POLITECNICO DI TORINO

Master's Degree in Embedded System

Master's Degree Thesis

Research on Tagless indoor person localization system

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Abstract

In the Internet of Things (IoT), the requirements for person localization and monitoring are getting higher and higher. The accuracy of the positioning is increasingly important as Location Based Service (LBS) are developing more and more quickly. Indoor person localization technologies have attracted widespread attention. Nowadays, more and more technologies are used in indoor person localization system.

Earlier techniques required people to wear devices that sent signals, such as infrared light or ultrasonic waves, to allow the system to localize the human body through cooperative processing of receiver devices installed in the monitored space. However, these techniques have many limitations, such as the cost of the wearable devices for monitoring many persons, and in some cases, or discomfort or other problems related to wearing a device (e.g., forgetting, interference with specific activities, or psychological effects of a constant reminder of being monitored).

Therefore, it is particularly important to design tagless indoor person localization systems. They are usually composed of one or more sensors installed in different locations in the monitored space as needed, and they do not require the person to wear any specific equipment or to explicitly interact with the monitoring system. They detect certain biological characteristics of the human body or specific life signs, such as temperature, weight (pressure), electrical capacitance, effects on the propagation of ultrasonic or electromagnetic waves, infrared radiation, etc. to achieve recognition, localization, tracking, and can also achieve the inference of activity using specific processing of the sensor data. The most commonly used sensing techniques are infrared sensing, ultrasound sensing, Wi-Fi based sensing, radar sensing, sensing based on ZigBee radio, ultra-wide band radio sensing, sensing using visible light processing, capacitive sensing, and pressure sensing.

In this work is researched the state-of-the-art of the techniques and the results for tagless indoor person localization systems in the past 15 years. Are analyzed first the development of tagless indoor person localization systems from the technical principles, algorithms, solutions of challenges, experimental design schematics and results. Then are introduced the typical sensing techniques, processing techniques, and compared the techniques using several performance metrics: accuracy, privacy, power consumption, cost, size and installation effort, noise immunity, and activity detection. Last is provided a summary of advantages and disadvantages of each technique to help designing and improving tagless indoor person localization systems.

Keywords: Tagless, Infrared, Ultrasound, Wi-Fi, Radar, ZigBee, UWB, Visible Light, Capacitive, Pressure, RSSI, TOA

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Introduction

With the development of science and technology, the quality of life of persons is constantly improving. Especially after entering the information age, person localization and tracking services are increasingly important to enable intelligent environments, services and security. The ubiquitous availability and accuracy of person localization is becoming more and more important.

For example, in production activities it becomes important to track the presence of persons, their movements, and infer their activities to improve workflows and safety. In retail it is often useful to sense the change of the number of customers in time, along with the specific activity for better analysis and improved service. In medical application it is important to monitor important vital signs and specific health-related parameters and events (e.g., falls, disorientation) by monitoring the environment and the person location and activity.

Person localization has many applications and is essential to provide intelligent and secure environments for a broad range of human activities.

1.1 Tagless Human Sensing Background

Over the years, under the constant stimulation of demand, localization technology has become more and more mature, especially outdoor localization technology. Many countries have adopted large-scale satellite navigation system based outdoor localization programs, such as Global Positioning System (GPS), Glonass and Galileo satellite navigation system, these positioning systems can be controlled on a global scale accuracy in the order of ten meter or even in the order of meter. On the contrary, the development of indoor positioning system is relatively slow due to the changing indoor environment and initially due to the lack of significant military interest.

In the early days, people wore well-signaled communication devices to get location information by connecting satellite systems, but this approach was more demanding and expensive, usually it only used in important military activities. Gradually, it was discovered that some sensing devices such as infrared, ultrasound, etc. could be worn to localize human positioning by interacting with the receiving devices that have already installed indoors. However, this approach has many limitations, such as the cost of wearables increases significantly as the target body increases, and in some cases the target body cannot wear the device. Therefore, it is particularly important to design an indoor tagless human body sensing system.

Tagless human sensing systems do not require the target body to wear any auxiliary equipment. They are usually composed of one or more sensors installed in different locations indoors as needed, and sense certain biological characteristics of the human body, such as temperature, weight (pressure), electrical capacitance, to identify, localize, and through some algorithms to track movements and activities of the target body. Today, such systems can play a huge role in many areas, such as family life, health care, business, and security.

1.2 Indoor Localization Challenge Analysis

The most significant difference between indoor localization system and outdoor localization system is working environment of the system, the outdoor localization system works in an environment with wide field of view and less blocking, but the indoor localization system usually works in relatively closed space, such as classrooms, shopping malls, factories, etc., the environment of these areas is ever-changing and the sensing range is relatively small, in a relatively small space, relative to the outdoor positioning of the "ten-meter range" or even "meter range" measurement accuracy cannot meet most application requirements.

The above two important issues, namely, the complex environment and the need of higher accuracy, have brought many difficulties to the development of indoor localization system, which mainly face the following challenges:

1. *Signal masking problem*: According to common sense, today's buildings are more reinforced concrete structure, which leads to the wall experience seriously affect the transmission of signals, so that most satellite navigation systems are difficult to work in indoor environments, in addition, it will have a significant impact to some common sensors such as ultrasound, radar signals, Wi-Fi signals, etc. So that leads to the system designers limited in the choice of sensors.
2. *Diversity of indoor environment*: In life, people choose different decoration structures and place different furnishings based on the different functions of the room, these differences make indoor localization become difficult, for example, for an infrared-based sensing localization system, the thermal interference of different rooms will pose a considerable challenge to the accuracy of the system. This requires the system designer to take full account of the portability of the system.
3. *Signal interference*: People live in a space that full of various signals, such as sound, light, electromagnetic waves, etc. The interaction between various signals will lead to signal offset problems, signal offset will seriously affect the accuracy of the localization system, which requires system designers to fully take into account the

complex and variable signals in the room, to improve the system's ability to cope with interference.

4. *Safety issues*: people in life every day have a high probability to stay indoors for a long time, so a safe and comfortable indoor environment is the basis for system construction, some medical research reports show that some sensors such as ultrasound and infrared in the case of excessive exposure to the human body will have irreversible effects, which requires system designers to fully consider the impact of signal strength.

1.3 Classification of Indoor Person Localization Systems

Indoor person localization system is usually composed of three parts: signal transmission device, signal receiving device and signal processing device. Typically, the indoor person localization system can be divided into two parts based on whether the person under test is involved in the transmission of the signal: active techniques and passive techniques.

1.3.1 Active Techniques

Active indoor person localization system refers to the person being tested carrying a signal transmission device or the identification information that can be detected by the receiving device: type A as shown in Figure 1.3.1, when the person under test moves indoor, the signal transmission device can send a signal to the signal receiving device in different locations in the room, based on the differences of signal in the receiving device to calculate the location information of the person.

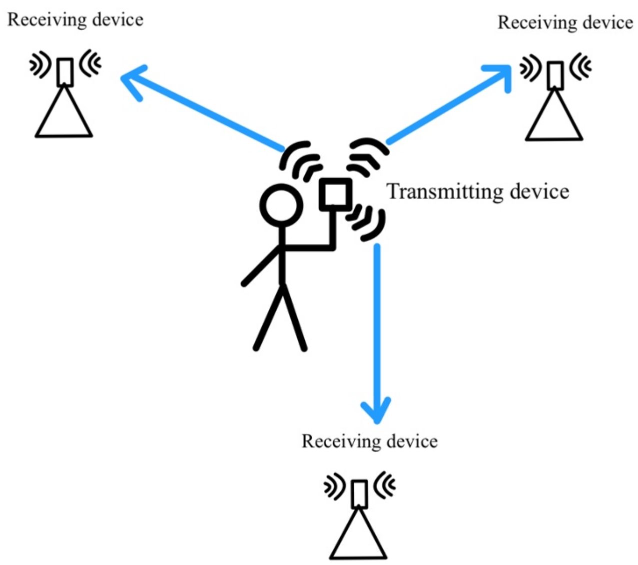

Figure 1.3.1: Schematic of Active techniques type A.

Type B as shown in Figure 1.3.2, when the person under test moves indoors, different signal receiving devices in the room can detect the identification information carried by the person under test, and then calculate the location information of the person based on the difference of the signal.

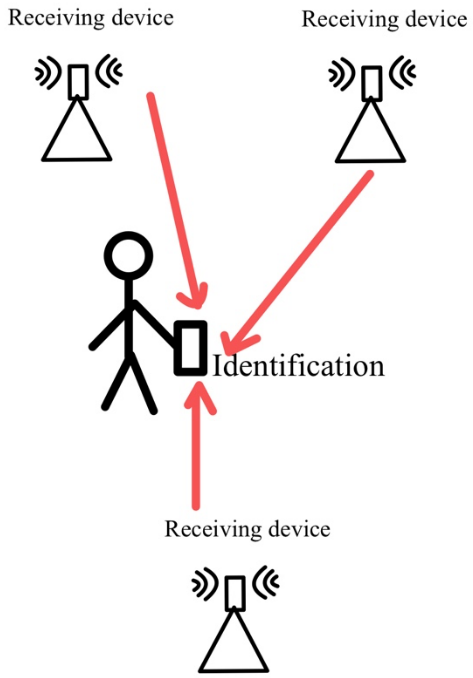

Figure 1.3.2: Schematic of Active techniques type B.

1.3.2 Passive Techniques

Passive indoor person localization system refers to the person under test does not need to wear any auxiliary equipment, through the detection of some biological information of person or the influences on certain signals to calculate the location information of the person as shown in Figure 1.3.3. Such as the temperature of the person, pressure of the person or the influences of electromagnetic waves made by the person indoor: masking, reflection, or causing doppler effects, etc.

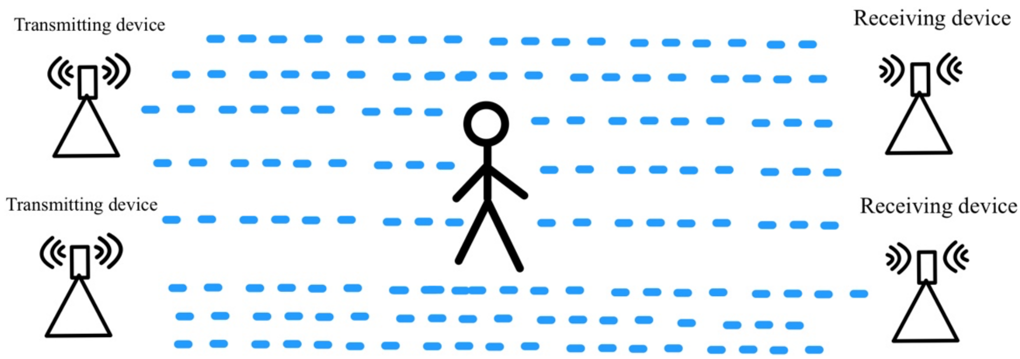

Figure 1.3.3: Schematic of Passive techniques.

