.

Figure 3.9 and Figure 3.10 here are two typical constitute of small restaurants. If the system proposed by this thesis could work in those four situations will be analyzed, and the reason as well. Figure 3.9 are two pictures of restaurants with counter seats.

The picture left is a sushi counter from Yamazato Restaurant, where chairs are mostly fixed at the place that perpendicular to the counter table. The right one is a counter bar without single chairs. In the left picture is a sushi counter where chairs are mostly fixed at the same place as the tableware are settled before customers sit in. Using distance sensor to detect the vacancy situation of chairs would be very easy and simple in such restaurants, as usually customers would only sit right in front of those tableware in such restaurants and the narrow sitting space also could help confirm this fact, so we would only need to set sensors in parallel so that they would work in such space.

And in the right picture is a counter bar without single chairs, where customers would sit is hard to distinguish in such constitute, even though there are some broken lines that would help separate customers. In other words, as the chair is carbonated in one which is related to each other so that customers could move easily. This would only make the detection work more difficult.

Under such situation, the number of seats would be changeable and hard to count as the vacant space depended on or we should say could be affected by the figures of all the customers. Customers with very large organisms would soon occupy the whole seats, and if customers are all those with little organisms, the number of customers this restaurant could hold would even be twice more than the number when the customers are all with large organisms.

Figure 3.9: Pictures of two restaurants with counter seats.

Figure 3.10: Pictures of two restaurants with table seats.

The two pictures in Figure 3.10 are two restaurants where both have movable tables and chairs (one side of chairs in the right picture are unmovable though).

The picture left is a restaurant in Pacific Place, Admiralty, Hong Kong. The right one is a restaurant in Edinburgh. Most restaurants have such template of chairs and tables. As the shapes of tables in both restaurants are all square, if there are customers in a group or groups want to put tables along to sit together, and in this situation, the circumstances would have to be divided for the two restaurants.

For the left one, the tables could be united in several combinations even when they only put two tables together, of course if they put three or more tables together, it would be more complicated. Turn back to the situation of putting two tables together, it would be hard to judge what combinations of the tables and chairs would be, and the position of chairs would very probably to be not at right the middle of tables as well, which is the system required, and they could even be in front of the line between two tables, and the sensor would never detect the customer sitting on such seat. So in this situation, this system would not work appropriately in large part.

And as for the restaurant in the right picture, as long as one side of the chairs are stick to the wall and apparently unmovable, if there are a group or groups of customers that want to share tables together, they could only unite the tables in one way, which is to put the tables together in a parallel line, and mostly we could assume that the chairs would still be right in front of those single tables, and sensors set under the tables and right in the middle of the table line should still be able to detect the vacancy situation of chairs as same as they normally do.

Of course there are still a lot of restaurants that have totally different interior templates, such as round tables in Chinese restaurants may be the most difficult case for this system. Those special circumstances all need to be confirmed case by case. But as discussed in this section, the system proposed by this thesis could be used in many restaurants directly without modifying its design or hardware.

Chapter 4
Implementation

How SEATEC system would work to detect vacancy situation the circumstances that are suitable for this system will be described. The the specific configuration of this system both from hardware and software aspects will also be introduced in this chapter.

4.1 System Overview

First of all, the main part of this system is the distance sensor which is used to detect the vacancy situation, and is absolutely the core function of this system. The most important problem to be solved in such system is to find out a way to sense and count customers enter and exit restaurants, or sense the vacancy seats in restaurants, and this way should lower the barriers of entry for both supply and demand side. According to the experiment and tests introduced before, in this system the sensors will sense the vacancy seats in restaurants, distance sensors are set under tables right in front of every chairs, and detect the distance between human or object and sensors to tell the vacancy situations of chairs. As shown in Figure 3.5, we could find out the state of customers pulling out the chair, sitting on the chair and leaving the chair according to the distance data collected by those distance sensors.

The default circumstances that this system is suitable for so far would be departed into some specific kinds, for example, those restaurants with unmovable tables and chairs, unmovable tables with movable chair (such as introduced in chapter 3, see Figure 3.9) are suitable for certain, those with movable tables and unmovable chair (rarely existing), movable tables and partial movable chairs (also introduced in Figure 3.10) could be suitable in some cases. The circumstances are hard to be classified and the suitability between the system and interior template of restaurants should also be discussed case by case.

And to set the system securely and easily for restaurants, apparently it needs to use as few cables as possible, and to achieve this requirement, wireless technology would be the very appropriate solution. But as there are many kinds of wireless that could implement this requirement, Bluetooth module was chosen in this system, the comparison of Bluetooth and the other wireless technology would be introduced below. Also for security consideration, an individual power was also designed for the system, as the system don't consume much power, alkaline battery became my first choice.

All the hardware used in this system are under consideration about the cost, as it's actually the most important problem besides the core function of the system, its detection capability. The whole procedure of this system would be as follows: first the distance sensor senses the distance between its lens to the chair or human/object sitting or ready to sit/leave the chair in a fixed time interval; then the sensor sends the distance data to the controller which would be a personal computer, and the computer would collect the data to distinguish the situation of the chairs as vacant or occupied by analyzing the data in another fixed time interval.

4.2 Hardware

According to the conclusion of the experiment of distance sensor GP2Y0E03 in the section of Approach. So to complete the system, Arduino and this sensor will be used. As too many cables would easily cause security and broken problems, the fast-growing technology, wireless communication which could provide flexibility and mobility is a suitable tool. It could reduce the restriction of cables and has advantage in short-range wireless communications with low power consumption. So to wireless technology is needed here to implement the wireless communication between Arduinos and computer act as the main controller.

4.2.1 Wireless Technology

There are various kinds of wireless technologies that could help devices to communicate with each other or to the Internet without cable, which literally means that help them send and receive data wirelessly. There are large amount of choices to be used in hardware for the Internet of Things (IoT) and Machine to Machine communication.

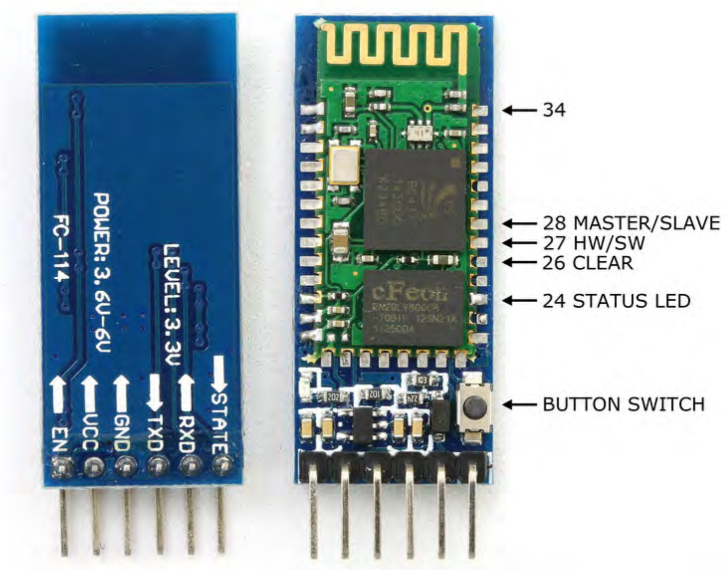
To implement wireless communications in short distances consuming low power, there are four protocol standards made by The Institute of Electrical and Electronics Engineers (IEEE, which defines the physical and MAC layers for wireless communication), which are Bluetooth (over IEEE 802.15.1), ultra-wideband (UWB, over IEEE 802.15.3), ZigBee (over IEEE 802.15.4), and WiFi (over IEEE 802.11). Table 4.1 is some comparison of those four standards.

Table 4.1: Comparison of wireless technology

	Bluetooth	UWB	Zigbee	WiFi
Standard	802.15.1	802.15.3a	802.15.4	802.11g
Usage	WPAN	WPAN	WPAN	WLAN
Nominal Range	10m	10m	10-100m	100m
Nominal TX power	0-10 dBm	-41.3 dBm/MHz	(-25)-0 dBm	15-20 dBm
Max Data Rate	0.72 Mbit/s	110 Mbit/s	0.25 Mbit/s	54 Mbit/s
Max Data Payload	339 bytes	2044 bytes	102 bytes	2312 bytes
Minimun Cost	3 dollar	20 dollar	30 dollar	7 dollar

Relatively speaking, WiFi and Bluetooth are two well-known tools among four protocol standards above. WiFi is known for being used to connect Internet routers to devices like computers, tablets and smartphones. However, it also has some weaknesses, like it could be identified by crypt analysts, any wired equivalent privacy (WEP) key can be cracked with readily available software in two minutes or less. Meanwhile, WiFi Protected Access (WPA) is a wireless security standard which increases the security of wireless networks over the previous standard, the Wired Equivalent Privacy (WEP) algorithm. During development IEEE wireless networking standard, WPA has been superseded by WPA2 [16]. As for the comparison of Bluetooth and Zigbee, Zigbee could manage to work with lower power consumption than Bluetooth, and Zigbee devices are usually 2.5-3 times more efficient than those working at Bluetooth. As for the affected range, Bluetooth based networks can exist up to 10 meters, while WiFi-based networks can spawn from 10-100 meters. Hence when considering which is suitable for small restaurants, those differences would not influence too much, and the definitive part is the price, Zigbee modules are too expensive to control the whole cost for this system. We can see the price of a single module for each standards in the Table 4.1, which is the lowest price from Amazon America as a reference here. [8, 9, 28, 35]

Hence, there is a kind of Bluetooth module called HC-05 which is relatively extremely cheap than most Zigbee modules. Bluetooth Module HC-05 is a Bluetooth Serial Port Protocol (SPP) module as illustrated in Figure 4.1, designed for transparent wireless serial connection setup, mostly used for converting serial port to Bluetooth. [23] Serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3M bps Modulation with complete 2.4GHz radio transceiver and base band. This one is based on the Cambridge Silicon Radio BC417 2.4GHz Bluetooth Radio Chip (a complex chip uses an external 8M bit flash memory) with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). Its footprint is as small as 12.7mm x 27mm, and its operation does not need drive. The main function of Bluetooth serial module is to replace the serial port line. It communicates by serial communication, which makes an easy way to interface with controllers or Personal Computers. HC-05 could provide switching mode between master and slave mode, which means it is able to be used in either receiving or sending data.



(Source: imamtechinovation [2])

Figure 4.1: Bluetooth Serial Port Protocol (SPP) module HC-05.

HC-05 would be interfaced with Arduino by connecting its TXD pin to Arduino's Rx and RXD pin to Tx respectively to form serial communication between the devices. [18] In a word, after connecting the cables to set the module on Arduino and with battery to provide power, computers and other devices could simply connect to the Arduino wirelessly. Here are the steps: find it in the Bluetooth device list, add it as a new device, the computer would install its drive automatically, then the service named Serial Port (SPP) 'Dev B' could be found in its properties. When two new ports appear at Ports (COM & LPT) in system device manager, finally we could upload sketches to Arduino to ask sensors to collect data wirelessly. The master and slave mode of HC-05 and other properties could also be modified by AT command while keeping its button switch being pushed.

4.2.2 Hardware

As mentioned in chapters and sections before, the distance sensor GP2Y0E03 to sense the vacancy situation of chairs and the Bluetooth SPP module HC-05 to get wireless communication between computers and sensors are suitable tools for the study, and would be the main hardware of the system. Therefore, here is the hardware list used for the system and the picture below as illustrated in Figure 4.2 it is the schematic without battery. The sixth (SCL) and seventh (SDA) pin of the distance sensor GP2Y0E03 is used for I^2C output, and if we use I^2C output, the slave address of distance sensor needs to be modified, or they could not be controlled separately. However, the slave address could only be modified once, once its address changed, it would be permanent change, also even we got all the distance sensors modified to independent slave address, only sixteen sensors could be controlled with the same device at the same time. So we use analogue output here, which means those pins would not be used. To simplified the schematic, the battery setting is not included here.

- Arduino Uno
- Windows 7 PC
- Sharp Distance Sensor GP2Y0E03
- Bluetooth SPP module HC-05
- 006 (9V) Battery

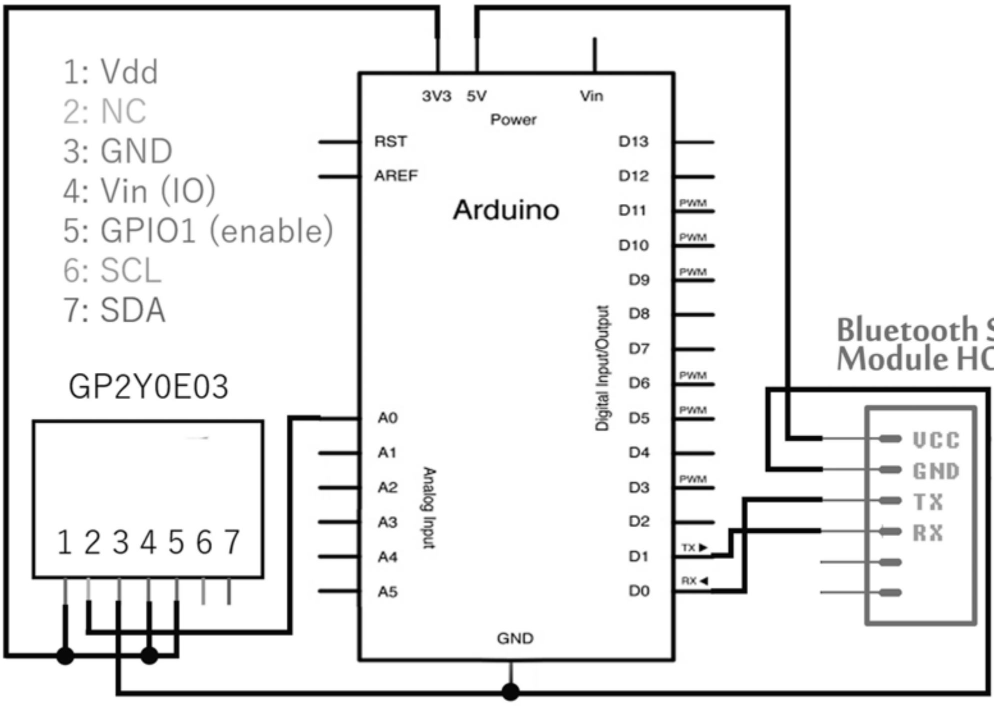


Figure 4.2: System schematic without battery setting.