1.4 Typical Technologies for Tagless Indoor Person Localization Systems

Nowadays, typical technologies of Tagless indoor person localization system are: Infrared Sensing, Ultrasound Sensing, Wi-Fi-Based Sensing, Radar Sensing, Sensing Based on ZigBee Radio, Ultra-Wide Band Radio Sensing, Capacitive Sensing, Pressure Sensing.

Chapter 2

Sensing Techniques for Indoor Person Localization

2.1 Infrared Sensing

Any object with temperature above 0 K (-273 °C) generates thermal radiation (infrared spectrum). The thermal radiation spectrum of objects whose temperature is lower than 1725 °C is concentrated in the infrared region, so almost all objects in nature can be directed towards external radiating infrared heat, objects of different temperatures, the wavelength of the infrared energy released is different, so the infrared wavelength is related to the temperature. The wavelength and distance of infrared radiation produced by any object due to its own physical and chemical properties and temperature are also different. The wavelength of infrared light radiated by the human body is 3-50 μm, of which 8-14 μm accounts for 46 %, the peak value of the wavelength is 9.5 μm [1].

Using knowledge of Infrared, we can detect indoor people based on the difference between infrared wavelength and temperature. Specifically, we can use a passive infrared (PIR) sensor, which can detect the infrared light emitted by the target. By analyzing and filtering the input infrared rays, we can separate the human body from the environment, thereby realizing the localization of indoor person.

In [2], the author uses a passive infrared (PIR) temperature sensor to locate indoor person. They choose a sensor made by Omron Corporation company as shown in Figure 2.1.1, an infrared ray array sensor module which can measure ambient temperature between 270 K to 320 K with 16 bit resolution.

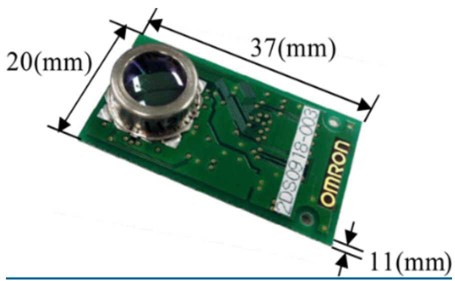

Figure 2.1.1: Schematic of thermal sensor. Source: [2]

To achieve the positioning of the indoor human body, the author first acquires an indoor thermal distribution and then remove the indoor temperature from the indoor thermal distribution, finally they calculate a distinction map from thermal difference distributions show in Figure 2.1.2. Here the author draws a temperature distribution map based on the temperature of the indoor floor. In this figure color black means the temperature of floor, which is also being the base temperature, color white means the temperature of other objects and green means the person indoor.

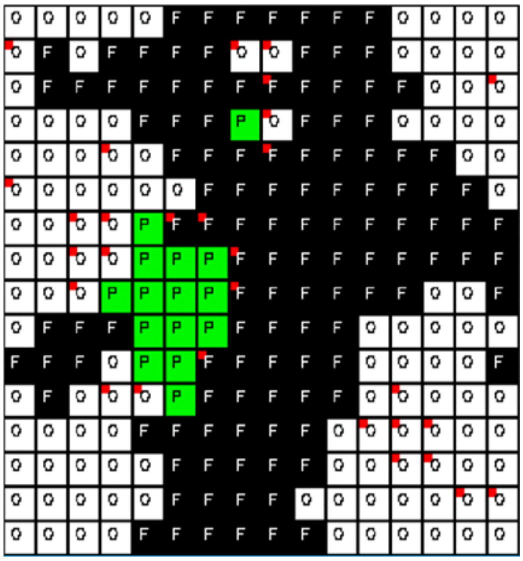

Figure 2.1.2: Distinction map. Source: [2]

The authors did an experiment to verify the system's ability to locate the indoor person, the experimental scene is arranged in the school's regular office show in Figure 2.1.3. In this office there is a path in center of the measuring area, and there are also some regular staff like tables, chairs, bookshelf, and a white board. In addition, there are some things that may heat the area for example, on the table there are some PC and a printer.

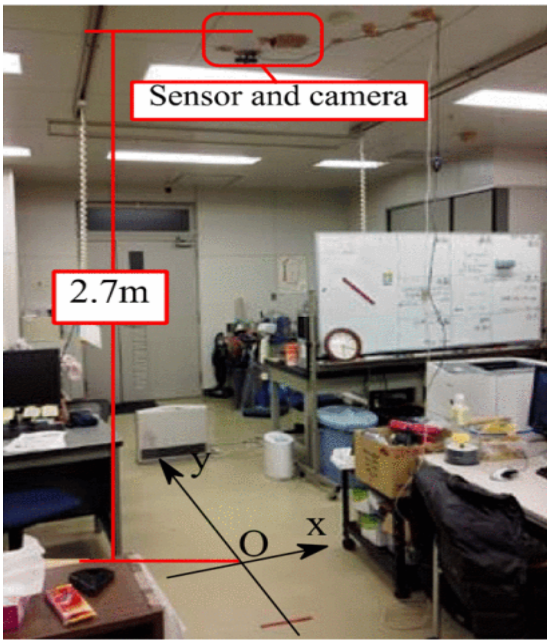

Figure 2.1.3: Photographs of the experimental area. Source: [2].

The sensor is installed on the ceiling of the office with a height of 2.7 m, infrared radiation radiates down from the top, assuming that the average height of the person is 1.7 m, and the sensing area of this sensor is about 2 m x 2 m. Figure 2.1.4

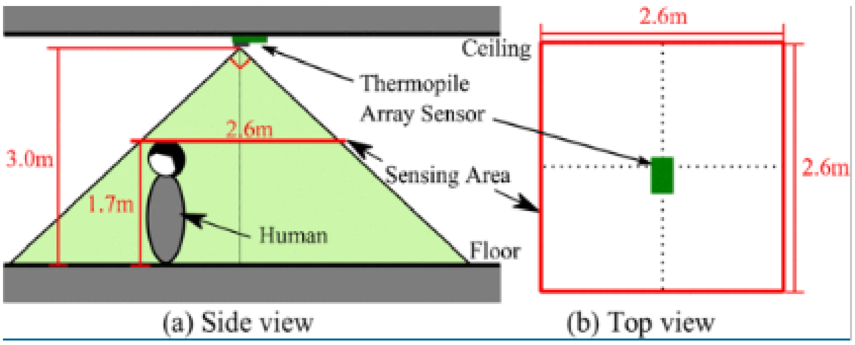

Figure 2.1.4: The sensing area of the system. Source: [2]

In the experiment they use a special way to improve accuracy for detecting the indoor person, they found that when a person leaved from his seat, the seat was detected as a person since the heat emitted makes the seat hot so the system miss-detected heat source as a person. They analyze some common senses and make a function to show the influence between temperature changed show in Figure 2.1.5.

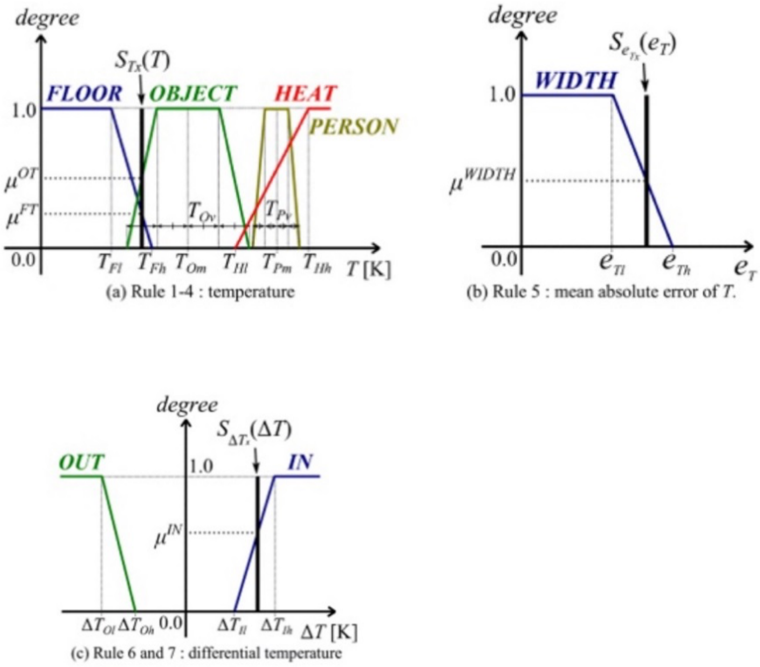

Figure 2.1.5: Functions for people detection. Source: [2]

In the experimental results, the system estimated people positions in the room with temperature 290.2 K, the results show in Figure 2.1.6. We can see in Patten #6 and Patten #7 the estimation accuracy of people is very good, in some cases are not, but the total estimation accuracy rate of people is 41.2 ± 28.4 %, So this system using fuzzy inference and room layout was suitable for estimating people positions in daily home environment, such as a living room and a study room.

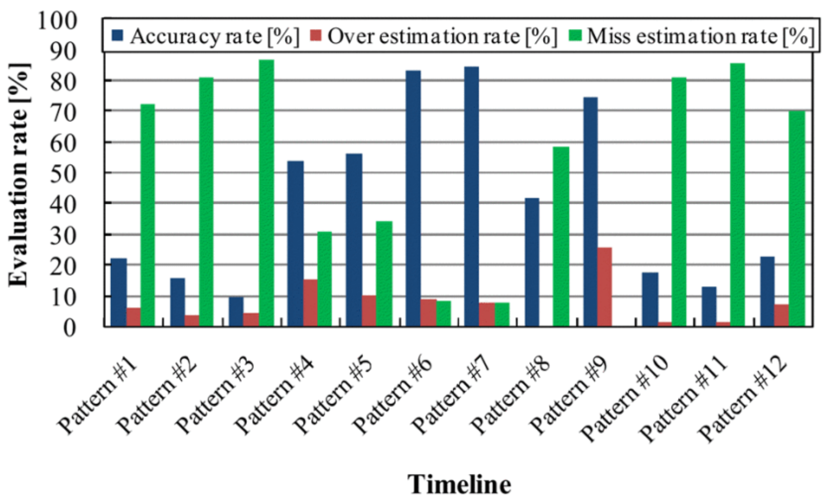

Figure 2.1.6: The estimation accuracy of people. Source: [2]

In summary, passive infrared (PIR) sensor is a very good sensor for indoor human body positioning, it has low price, small size, high accuracy, and easy to be installed, so it is very suitable for people's daily life environment monitoring.