4.3 Software

To confirm that distance sensors could detect the vacancy situations of chairs, its capability has already been demonstrated in chapter three with a series of tests in the experiment. The wireless communication between sensor and personal computer is also a main part of this system.

4.3.1 Distance Analysis

This is the main function that this system should implement, as we use distance sensors to check the vacancy situations of seats, which means the distance between the sensor and the object or human reflected could be defined as vacant or occupied. The definition data would be different which depends on the set position of sensors.

In the situation of experiment in chapter three, the data to define the chair as occupied should be generally stable distance data under thirty cm, and when the data is generally stable at its original distance or over forty cm, it should be defined as vacant. The procedure is to compile sketch through Bluetooth module to push sensors to measure distances, and collect data with a simple serial terminal application called CoolTerm [19]. The program to analyze those collected data is not yet finished so far.

4.3.2 Wireless Communication

Bluetooth is a method for data communication without cables between computers and the devices or units they tend to connect [32]. As already introduced in the section of hardware, in this system, the Bluetooth method used for wireless communication between personal computers and Arduinos is an easy to connect serial port Bluetooth module called HC-05.

The slave address, slave/master mode and all the other details of HC-05 could be modified under AT mode, and could autoconnect to the last device on power as default. There are many existed programs which could help connect smart phones [6,31] or other devices with single-board micro-controllers such as Arduino used in this system. As this module could simply create two ports called standard serial over Bluetooth link (one of them is sending port and the other would be receiving port) when it's related to Arduino while it's added as a new Bluetooth device on personal computers. After this procedure, the wireless communication would simply just send data from the computer to the single-board micro-controllers through the port it creates. As when Arduino is related to computers by USB cable, the computer could compile sketch through the port directly, and in the case of this Bluetooth module HC-05, the procedure would be the same other than it's wireless.

Chapter 5
Evaluation

This chapter evaluates the implementation in this thesis collated with the research questions listed up in Chapter 1. The content is focused on the practicalness of the data measured from experiment.

To find out the capability and precision of this system, such as human detectability, the accuracy of the detection, the maximum detect interval, the battery consumption and of course the expense, a series of tests were performed.

5.1 Prototype Implementation

Figure 5.1 is the prototype of the SEATEC system proposed in this thesis. The hardware from left to right are 006(9V) battery, Arduino Uno, Bluetooth SPP module HC-05 and the distance sensor GP2Y0E03.

The system is designed to be set under tables right in front of chairs, and the position should be at the right middle of table line to align an Arduino Uno used in this system, has 6 channel (8 channels on the Mini and Nano, 16 on the Mega), 10-bit analog to digital converter. Therefore an Arduino Uno may able to support a table with up to 6 chairs. The prototype shown in Figure 5.1 is a diagrammatic sketch with distance sensors.

Each system needs one Bluetooth SPP module to provide communication with a PC to analyze the data sent from each chair and fixed counter tables.

5.2 System Capacity

The experiment in Chapter 3 suggested possibility of distance sensor in vacancy detection. Dozens of research participants have helped with the series of tests in this experiment to find out algorithms for vacancy detection.

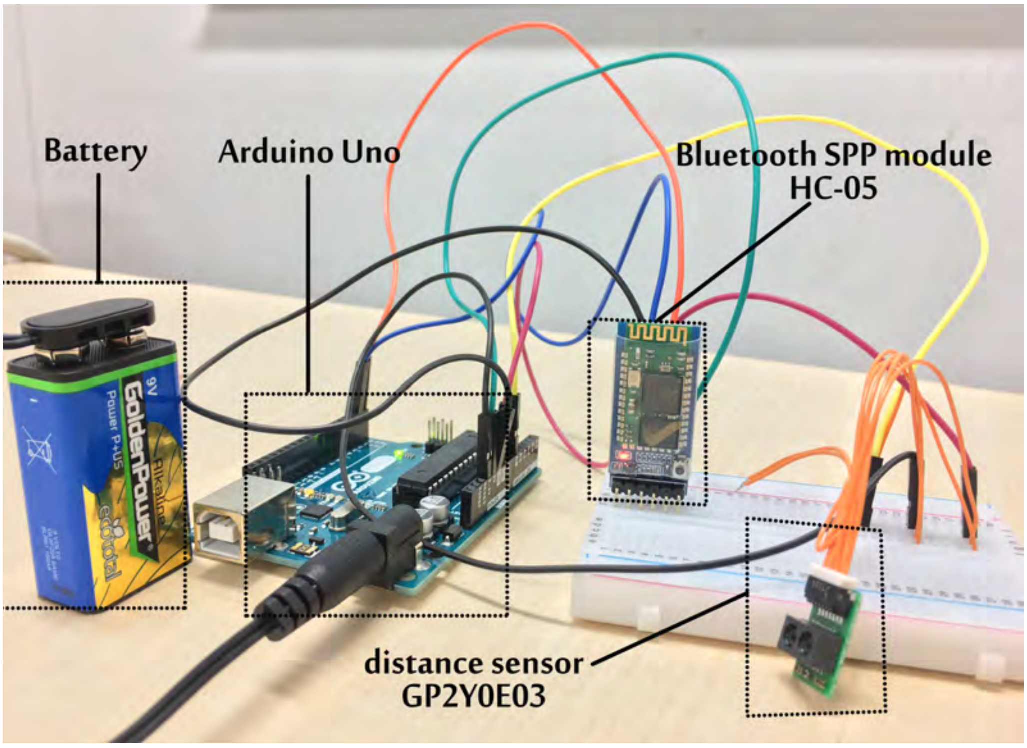


Figure 5.1: Implementation prototype of SEATEC system.

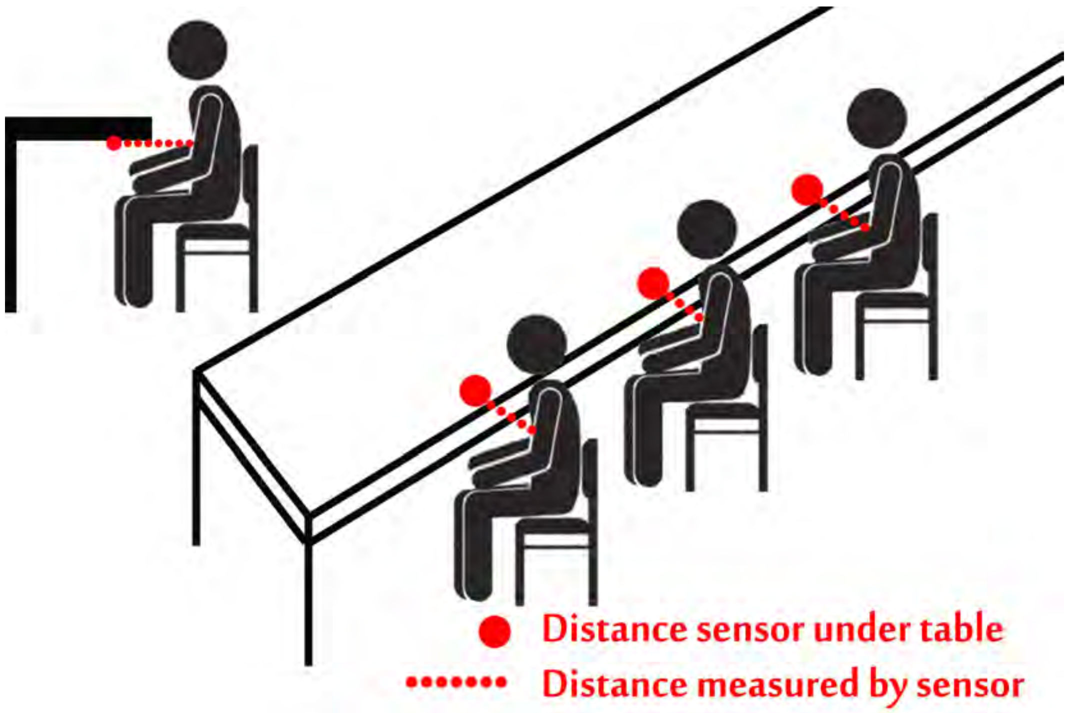


Figure 5.2: Distance sensors installed under a table.

5.2.1 Human Detectability

This part is to figure out the capability and limitation of the system. How the system confirm the vacancy situation and can this system distinguish the difference between a human and non-living things such as a chair, a back of a chair, and luggage put on a chair.

In the experiment, the distance data between the sensor and the participants were collected as showed in Figure 5.2. Note that the sensor is installed below the table to align the center of the chair, and the distance to the edge of the table is 5cm. After collecting the data of every movement of participants compared with the data. Figure 3.8 includes two graphs for two typical participants. It is clearly that the data measured can identify two cases: a human sit in the chair and vacant situation.

From the two graphs, the state of chair are generally stable at the same distance range before and after the participants sit on the chair, Other graphs show the same trend while the distance measured is different each other. About 90% of the measured values stay the same within 5cm range. When a person doesnt sit on the chair, the measured distance varies between 10cm upto 60cm. Note that the sensor returns back about 60cm when nothing is detected. Notable fact is the value is quite stable (within a few cm range) over time when nobody sits on the chair.

According to the graphs we can tell a few rulesas below:

- When a non-living thing is detected, the measured value is quite stable over time, and the range is less than a few cm
- When a human takes the seat, the measured values are changing over time for more than 10cm over time

In detail, firstly, when human beings are sitting on the chair, the error range of the distance data is always around 10cm, in the meantime, the error range for non-living thins like chair and bags is under 1cm. But the difference between chair and luggage of customers is a little bit difficult, which could be solved by confirm the first and regular positions of chairs. Secondly, when the object or human has taken a seat and settled, the data would be generally stable, which means the data would not easily be moved or disturbed. The stable distance data is different for people with different physical characteristics. It's also different when the human sit on the chair is talking to someone beside. But whatever the situation and the