2.2 Ultrasound Sensing

Ultrasound is essentially a kind of sound wave, the wave range that human ear can receive is 20 Hz to 2000 Hz, when the frequency of sound waves exceeds the range that the human ear can receive, it is collectively referred to as Ultrasound.

The frequency of ultrasonic waves is very high, so its energy is large and has a strong penetration, so it is often used in positioning systems. The ultrasound indoor positioning system is developed based on the ultrasound ranging system, and the entire system is composed of an ultrasound transmitting device, an ultrasound receiving device, and a central control circuit show in Figure 2.2.1

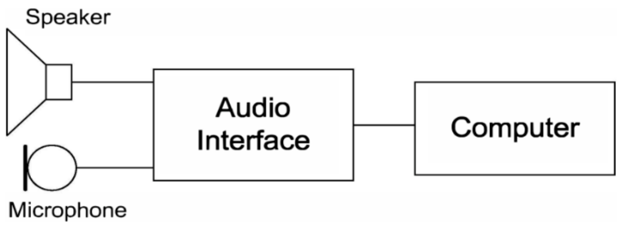

Figure 2.2.1: Schematic of ultrasound system. Source: [3]

First, the ultrasound transmitting device transmits ultrasonic waves, ultrasonic waves are transmitted to the receiving device through the medium, the receiving device responds after receiving the wave signal, and the central controller calculates the distance from the transmitting device to the reference node based on the response time of the receiving device and the reference speed of the ultrasonic wave, and then locates it based on a certain algorithm.

In [3], the authors used ultrasonic sensors to achieve indoor human body positioning, which is based on measuring the time-of-flight (TOF) of ultrasonic signal reflections of the human body and indoor walls. Here the speaker is used as the ultrasonic transmitting device and the microphone as the ultrasonic receiving device. The principle of the system is: First, the speaker emits ultrasonic waves, ultrasonic waves propagate through the air medium in the room, when the ultrasonic waves encounter obstacles will reflect ultrasonic waves, the microphone can receive the reflected ultrasonic waves, measure the reception time, and then the system obtains the accurate position of the target body based on the difference in flight time.

In the algorithm section, the author first uses fast normalized cross correlation know the time stamps of the received ultrasonic signals, here it refers to estimating the time difference between two correlated signals which means compare the sent chirp with the received signal, to gets strong peaks which correspond to the line-of-sight signal and the reflections of static objects like walls, furniture, etc. So, they can locate the distance to such objects.

Finally, the author proceeded human and second reflections detection. The purpose is to eliminate the interference of the ultrasonic signal reflected by the static object to the ultrasonic signal reflected by the target human body. Since the human body is in a non-stationary state in its natural state (even if it stays still, it still produces a slight shaking due to breathing) and static objects such as walls and furniture remain unchanged for a short period of time, it is possible to directly eliminate their contribution by subtracting the response of continuous chirps.

The authors did an experiment to verify the system's capability of this approach of tracking a moving target and a static target. The experiment was conducted in a regular room using one microphone and one speaker named Earthworks M50 which can emit a signal chirp with a frequency from 18 kHz to 22 kHz.

The author first carried out static position localization, starting with no one inside the room, then the transmitter emitted ultrasonic waves, and by integrating the feedback of the receiver, the position of the wall was obtained, as shown in Figure 2.2.2. The results show that the distance of the wall surface is 0.70 m, 1.16 m, 2.06 m, and 5.37 m, compared with the actual wall distances of 0.8 m, 1.15 m, 2.10 m, and 5.21 m, and the average error of the system is 0.08 m.

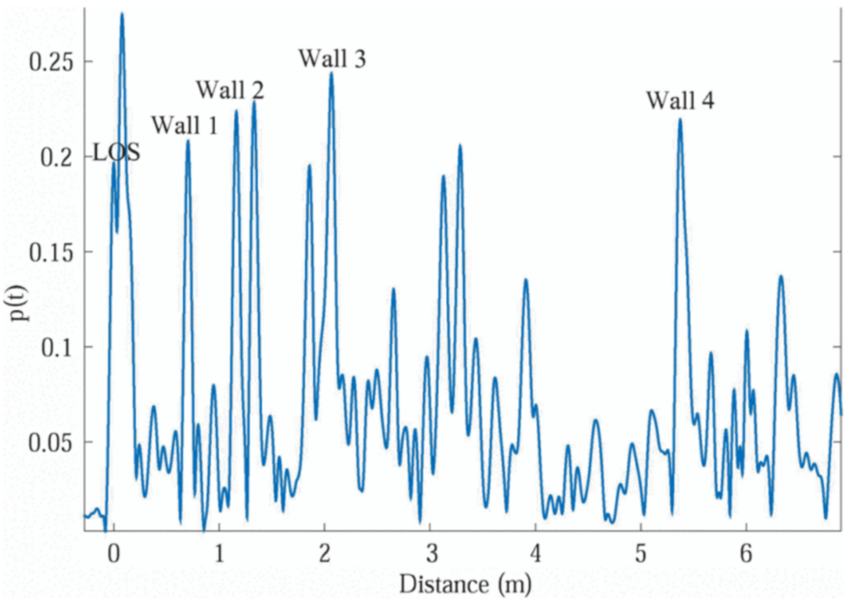

Figure 2.2.2: The walls produce noticeable peaks in the received signal. Source: [3]

The experiment was then continued with several stationary human targets set indoors, eliminating static reflections by subtracting the responses of successive intervals and comparing the correlation of signals before and after subtracting multipaths. After that, the first reflex and the second reflex of the indoor human body are obtained as shown in Figure 2.2.3.

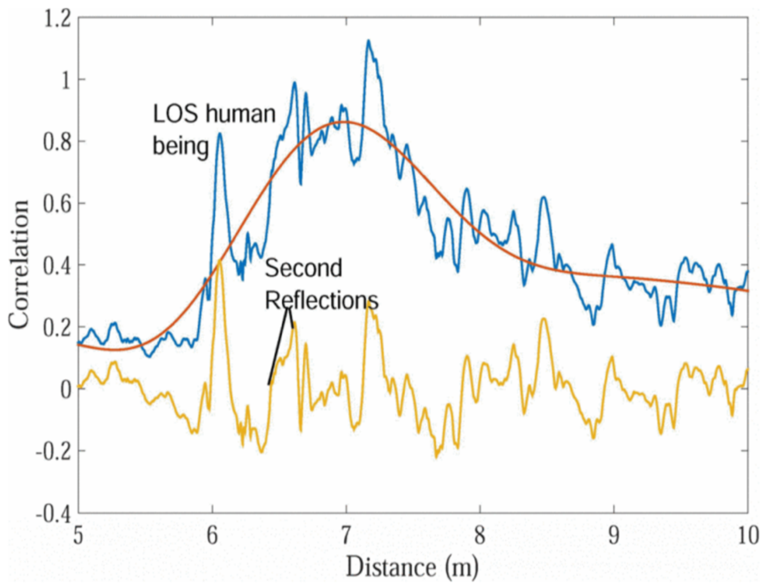

Figure 2.2.3: The first reflection and the second reflection of the indoor human body. Source: [3]

Since there are always two opposing walls in the same place in an indoor enclosed room, there are two possible schemes, here the author assumes that the human body always moves in coordinates with the wall on one side to obtain the coordinates of the position of the human body relative to the wall, as shown in Figure 2.2.4.

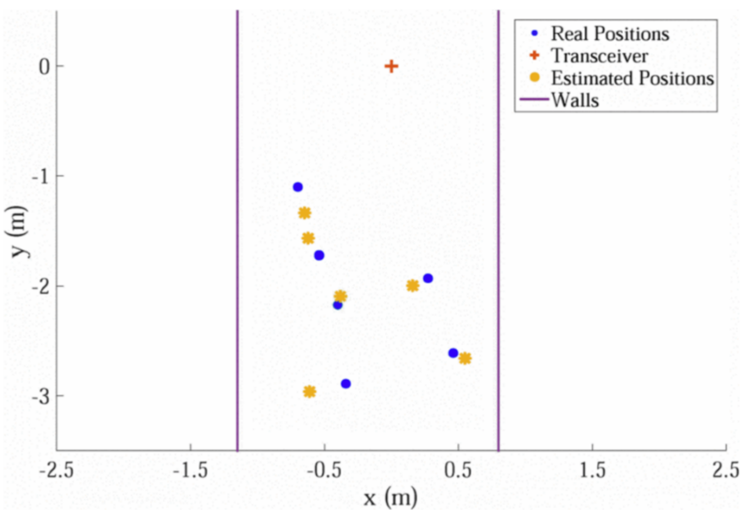

Figure 2.2.4: The result when people standing at certain positions. Source: [3]

The authors then did an experimental test of continuous movement, which were designed to test the system's feasibility of tracking the human body indoors.

First, the distance of the wall is measured based on the static positioning, and then a target person is set to move indoor, where the path of the person in the experiment is a triangle as shown in Figure 2.2.5.

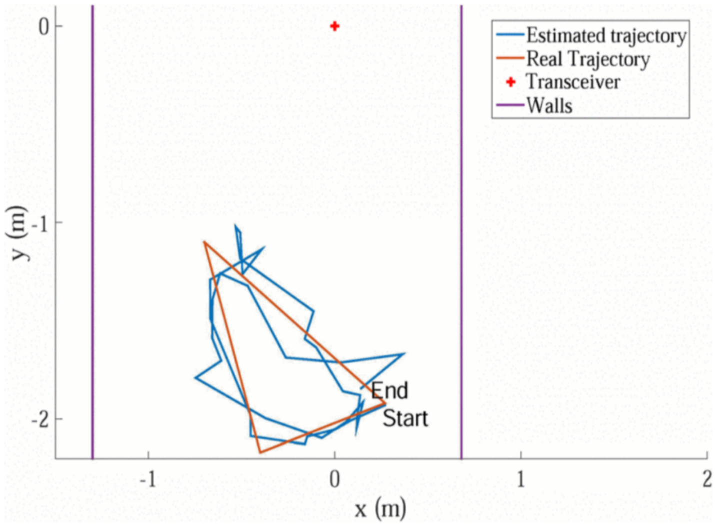

Figure 2.2.5: The result when people move in a triangle path. Source: [3].

The person is tracked based on the time difference between the first and second reflections. According to the conclusions of the two experiments, the system can track the indoor human body with a median error of 0.08 m and a standard deviation of 0.13 m.

In summary, ultrasound sensors play a great role in indoor human body positioning, its low price, high accuracy, and simple installation make it very suitable for indoor human body positioning.

2.3 Wi-Fi Based Sensing

Wi-Fi is a kind of wireless LAN communication technology that uses the 2.4 GHz and 5 GHz bands and has been applied in various scenarios of people's lives, such as computers, mobile phones, game consoles.

Wi-Fi technology now is not only a way to connect to the Internet, but also a communication way, it has an important purpose in many fields. For example, for smart cars, car developers connect car instruments and devices through Wi-Fi technology to achieve intelligent monitoring, which provides great help for our travel. With the popularity of Internet technology, Wi-Fi devices are also spread to all corners of people's lives, and many researchers have found that Wi-Fi devices can be used to locate the indoor human body.

For positioning systems, information such as the ID, strength, propagation time, and reception angle of the Wi-Fi signal are often used:

ID: Each Wi-Fi hotspot has a different Mac address as an identification, this Mac address is also the ID of the Wi-Fi hotspot, by determining whether the mobile terminal is around the fixed Wi-Fi hotspot which has a known location to determine the location of the mobile terminal. When a mobile terminal detects a Wi-Fi hotspot, it indicates that the mobile terminal is around a Wi-Fi hotspot.

Signal strength: The strength of the signal is generally determined by the energy transmitted by the transmitter antenna and the signal propagation pathway. In the case of the same transmitter, the difference in the propagation pathway affects the signal strength of Wi-Fi. We can take advantage of this by measuring Received Signal Strength Index (RSSI) of Wi-Fi for localization.

Propagation time: Wi-Fi signals travel at the same speed in the same environment, and the time it takes for signals emitted from the transmitter to reach different locations is different. Mobile terminals can record the time when the Wi-Fi signal arrives in a specific way. The speed at which the signal propagates in the same environment is consistent, so we can use speed and time to deduce the position information of the mobile terminal to achieve localization.

Reception angle: The reception angle of the Wi-Fi signal is determined by the position of the transmitting antenna and the receiving antenna, and the angle of the Wi-Fi signal can be obtained at the receiving end, and we can use the difference in angle to determine the position information of the receiving end, to achieve localization.

In [4], the author use Wi-Fi sensing to detect indoor person. The system uses a deep Convolutional Neural Network (CNN) architecture which can automatically extract effective features from the wavelet coefficients of the Wi-Fi RSSI measurements to conduct person detection.

They use a Raspberry Pi development board to make the system, in the board, there are three types of Wi-Fi adapters: Alfa Network AWUS036H, Edimax EW-7822, and Ourlink 150M USB adapters that can transmit and receive Wi-Fi packets as shown in Figure 2.3.1.

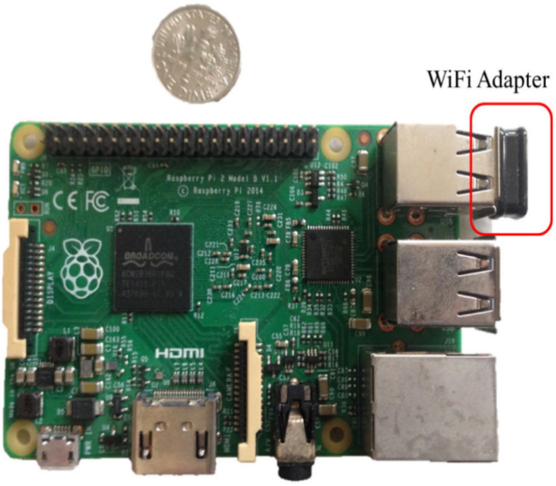

Figure 2.3.1: Picture of the system. Source: [4]

In the algorithm section, the author first does data preprocessing. The aim is to reduce interference from factors unrelated to human movement events:

A. *Wireless interference*: This refers to the impact of the signal emitted by some other electrical appliances in the room on the experimental target signal, such as some Bluetooth signals, where the author first directly deleted less than 1 % of the data, and then used the median filter to delete the signal profile, which can effectively remove some serious interference situations.
B. *Packet loss*: This refers to the loss of packets due to the bad link state of AP and MP bursts, causing abnormal fluctuations in the RSSI signal. To address this, the authors solve this by actively dropping packets, that is, by recording the sequence number of packets and actively dropping when a bad link state is detected.
C. *Packet rate irregularity*: This refers to the fact that the collected RSSI signal rate is not constant due to packet loss, and here the author resampled and recorded the RSSI data as needed.

And then the author dose data augmentation, the purpose of this is to transform the training data generated by the experiment into new data to better learn and train the neural network model:

A. *Enhance data at different speeds*: This is due to different walking speeds that change the duration of signal fluctuations, randomly selected time series slices by resampling up or down as shown in Figure 2.3.2.

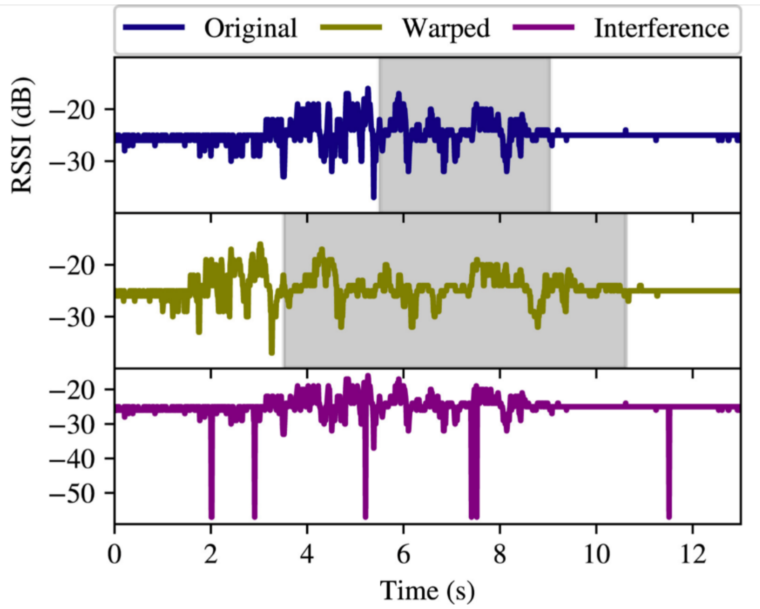

Figure 2.3.2: Synthesized augmenting data for different moving speeds and wireless noises. Source: [4]

B. *Use added noise enhancement data*: This is due to the removal of too much noise information when removing the interfering signal in the first step.

After this, the author does wavelet coefficients extraction. A set of wavelet coefficients most sensitive to human activity was selected and the original RSSI signal was attached to form a two-dimensional image, as shown in Figure 2.3.3.

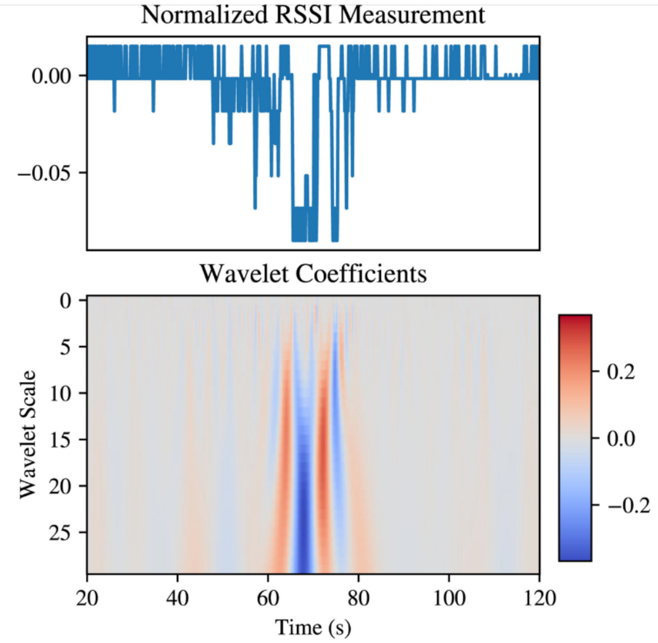

Figure 2.3.3: Wavelet coefficients extraction of RSSI signal. Source: [4]

And then the author does Deep convolutional neural network architecture, finally they do Collaborative moving direction detection based on DTW: Compare the fluctuation time of RSSI signals by different Wi-Fi transceivers to determine the direction of human walking.

For the experiment section, they took the experiment in the office. The entire system consists of three Wi-Fi transmitters and a receiver as shown in Figure 2.3.4. The experiments have been repeated at different times across multiple days, and 163 movement events are recorded.

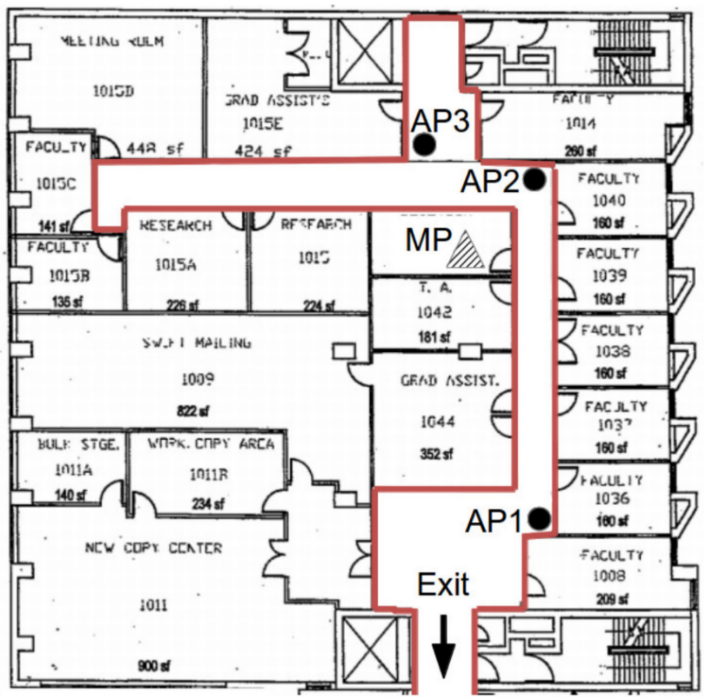

Figure 2.3.4: Photographs of the experimental area. Source: [4]

The author first evaluates the accuracy of the system to detect walking people. The results are shown in Figure 2.3.5.