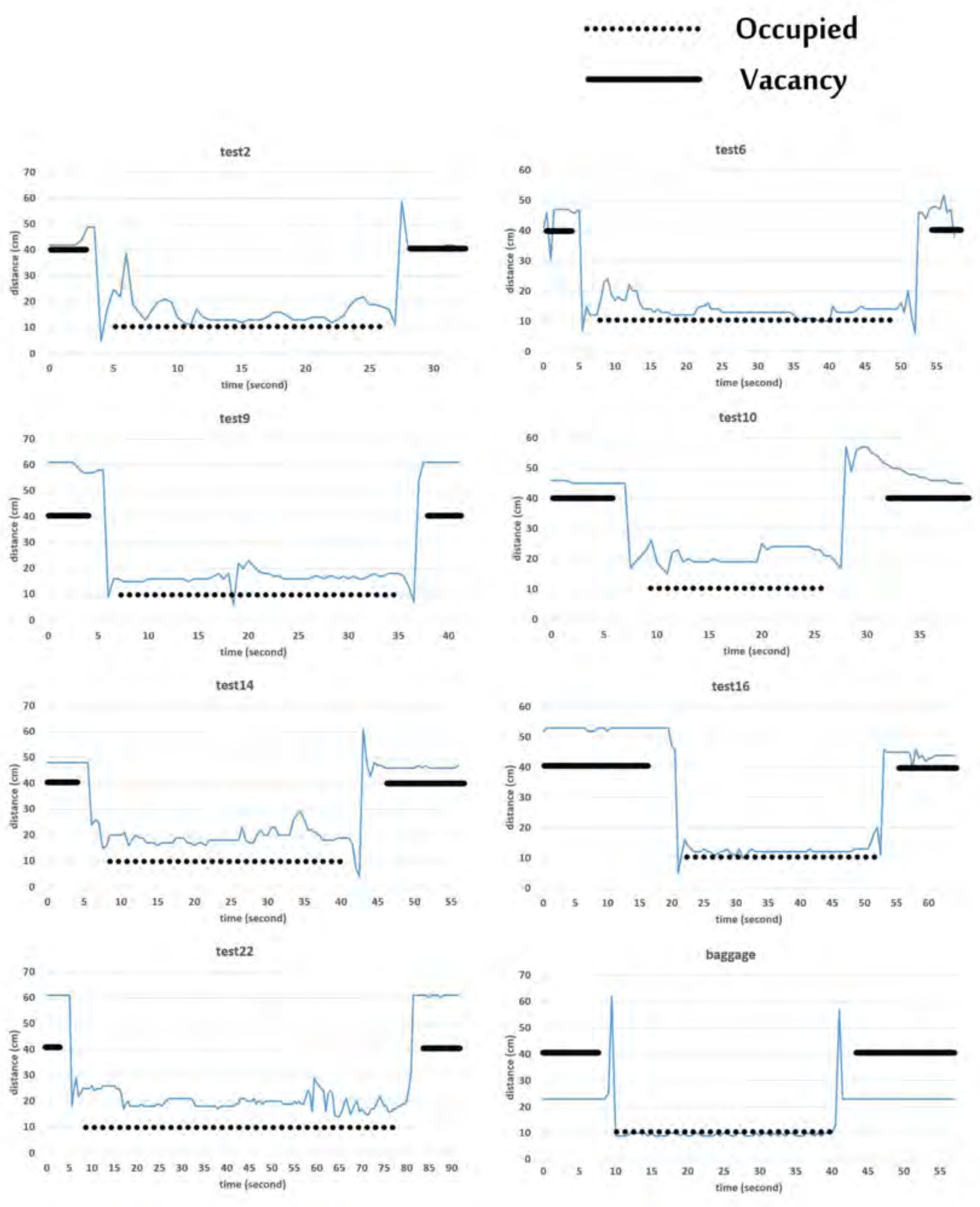


Figure 5.3: Several examples of research participants.

physical characteristic is, when the object or human is settled, and to be fair, most people rarely changed their position and posture when they settled down on the seat, which could also be observed from the tests before, so the distance data are generally stable. Here are also several examples of other participants in Figure 5.3 that could verify the rule.

5.2.2 Detection Accuracy

This part is to figure out the maximum distance customers can make both horizontal and vertical direction to table that this system can detect. The experiment was divided into two parts.

The last subsection has proved that this system could detect seat vacancy situation and could distinguish human being and non-living things. Now we need to verify the accuracy of this system. Would it has affect on the data while customers moving left or right, what is the maximum distance from the sensor to customers for the system to detect. To find out this, two sets of experiment are implemented, one is to ask test participants to move left/right, the other is to change the distance between the sensor to participants, to figure out the maximum detectable distance.

Figure 5.4 is the data of one of the participants when moving left. The width of waist of this participant is about 30cm, and the participant was wearing a casual coat when doing this test, which would have influence in the data so listed it up here first. The graph above is a time-distance graph, almost the same as the graph left below. Here the data when the chair is pushed fully under table were inserted, it's stable at 10 centimeter and didn't change all the time. So this situation could be distinguished when some human being is sitting on chair. Back to the main problem, from the graph above and left below in Figure 5.4, when the moving distance is over 20cm, which are 20 and 25 in the graph, the distance from sensor to tester are all 61cm, which is beyond the sensor's detectable range. So the sensor couldn't sense the participant after the moving distance is over 20cm. To increase the accuracy, another set of tests were implemented to change the distance between 15 to 20cm, 1cm apart. Then we got a more accurate data that when this participant move more than 19cm, it would be out of detectable range. So when designing for specific small restaurants, this should be considered on system settings and indoor template of chairs case by case.

While introducing the sensor used in this system, the distance that this sensor could actually detected has already been mentioned, which is between 4 to 61cm.

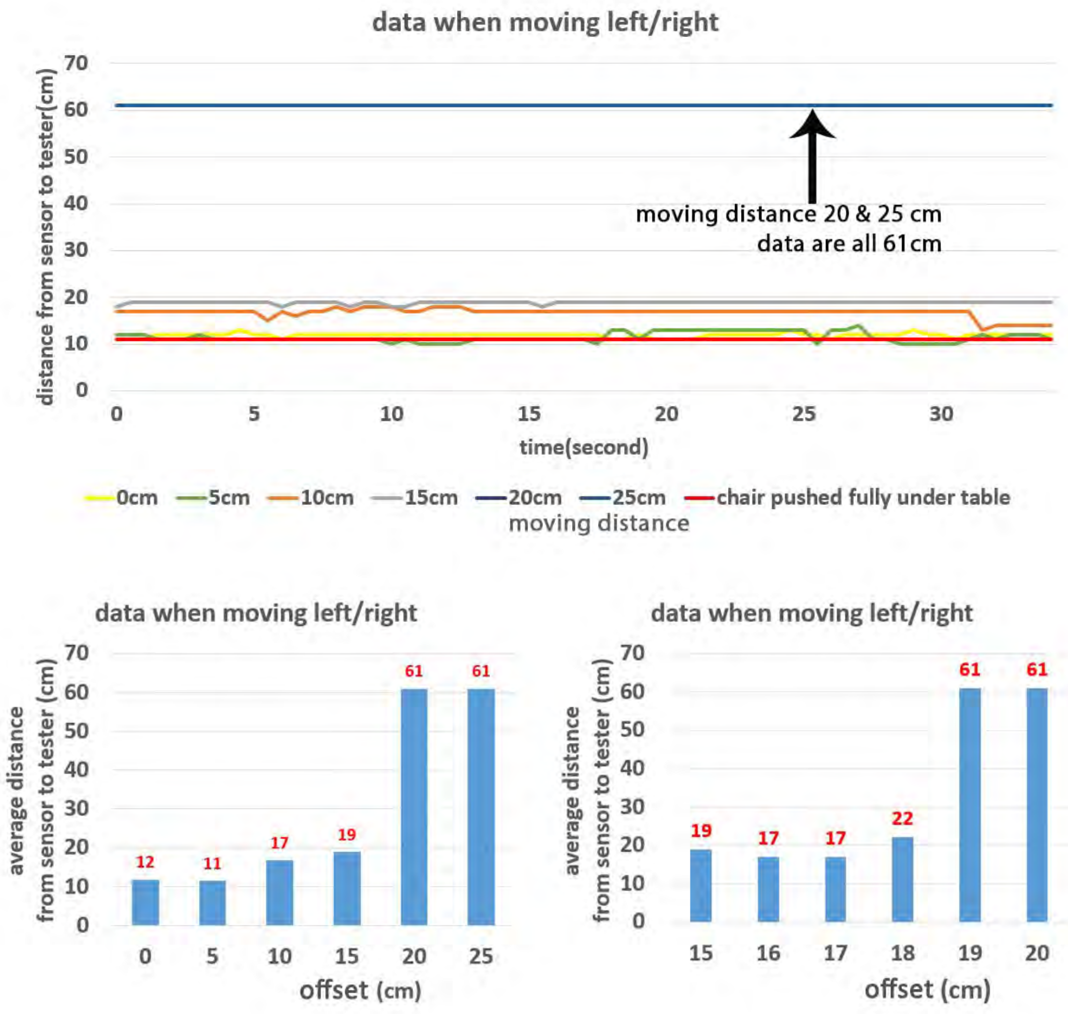


Figure 5.4: Data when test participants move left or right.

So the detectable range of this sensor should also be defined. As when customers are sitting on chairs in restaurants, there are many postures, and in this experiment, the tests were divided into two situations. One is when the testers only stay sitting on chair, the other one is when the testers are eating. The tests are ask the testers to stay at a pointed distance to the table, and to figure out the maximum detectable distance by changing this distance. Hereby, as very few people would stay sill when sitting on a chair in a restaurant, the data were only stable at the pointed distance at the very first.