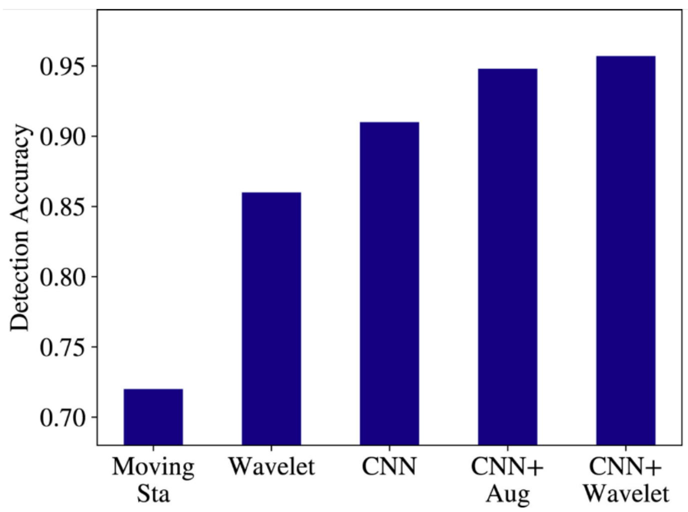

Figure 2.3.5: The result of the accuracy when people walking. Source: [4]

We can see that by using the data augmentation technique in the training phase, they can improve the performance of the CNN to 94.5 % and after combine both the raw RSSI measurement and its wavelet coefficients as the input for the neural network, the detection accuracy is improved to 95.5 %.

Finally, they do move direction detection, the results as shown in Figure 2.3.6.

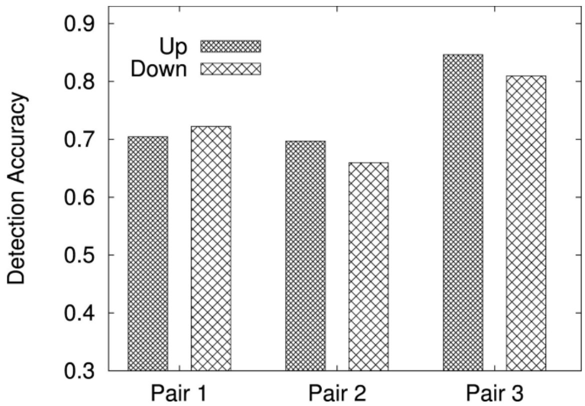

Figure 2.3.6: The result of the accuracy movement direction detection. Source: [4]

We can see that this kind of system can both detect indoor people and the moving direction. In an experiment with 163 walking events, they show that the system can detect walking events with over 95.5 % of accuracy.

In summary, Wi-Fi based sensing is a very good technique for indoor person localization. It has a high degree of accuracy and can be easily used with existing Wi-Fi devices. Therefore, Wi-Fi sensing technology is a good choice in indoor person positioning systems.

2.4 Radar Sensing

Radar sensing is a commonly used positioning technology in modern society, the principle is that the transmission device of the radar equipment transmits electromagnetic waves to space through the antenna with a certain power, electromagnetic waves propagate in the space medium, when the electromagnetic waves encounter the object, the object will reflect the electromagnetic waves, while the radar antenna will receive the reflected electromagnetic waves, through the mathematical processing of the reflected electromagnetic waves, we can get the information of object like distance, height, speed or others, to achieve the positioning function.

In practical applications, positioning systems using Doppler radar are very common. Doppler radar is a radar device that uses the Doppler effect to monitor the position and relative speed of the target body. The main content of the Doppler effect is that the wavelength of the radiation of the object changes due to the relative motion of the wave source and the observer, and when the wave source and the observer are close to each other, the received frequency increases. When the two leave each other, they decrease.

Doppler radar works the same way as radar, and there is a specific variable here: the Doppler frequency, which refers to the frequency difference between the frequency of the return wave and the frequency of the transmitted wave when the electromagnetic wave encounters the target body. As the doppler frequency is a dynamically changing value, Doppler radar can naturally filter a lot of static clutter waves, in addition the penetration of radar signal is better, so Doppler radar is often used in military, weather monitoring and other fields.

In [5], the authors used Doppler radar to achieve a method of human detection by examining the physical characteristics of the target body. The author uses a Doppler radar device as shown in Figure 2.4.1, which uses two Vivaldi antennas with a gain of 7 dBi and radio frequency output power is 15 dBm. Since the human body stays in vertical positions for long time, the two antennas use vertical polarization, which interact more effectively with a vertical human body.

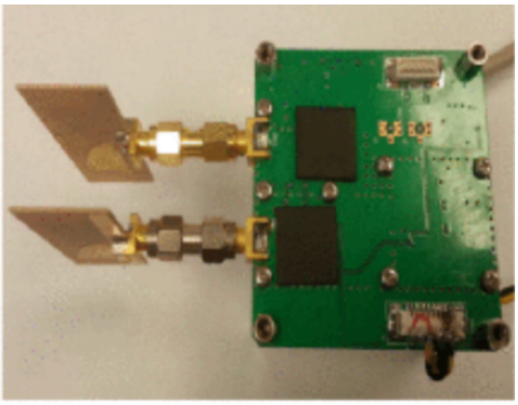

Figure 2.4.1: Schematic of the Doppler radar. Source: [5]

In the algorithm section, the author first does target measurement and data processing. Doppler shift is made when an object moves relative to a transmitter and a receiver. The authors need to see the target behavior in a Doppler domain in time, so they apply short-time Fourier transform (STFT) to the received signal as shown in Figure 2.4.2.

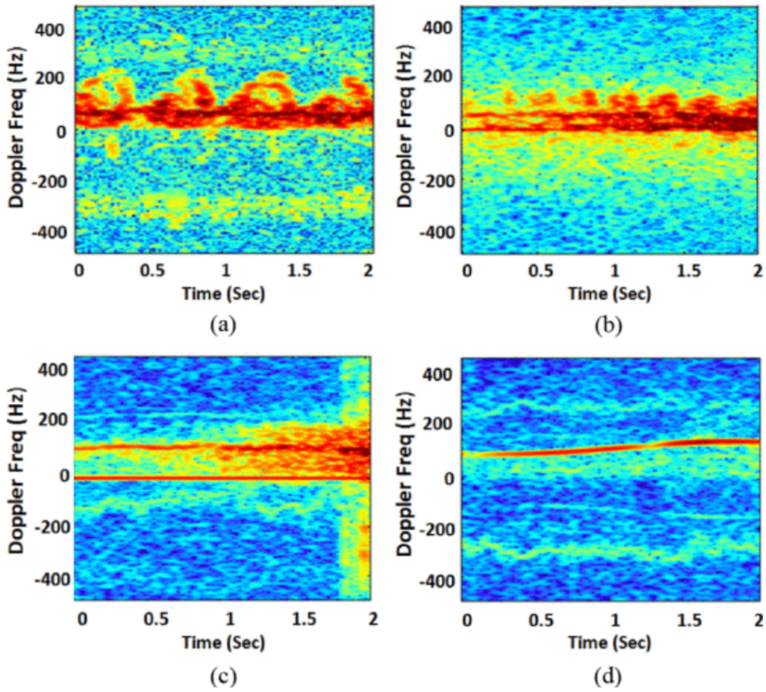

Figure 2.4.2: Spectrogram of moving targets. (a) Human. (b) Dog. (c) Bicycle. (d) Car. Source: [5]

After that, the authors do feature extraction, based on the physical characteristics of the human body. The characteristics are distinguished from the following four aspects:

A. *Frequency of the Limb Motion*: Human movement is based on the swing of hands and legs, when people move, limb movements produce micro-Doppler, so we can detect the movement of the human body by the phase between micro-Dopplers, as shown in Figure 2.4.3

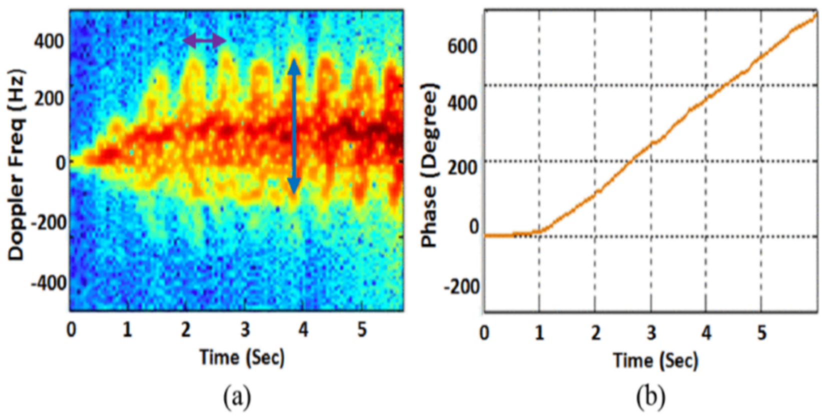

Figure 2.4.3: (a) Description of the target features. (b) Change in phase. Source: [5]

B. *Target Stride*: distinguish from other organisms, humans have a unique stride, and the ranges of the stride of human are typically from 60 to 80 cm.

C. *Bandwidth of the Doppler Signal*: The speed of limb movement is a function of limb length and angular velocity, while the maximum Doppler frequency is related to the speed of limb movement
D. *Distribution of Strength of the Doppler Signal*: The intensity of the Doppler signal can be used to analyze the limb proportions of the target body, so the target body can be distinguished based on the physical structural characteristics of the human body.

The authors did an experiment to verify the effect of Doppler radar in detecting humans. They test humans (average height 175 cm), dogs (average weight 15 kg), bicycles (size of wheel 26 cm) and cars. For each target body, it is necessary to move 5 times within the radar range and generate 100 data tuples. Each movement of the target body is at a different speed. The result is shown in Figure 2.4.4. We can see that using this method, the authors could detect a person with an accuracy of over 96 %.

Estim \ Actual	Human	Dog	Bicycle	Car
Human	96%	10%	0%	0%
Dog	4%	90%	0%	0%
Bicycle	0%	0%	76%	21%
Car	0%	0%	24%	79%

Figure 2.4.4: Confusion Matrix of the Classifying Result. Source: [5]

In summary, Radar Sensing is a very good technique for indoor person localization. Its penetration is good and anti-interference ability is strong, so it very suitable for application in a wide range of indoor human detection.

2.5 Sensing Based on ZigBee Radio

Zigbee is a new type of wireless communication technology, essentially a relatively low-rate two-way wireless network technology, specified by the IEEE 802.15.4 wireless standard. Its name is very vivid, based on the contact between bees to each other. Zigbee wireless communication technology compared to the traditional network communication technology, which shows more efficient characteristics. It is a low-cost, close-range, low-power networking technology.

In recent years, ZigBee technology often appears in indoor positioning system. When using ZigBee technology for indoor human localization, first thing is set a central reference node and gateway, while deploying a lot of nodes in the indoor environment, and they work together to form a localization system. Different nodes communicate with each other by ZigBee Radio.

In [6], the authors use ZigBee to locate people and two methods to improve the accuracy of the system. The authors use a micro kernel named Octopus X on the 8051 series microcontrollers embedded in CC2431, as shown in Figure 2.5.1.

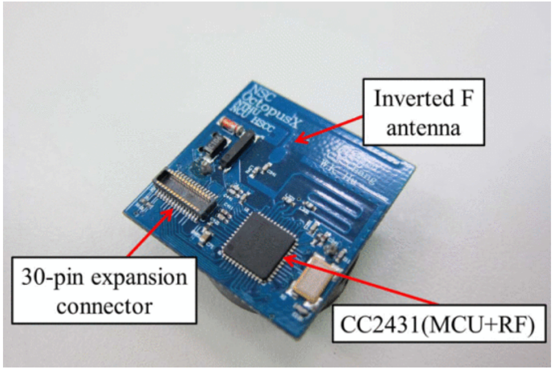

Figure 2.5.1: Picture of the Zigbee device used in [6]. Source: [6]

We know that ZigBee's signal transmission is greatly affected by the multipath effect and movement, ZigBee usually results in inaccurate estimation such as drifting. So, in the algorithm section, the author used two methods to improve accuracy:

A. *NAMVPC*: this method requires assigning a dedicated region code to each predefined region, so that for each node we know the node's private ID. In this way, when the system is working, the blind node receives a signal from the reference node, and the blind node will know the ID of the node and thus know the location information of the node. This method can greatly reduce signal drift.
B. *EPC*: this method refers to use signal dBm (parameter A) and consumption of the path attenuation (parameter N).

The authors did an experiment to verify the effect of ZigBee in detecting humans. The authors conducted the experiment in an area that included two meeting rooms and two paths as shown in Figure 2.5.2. The system including a total of 42 reference nodes and 3 blind nodes. During the experiment, the target person walks within the area and walks through path 2, path 1, meeting room, and video meeting room.

Figure 2.5.2: Sensor deployment sketch. Source: [6].

The author uses two kinds of methods to analyze the data: NAMVPC and N-E combination (combination of NAMVPC and EPC). And the result is shown in Figure 2.5.3. We can see that in the experiments, the methods increase ZigBee accuracy to at most 60 %. The drifting has been lowered to only about 3 % of the time.

Parameters: A, N	Measure times					Average positioning error
	1st	2nd	3rd	4th	5th	
A=76, N=12	5.26	6.04	5.84	6.21	5.61	5.792
A=72, N=12	4.28	4.57	5.02	5.16	5.01	4.808
A=70, N=14	5.56	6.02	5.41	5.98	5.74	5.742
A=72, N=10	3.49	4.21	3.94	3.26	3.54	3.688
A=72, N=8	3.56	3.65	4.25	3.98	3.26	3.74
A=72, N=6	4.52	4.59	3.98	4.18	4.23	4.3
A=70, N=8	3.98	4.52	4.26	4.17	4.58	4.302

Figure 2.5.3: Positioning error for different sets of environment parameters. (Unit: 0.1 m). Source: [6].

In summary, Sensing Based on ZigBee Radio is a good technique for indoor person localization. ZigBee is a short-range, low-speed wireless network technology that requires very little energy for these sensors. As a low-power and low-cost communication system, ZigBee has a high efficiency of work, but there are also some problems, such as it is easy to receive the impact of multipathing and signal drift, so it should be deployed in combination with the specific environment in the application.

2.6 Ultra-Wide Band Radio Sensing

Ultra-Wide Band Radio Sensing technology is a new type of wireless communication technology, compared with the traditional wireless communication technology, it transmits data by sending and receiving extremely narrow pulses with nanoseconds, with GHz-level bandwidth, so the ultra-bandwidth technology has strong penetration and good effect of multipath resistance.

Recently, more and more Ultra-Wide Band Radio Sensing technology have been used. In the indoor human body localization system, the most used is the use of a single UWB device short-range positioning method, in addition, we can also make multiple UWB equipment networking, thereby greatly improving the accuracy of the localization system. UWB indoor human body localization system often uses Time of Arrival (TOA) algorithm.

Because of its high accuracy and relatively anti-interference and is often used in emergency rescue and military fields.

In [7], the author uses Ultra-Wide Band Radio Sensing technology to track people. The authors used two UWB devices to network, the first UWB device S1 had a chip clock rate of 4.5 GHz, 511 impulse response samples, and its measurement range was 17 m. The other UWB device S2 had a chirp clock rate of 9 GHz and the same impulse response samples. Both devices are equipped with three double-ridged horn antennas, arranged in a line between Rx1 and Rx2 as shown in Figure 2.6.1.

Figure 2.6.1: UWB radar network. Source: [7]

Through previous experiments, when the UWB system locates and tracks the human body indoors, one of the more obvious effects is the shadow effect between multiple target people. To solve this problem, in the algorithm section, the authors adopt two ideas:

A. *Enhancement of Weak Signals*: we know that the level of signal components scattered by a target and received by the radar depends among others on the distance between transmitting antenna-target-receiving antenna. At this time, the target body near the antenna can reflect a strong reflection, while the target body far from the antenna can only reflect a weak signal, which is more obvious when there are multiple target bodies in the system. At this time, the weak signal needs to be enhanced. The method that the author used is based on serial searching of maxima in the interval and consequential normalization of a current signal in the interval. This method can effectively improve accuracy as shown in Figure 2.6.2.

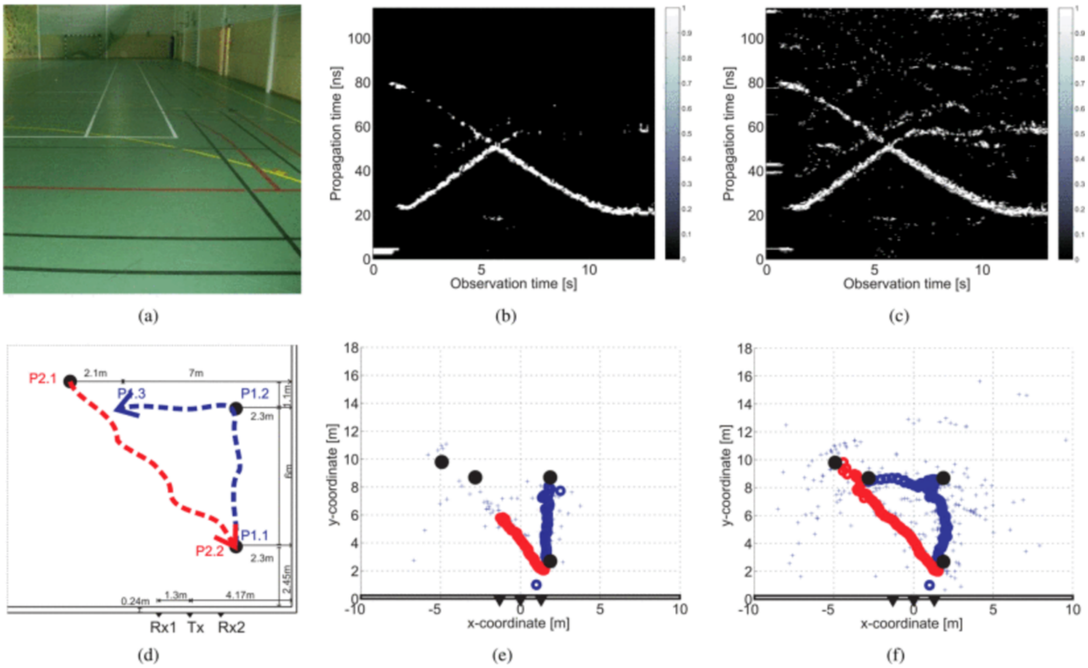

Figure 2.6.2: Weak signal enhancement. (a) Interior of monitored region, (b) detector output without weak signal enhancement, (c) detector output after weak signal enhancement, (d) scheme of measurement scenario, (e) final target tracks estimated without enhancement, (f) final target tracks estimated with enhancement. Source: [7].

B. *High-up Setting of Radar Antennas*: Due to the characteristics of the physical structure of the human body, when the height of the antenna is less than 50 cm, the signal will be affected by the swing of the legs of the target person and some furniture, so the use of a higher antenna height of 180-210 cm can improve the tracking detection of multiple moving people.

In summary, Ultra-Wide Band Radio Sensing is a good technique for indoor person tracking and localization. Ultra-Wide Band Radio Sensing technology has the advantages of strong penetration, good anti-multipath effect, high security, and accurate positioning accuracy, but also because of its working principle, its power consumption is high, and it is difficult to popularize it in practical applications.

2.7 Sensing Using Visible Light Processing

Visible light refers to the light that can be directly observed by the human eye. Humans used visible light to record some information for a long time, such as cameras that record visible light to store image information. In the field of indoor human body localization, the number of systems that uses visible light is the most, because the area can be monitored intuitively through carriers such as image and video, and the output of the sensor does not require a very complex processing procedure, which can be directly recorded by the experimenter, so the indoor human body positioning system of the video accounts for a large proportion of the market by using visible light images. However, this technology also has obvious disadvantages, one is that the data recorded through the image greatly violates the privacy of the subjects, and the other is that the image information often requires a large information storage space.

In [8], the authors used a monitoring system for human activity based on visual records of visible light. The authors used the camera to record the image information of the experimental area and realized the monitoring of indoor human activity through the processing of the collected information. In the algorithm section, the author mainly uses the following three methods:

C. *Remove the background*: the first step in the processing of image information is to simplify the background so that the measured target is highlighted in the image, combined with experience, the author uses the Gaussian probability density function to model each pixel of the background, and because the background environment is not completely static, it is also necessary to add or remove static images in a targeted manner
D. *Dynamic tracking*: Through the first step, we have obtained a simplified background. Here we need to collect and connect each target body to form a new component. Here the author sets a specific color for each target body to distinguish and applies smoothing Temporal misclassification to improve the accuracy of the system as shown in Figure 2.7.1.

Figure 2.7.1: From the left to the right: original image, result obtained after background subtraction and finally after connected components gathering. Source: [8].