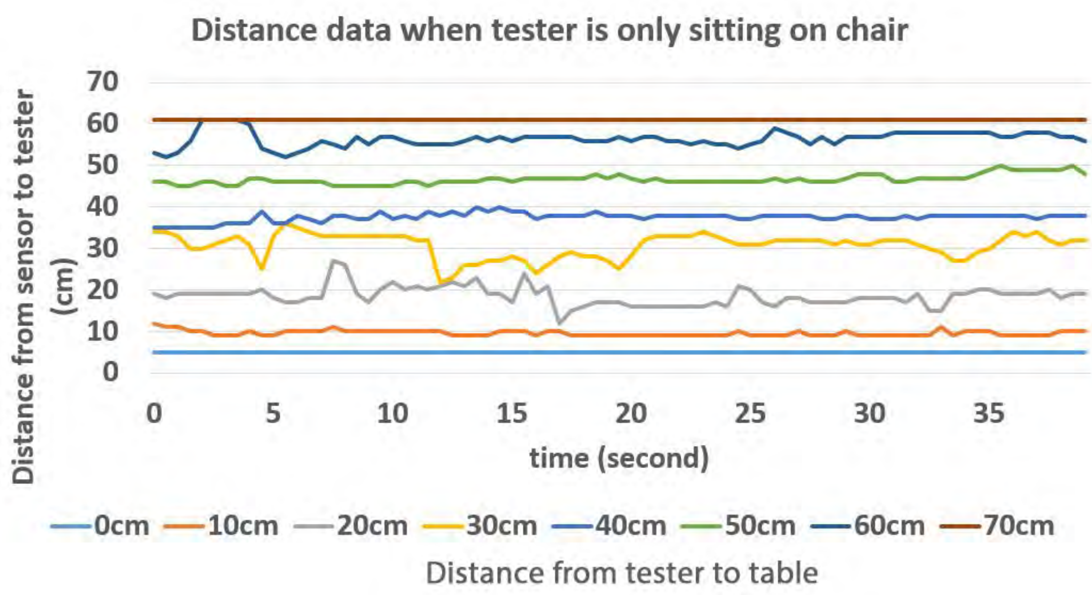
Figure 5.5 is the data of tests of one participant to find out the maximum detectable distance. The graph above is when the participant is only sitting on the chair, and the one below is while eating. According to the graph above, when the participant is 60cm away from the table, the sensor could just barely detect that there is a person on the chair, and when the distance increased to 70cm, the data is out of range. According to the graph below, as the participant need to eat food on table, which means need to get close to the table to reach the food, so the sensor could detect the vacancy situation very clearly, but actually when the distance between the participant and the table is up to 60cm, the participant could just barely reach the table and can't eat with such posture. So the maximum distance customers keep from the table should also be considered in specific restaurants' system design.

According to the tests above, the movable distance in the detectable range can be roughly defined. In horizontal direction, the maximum movable distance is longer than half of customers' waist width, which is not a fixed number but could be set referring to the average and minimum waist width. In vertical direction, the maximum distance is 60cm, and as at the distance of 60cm, customer would not be able to eat, so the vertical direction distance would not have influence on the detection while eating, but when customer is just sitting on the chair talking or else, the distance could be longer under 70cm, due to the template of chairs and tables in specific restaurants.

5.2.3 Interval of Detection

To reduce the electricity consumption, the interval of detection should be set as the maximum time in the detectable range.

The tests above are all at the setting of a interval of 0.5 second, which is relatively accurate, but would consume a large amount of electric. So the detect interval should also be defined to decrease electric consumption. To find out



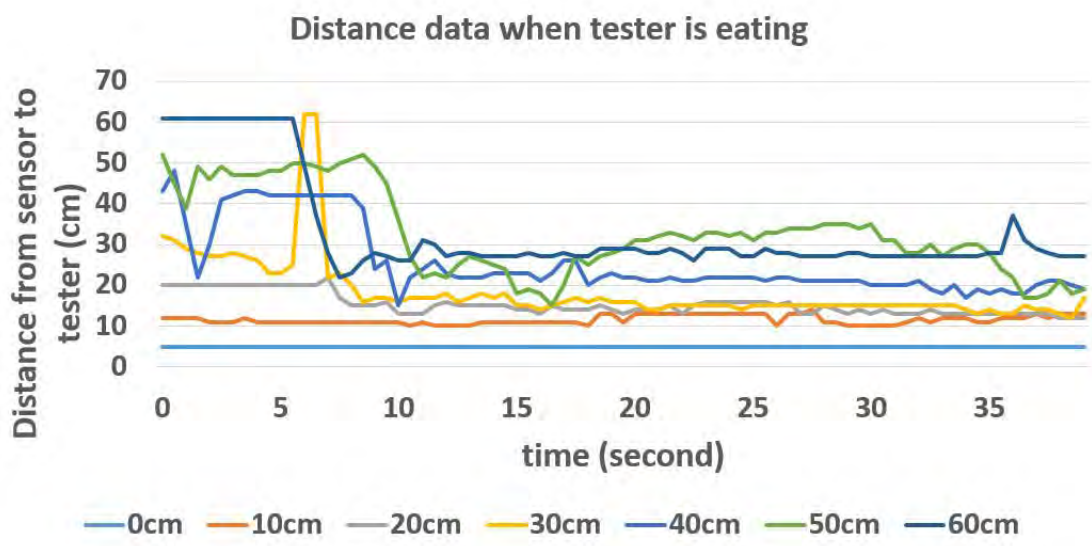


Figure 5.5: Tests to find out the maximum detectable distance.

the possible interval, Figure 5.6 is the data during the whole dinner time of a participant, and the four graphs are using four different intervals. The participant is sitting on the chair from 1 to 37 minutes, and according to the graphs, the fist three graphs could clearly defined the occupied and vacant situation.

Considering the worst situation of a customer stay no breathing and stable, the test of Figure 5.7 was implemented, according to the graph, the participant, who has big vital capacity kept stable for as long as could bear. According to the graph, the participant persisted for 34.5 seconds. On average, human could hold breath for about 30 seconds.

To conclude, according to the data above, set the detect interval between 30 to 90 seconds would definitely sense vacancy situation. The duration between 90 and 120 seconds and the maximum time would need more tests.

5.2.4 Electricity Consumption

Electricity consumption is also a big expense in this system. To reduce the consumption, how to provide electric and how much electric would be used in different situation need to be figured out.