E. *Human verification*: the purpose of this step is to verify whether the previous components are human objects of interest for the experiment. The method used by the authors here is based on Haar-like filters and a series of boosted classifiers. After the second part detects a human, the target body is analyzed with a classifier with different positions and scales to improve the accuracy as shown in Figure 2.7.2

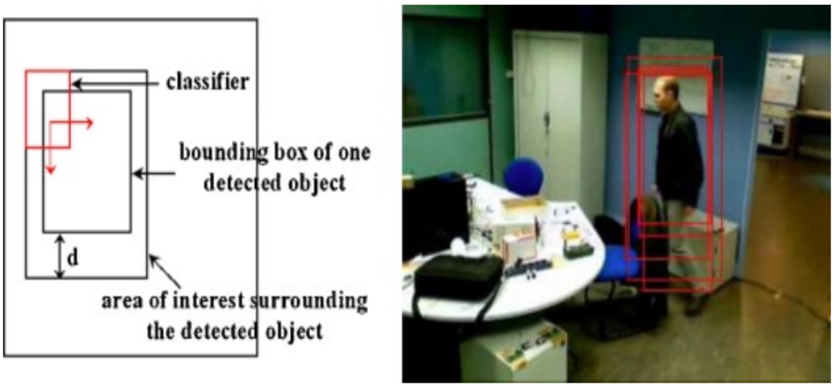

Figure 2.7.2: From the left to the right: search area analyzed by the classifier and resulting multiple detections. Source: [8]

To verify the system, the author did the following experiments. In the experiment, the author sampled data in the following three cases based on the actual situation. First, in a regular room, such as an office or a meeting room, in this scene there are multiple static or moving people, they are standing or sitting in the room. Secondly, in a corridor, there are some people walking through. Finally, the scene contains some abnormal variables, such as lighting changes or moving objects. The author uses a camera with a resolution of 320x240 for testing and averages the quality of the data from different locations. The results are shown in Figure 2.7.3, Figure 2.7.4, and Figure 2.7.5. The experimental results show that the method can have a detection rate almost over 97 %.

Figure 2.7.3: Result in a meeting room with some people sitting and standing. Source: [8]

Figure 2.7.4: Result in a corridor with some people walking through. Source: [8]

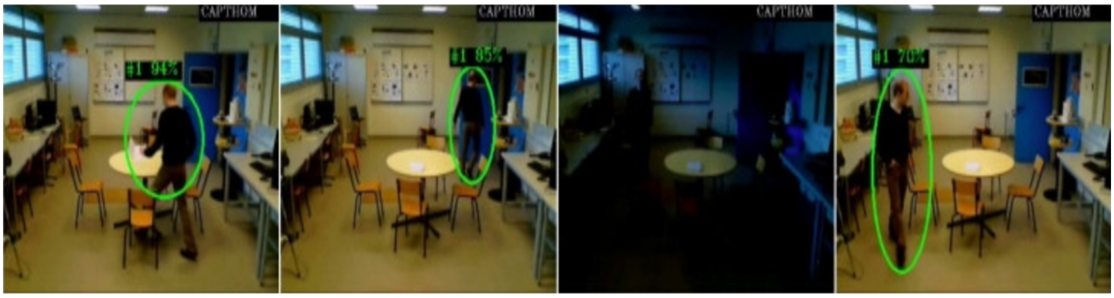

Figure 2.7.5: Result in a library with lighting changes. Source: [8]

In summary, sensing using visible light processing technology plays a great role in the field of indoor human positioning. It has high accuracy and strong anti-interference, so it is widely used in the commercial field. However, due to its violation of user privacy, it is used less in the home environment.

2.8 Capacitive Sensing

Capacitance is an indispensable physical quantity that makes up the electronic world and can be seen in almost all circuits. In common circuits, capacitors play tasks such as bypassing, decoupling, filtering, and energizing, and later it was found that some information could be transmitted by using the principal characteristics of capacitors, because the size of the capacitor was determined by the corresponding area and distance of the substrate in principle. In particular, the measurement of small capacitors has become the main way of human-computer interaction, and people replace old buttons through touch screens, such as smart touch mobile phones, computers, etc.

In the field of indoor human body localization, scientists use the characteristics of capacitance to do this job, this technology is mainly to use the capacitance change between two or more electrodes: the size of the capacitor is determined by the area and distance of the conductor, fixing a known electrode conductor in the scene, while using the human body as another conductor, when people move indoors, due to changes in distance, the capacitance between the human body and the known conductor will change, using this we can locate and track the target person in the room.

In [9], the authors used capacitive technology to design an indoor human monitoring system. In the system, the authors used Ardunio Uno as a controller responsible for receiving and processing the data returned by the sensor, using tin foil as a known electrode conductor, while several capacitive sensors were formed into an array placed on the floor of the experimental area, and in order to increase the concealment, a large blanket was covered throughout the experimental area. At the same time, several LED small lights and buzzers are used as alarm devices for abnormal situations as shown in Figure 2.8.1.

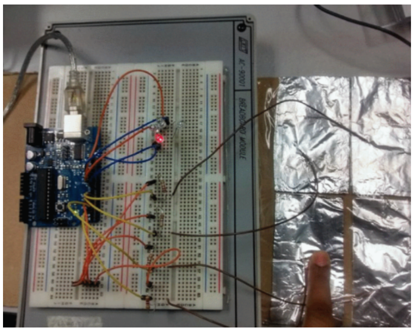

Figure 2.8.1: Schematic of the system. Source: [9]

In the algorithm section, the entire system operates in a cycle-cycle pattern in which the controller checks the electronic signals at each pin. The entire capacitive sensor is equivalent to a variable capacitance. And the human body is equivalent to a conductor, when the human body is close or away from the capacitive sensor, the sensor is being charged or discharged, at this time the capacitance that sensor returned to the controller is becoming high or low, so we can use this kind of changes to monitor on the target person as shown in Figure 2.8.2.

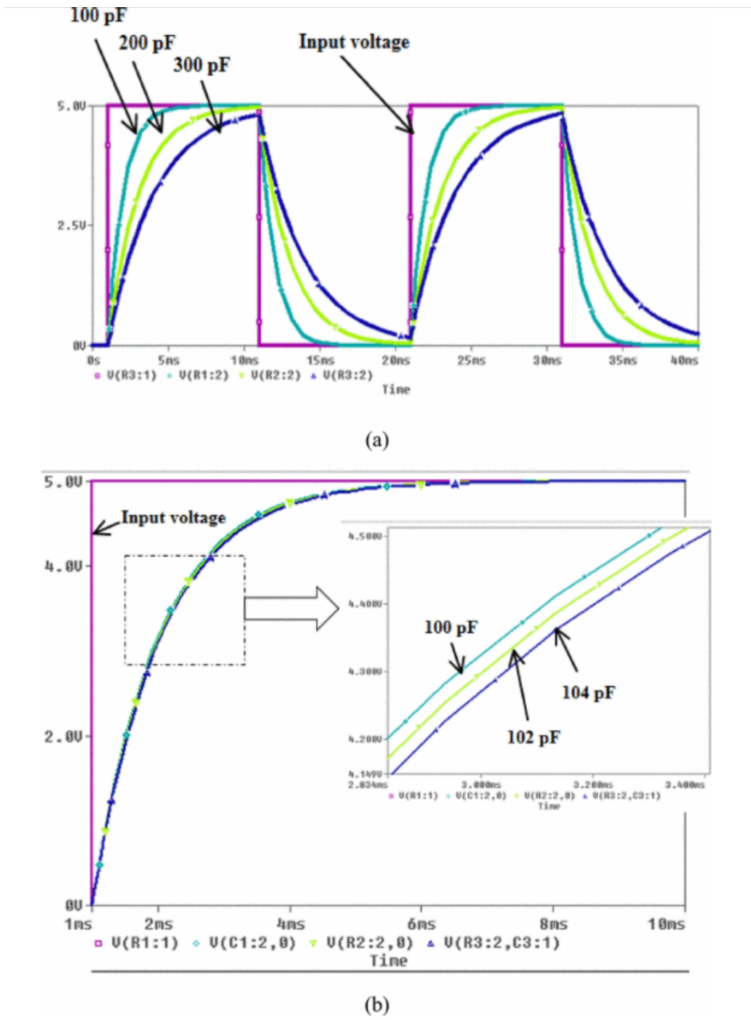

Figure 2.8.2: Simulation results indicating the presence of a human body (a) Larger capacitance variation, (b) small change in capacitance. Source: [9]

To verify the conclusions, the authors did the following experiment: the sensors were connected by an Arduino UNO control unit, which was represented by four sheets of aluminum foil. The sensor uses R = 10 MΩ resistance, the dynamic range of the capacitor is controlled between 100-400 pF, and finally the experimental results are expressed by measuring the voltage as shown in Figure 2.8.3. The experimental results show that when the target person is active in the experimental area, the system gives the correct voltage feedback, and at the same time, the target person can be located based on the position and feedback information of the sensor.

In summary, Capacitive Sensing is a good technique for indoor person localization. It has a low price, small power consumption and strong adaptability. So, it is very suitable for installation in small rooms, can contribute to the field of home health monitoring.

2.9 Pressure Sensing

Pressure is a force that humans can feel directly, and there are many sensors that use pressure in life, such as the electronic scales we commonly use. In the field of indoor human positioning and tracking, scientists have also tried to use pressure sensors to make systems. The principle of the system is very simple, that is, by converting the pressure of the human body into electrical signals. The processor then processes and calculates the signals to locate and track the target person indoors.

In [10], the authors designed a high-resolution human body positioning and tracking system that can realize the positioning of the target person and the recording of the trajectory of the movement. The system consists of 16 distributed pressure sensors, each pressure sensor is 500 mm square, and contains 4096 pressure switches distributed in a 64x64 array as shown in Figure 2.9.1.

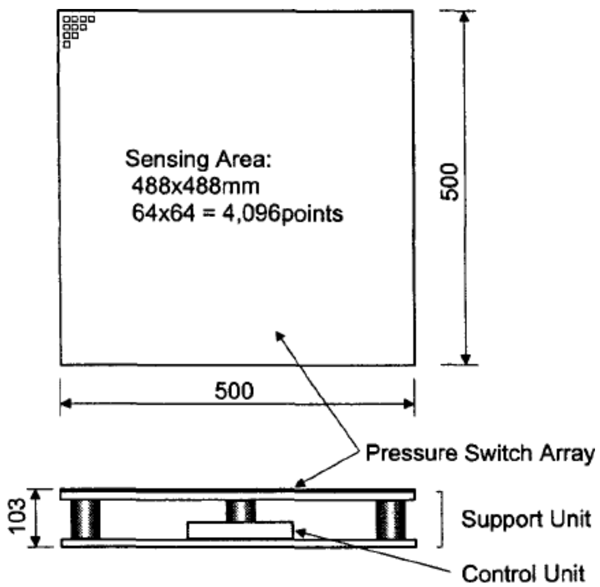

Figure 2.9.1: Structure of Pressure Sensor Unit. Source: [10]

The entire system includes: a pressure switch PCB (Printed Circuit Board) which detects the pressure distribution; a support unit to hold the switch PCB; a control unit to control the switch PCB as shown in Figure 2.9.2 [10].