To calculate the operational time of battery in the system, the current consumption of each device needs to be listed up first. There are three devices would consume current in this system, Arduino, the Bluetooth SPP module and the distance sensor. According to the product manual. The current Arduino itself requires is 25mA. The biggest current consumption of the Bluetooth SPP module HC-05 is divided by three situations, when it's matching to devices, the current is between 30 to 40mA, after it gets matched with the device and is not communicating with the device, the current would be between 2 to 8mA, and when it keeps communicating with the device, which would be its normal state, the current would be stable at 8mA. The average current consumption of the distance sensor GP2Y0E03 is 30mA at maximum.

Now assume there's a restaurant with four movable tables and each table could sit four people. In this situation, non-detachable power supply shouldn't be used, only batteries are available. When a 006P 9V battery is in use,, the electric capacity is generally 300mAh, so for the system with one sensor, the operational time of one battery keep working would be 300mAh$\div(25mA+8mA+30mA\times4) \approx 2hours$.

If rechargeable battery is used in this system, such as Eneloop developed by Sanyo, which is a kind of 1.2V low self-discharge nickelmetal hydride rechargeable

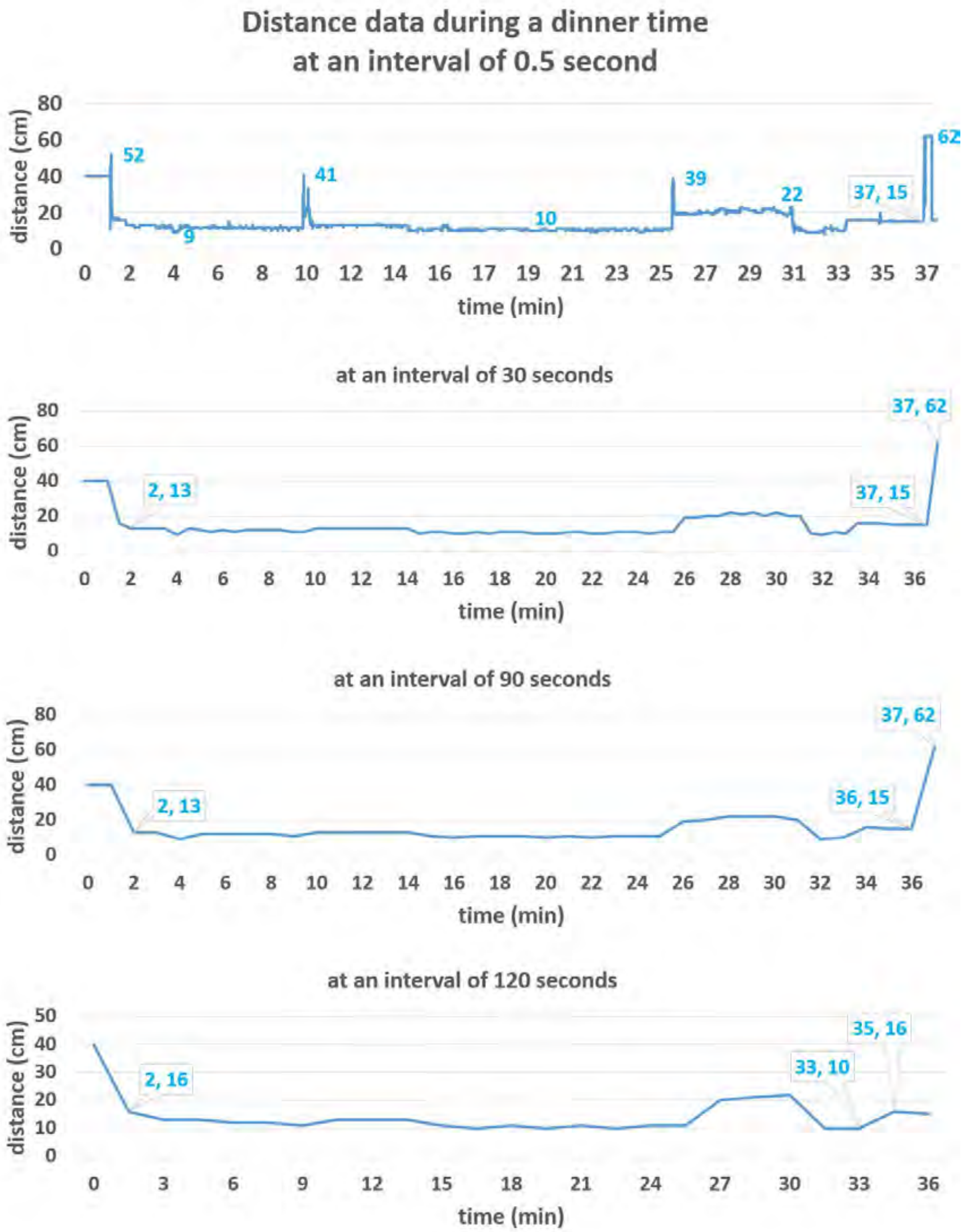


Figure 5.6: Distance data during a dinner time at different intervals.

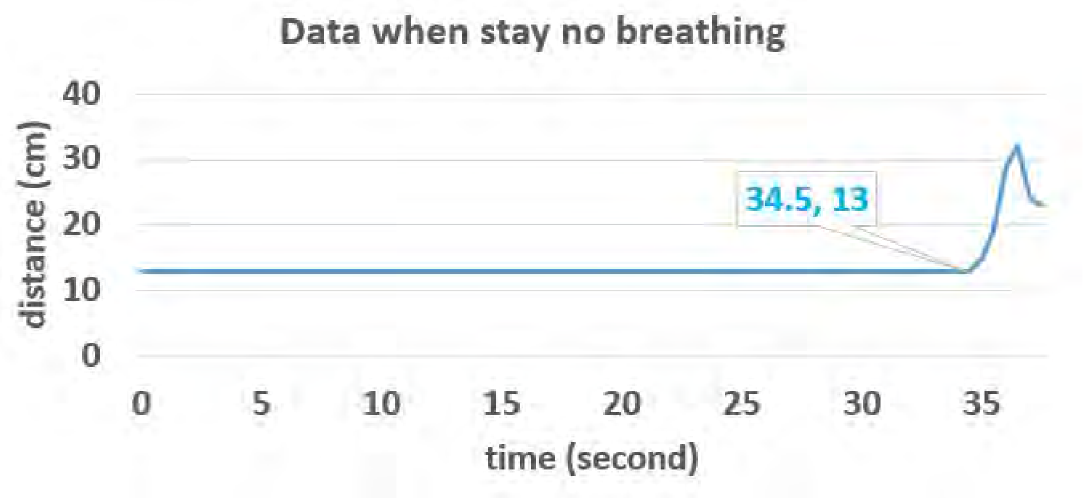


Figure 5.7: Data when the test participant stay no breathing as longer as could.

battery, whose electric capacity is 1900mAh. If Eneloop is used, the operational time while one battery keep working would be about 12 hours. Then assume this restaurant opens for five days in a week and 12 hours per day. To conclude, this battery could keep work for 1 day. So it need to be recharged every day.

Of course the interval for sensors to work could be longer than what was set in the experiments forward, which is as short as 0.5 second. So when this system is actually set in a small restaurant, the working interval of sensors and the most proper electric provider will be considered in the future.

5.2.5 Expense

How to reduce the expense of this seat monitor system is one main research question mentioned at the very first. Of course the opinion of the supply side which is the restaurant that will be willing to use this system is important. In this part the rough expense of this system will be figured out as a reference. The expense are listed up as below.

Initial Expense

- Arduino (one for each table)
- Communication tool HC-05 (one for each table)

- Distance sensor GP2Y0E03 (one for each chair)
- Cables laying, circuit protection and other cost

Long-term Expense

- Running and maintenance cost
- Electric expense
- Internet network and related devices

As different restaurants would have different amount of budgets. The cost of one Arduino is between 2000 to 4000 JPY, one distance sensor cost about seven hundred JPY, one Bluetooth module cost about 300 JPY, and the eneloop battery cost about 1000 JPY, and one eneloop battery can recharge for about 2100 times, and need to be recharged once per day, so one battery can keep for 2100 days, but need to prepare more for backup. Electric expense is different due to different electric companies. One Arduino can connect to at most eight sensors, which means could detect the vacancy situation of eight chairs at the same time. To send vacancy data to both the supply and demand side, Internet environment, data receiver and manager are also needed.

Assume there's a restaurant with four movable tables, each table could sit four people, opens for five days in a week and 8 hours per day, and the restaurant already has Internet environment and computer that can play as data receiver and manager. The initial expense including the circuits, cables and circuit protection tools are about 30,000 JPY. While the batteries need to be recharged every day, and the electric expenses for battery recharging and computer consumption are hard to be calculated right now, but such cost is not significant.

As every individual tables would need a whole system, the expense of which would be more expensive the more individual tables there are. Internet network and electric expense are not considered in this thesis. Those problem need to be figured out in the future.

5.3 Evaluation

As introduced in the first chapter, there are two main research questions in this research. The first one is how to define the vacancy state in restaurants with low cost, which means we need to find out a way to sense and count customers enter and exit restaurants, or sense the vacancy seats in restaurants. For this question, after a discussion about the comparison between the two ways listed up here, the way of sensing the vacancy seats in restaurants is selected for cost and installation consideration. To sense the vacancy seats in restaurants, the final choice was distance sensor. Through a series of experiment of verifying the capability of distance sensor, it could define the vacancy situation of chairs in some cases(which is defined by the interior template of restaurant and the movability of chairs and tables in restaurant) in a crude simple way, and the second research question is also included in this discussion. Besides, cases that the system could or couldn't work was also enumerated. The circumstances that the system could work is very limited by now. Further research and effort need to be devoted to solve the problems left.

And after the fair and theoretical discussion which gave a good overview for the research question of how to detect the vacancy situation in restaurants, whether those data from the experiment fit for this discussion was also verified that it needed to be discussed case by case. In the case that the system could work, the experiment data show that distance sensors could define the state of chairs as occupied or vacant by the range of distance between object or human sitting on the chair and the lens of sensor, also there are some exceptions during the series of test in the experiment, which appeared that the system has an error rate of about five percent, which would rarely affect the final result, and could be considered as under the error-tolerant rate.

Finally, the discussion about the solution to the two main research questions is clearly argued but still didn't get a perfect conclusion, which would need further research, but we could still get a conclusion and partial answer to the research questions based on the discussion and experiment.

There is another research question came up during the discussion, which is how to make the sensors and personal computers communicate wirelessly. As the system is assumed to be set and installed in small restaurants, the more cables it uses, the more dangerous and perishable the system would be. So to solve this problem, wireless communication came into discussion. After a systematic comparison among four major standards, which are Bluetooth, UWB, Zigbee and WiFi, Bluetooth became the final choice for it is easy to install and also for its low price and some other facts.

Chapter 6
Conclusion and Future Work

This thesis has proposed SEATEC system which is aim to be a low-cost online vacancy management system for a small restaurant. As the goal of this thesis is to solve two main problems or we say research questions, which are how to detect the vacancy situation and what kind of restaurant is the system suitable for, considering the interior template, movability of chairs and tables and so on. Also an exceptional research question came up during the research, which is the wireless communication between the detection tool(which is the distance sensors) and the controller(which points to personal computers).

6.1 Limitation

After discussion and experiment about the human detection tool(which is the distance sensor GP2Y0E03 in this thesis) and the wireless communication tool(which is the Bluetooth SPP module HC-05), the final system as illustrated in Figure 5.1 is proved to be able to manage the vacancy situation in small restaurants with limited conditions of interior templates and movability state of chairs and tables.

So far, the system could only work in limited situations, those restaurants with unmovable tables and chairs, unmovable tables with movable chairs are suitable for certain, those with movable' tables and unmovable chairs (rarely existed), movable tables and partial movable chairs could be suitable in some cases. The circumstances are hard to be classified and the suitability between the system and interior template of restaurants should also be discussed case by case.

6.2 Future Work

As this system could only fix the vacancy management problem for limited small restaurants, listing up the general interior templates and movability state of chairs and tables in most small restaurants as many as possible, and try to modify the system to be suitable for all kinds of small restaurants, or design a few kinds of system that would allow restaurants to choose the most suitable one would need further research.

For the supply side, which would be the restaurant, they would need more data to help their business, like improve the system to develop more functions, such as calculate conversion rates, busy time and vacant time and many other data that could help the restaurants improve their service, and predict the peak of busy and vacant time in the future.

Also for many popular restaurants, not only vacancy management, but also waiting management is required. For such restaurants, they always keep the statement of all seats being occupied, and the system proposed would hardly help customers to check the vacancy situation as the vacancy time would be very short. To solve this problem in such situation, we may make the system to record the average staying time of every customer, and the statement of waiting customers would also be necessary.

Another problem to be solved is about the interference issues between working microwave oven and Bluetooth networks. [29] Generally, a microwave oven generates one or two kilowatts of radio frequency at some frequency in the low GHz range, a U.S. Federal Standard limits the amount of microwaves that can leak from an oven throughout its lifetime to 5 milliwatt of microwave radiation per square centimeter at approximately 5 cm (2 in) from the surface of the oven, and this could easily interfere any microwave receiver nearby, even one operating in a different microwave band. Microwave ovens are carefully designed to "contain" all the radio frequency with special gaskets on the door, housings, and an interlock on the door to disable operation when the door is open, but these can fail, wear out, or may have been incorrectly installed. Researchers have suggested that microwave oven interference can greatly reduce the data through-puts from Bluetooth network, which will severely affect its operation and usability [21].

To consider the future prospects of this system, I'm expecting it could fulfill the goal mentioned at first, that could help people from both supply and demand side be more economical of time and energy.

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