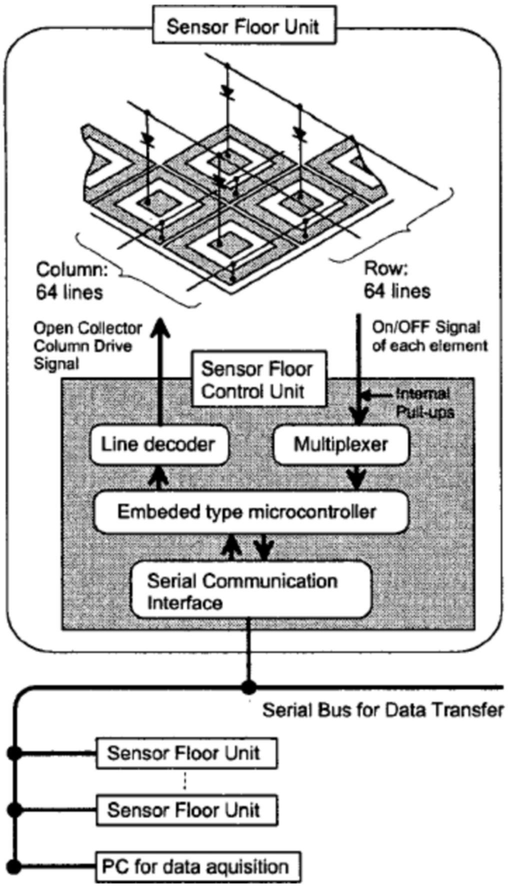

Figure 2.9.2: Structure of the Sensor Unit Controller. Source: [10]

Electrical interference is a very important influencing factor in the system during the experiment, and the authors apply diodes here, which can be solved at a very low cost by placing diodes at each node.

The controller consists of an embedded type of microcontroller, 64 bits open collector line decoder, 64 to 8 demultiplexer and other peripherals. During the experiment, the line decoder first selects a line to work, reads the data at a speed of 8 bits at a time, and sets a high level on the register, so when the system detects pressure, the logic level of reading is high. Conversely, it is low [10].

To verify the conclusions, the authors did the following experiment: The authors set 16 of the above pressure sensors on the floor to form a 2 x 2 m experimental area as shown in Figure 2.9.3.

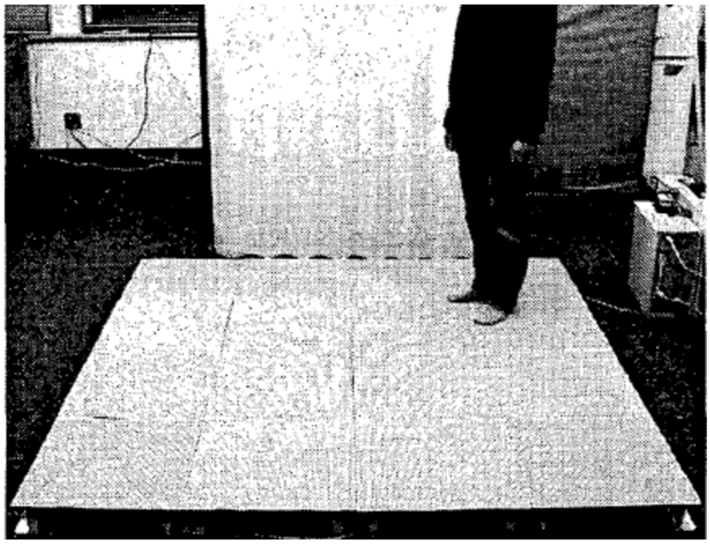

Figure 2.9.3: System Made with 16 Sensor Units. Source: [10]

In the experiment, the target person walks in the experimental area as shown in Figure 2.9.4, the author also tested the performance of the four-wheeler in the experiment, which was also verified. Through experiments, the system achieved positioning and movement monitoring of target people with a resolution of 7 mm.

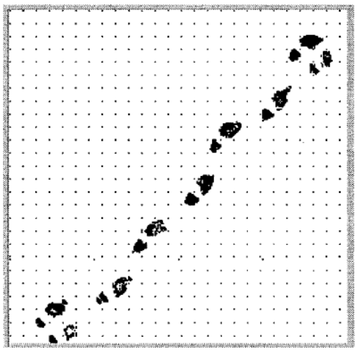

Figure 2.9.4: Images when people walking. Source: [10]

In summary, Pressure Sensing is a good technique for indoor person localization and tracking. It has a high resolution, can accurately locate and track movement, and its immunity to disturbances is very strong.

Chapter 3

Processing Techniques for Indoor Person Localization

3.1 Time of Arrival (TOA) Processing

Time of Arrival (TOA) is a common method in the positioning system, which refers to the time it takes for the signal to depart from the signal transmitting device and arrive at the signal receiving device. There can be many kinds of signals here, such as light and sound, and since the speed at which these signals travel through the air is known, we can multiply the speed by time to get the distance. The simplest application is a single-device radar positioning device as shown in Figure 3.1.1.

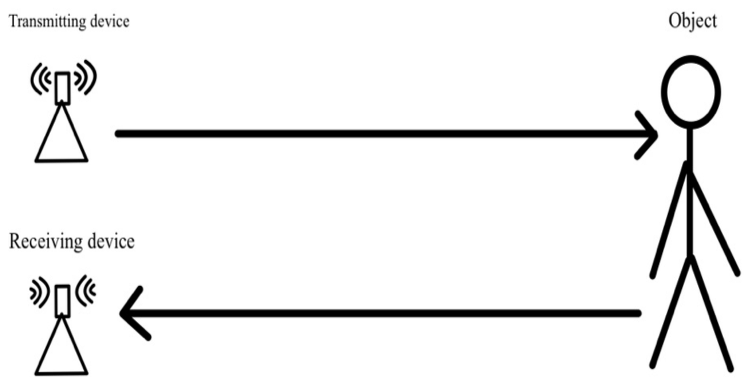

Figure 3.1.1: Schematic of Single-device radar device.

In the previous step, we can already obtain the distance from the measuring device to the target body, to achieve a specific target positioning, we can establish a two-dimensional coordinate system on the plane, and deduce the position of the target through three known test points as shown in Figure 3.1.2.

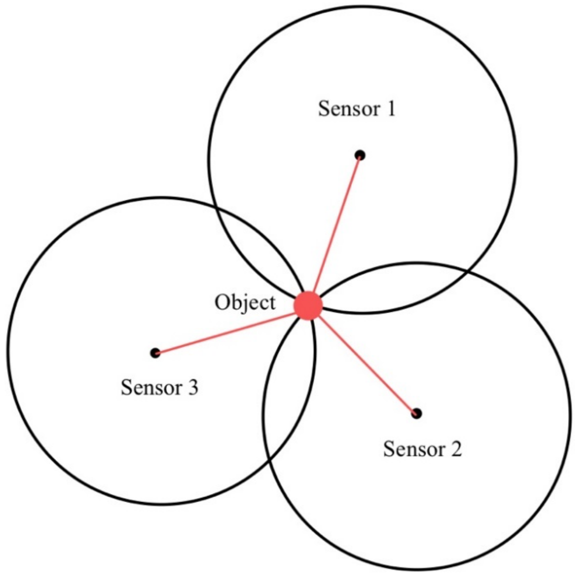

Figure 3.1.2: Schematic of target location estimation based on TOA.

We can form a system of equations based on the distance between the target and the three sensors, using the standard equations of three circles, and have a unique solution without considering noise interference and systematic error. Therefore, we can achieve the positioning of the target body in two-dimensional coordinates.

Also using the relationship between the distance and speed and time of signal propagation, Time Difference of Arrival (TDOA) locates by measuring the signal propagation time difference of different signal sources, compared with TOA, TDOA is calculated with time difference rather than absolute time, so the low requirements for time synchronization reduce the requirements of the system, and the accuracy will be better.

Time of Arrival (TOA) Processing is a very intuitive method that is often used in indoor person localization systems, for example Ultrasonic Sensing technology, Radar Sensing technology, Ultra-Wide Band Radio Sensing technology, etc. Its error mainly comes from signal transmission, such as the signal is obscured by obstacles in the environment, or the signal is drifted by other signal interference.

3.2 Received Signal Strength Index (RSSI) Processing

RSSI indicates the strength of the signal. In general, the larger the RSSI, the stronger the signal. The localization system based on RSSI is mainly designed by using the principle of regular attenuation of radio signals with the increase of distance. Based on the mathematical model, we know that in a stable environment, the value of the RSSI of the signal changes with distance is like the lognormal model

$$RSSI = a * Log (Distance) + b.$$

where a and b are related to the type of antenna of the device and the environment in which they are located, the values of a and b can be determined in reverse by specifying a known distance, and then the relationship between RSSI and distance can be found. In the indoor person localization system, there are two conventional methods.

One method is to match different RSSI values to different locations in the room based on the different RSSI values of the equipment in different places in the room, and then determine the position by measuring the RSSI value of the mobile terminal. This method is usually carried out using a trilateral measurement method, as shown in Figure 3.2.1. This method usually requires the target person to carry a device that can measure the value of RSSI of the device, and there are certain requirements for the target person in the application.

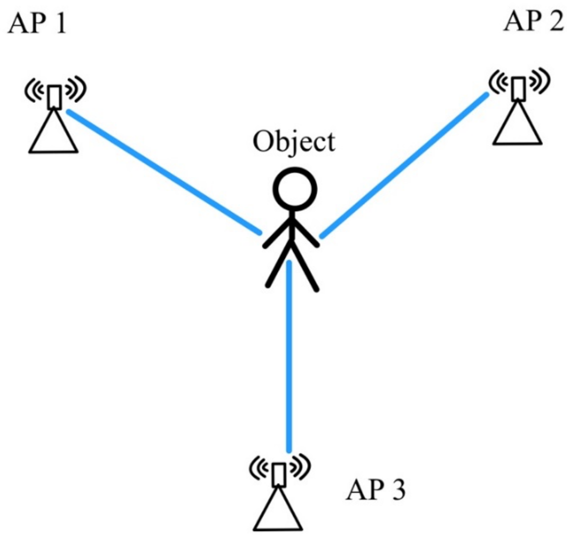

Figure 3.2.1: Schematic of a trilateral measurement method.

Another method is to locate and track the target person based on the principle that the movement of the target person indoors will affect the RSSI value of the device, based on the difference in the magnitude, frequency, and time of change of the RSSI. In this way, the system can be trained with multiple sets of data through machine learning, which can greatly improve the accuracy. This method is always used in Tagless indoor person positioning system.

RSSI signal is essentially a wireless signal, like other wireless signals, in practical applications, RSSI signal will be affected by many factors such as signal reflection, signal scattering, signal diffraction. The effect of reflection is the worst, because multipathing effects can occur, which greatly affect the stability of the received data. We can solve this problem by adjusting the transmit power of the device, but at the same time we need to consider the power consumption of the device.

3.3 Image Processing

Image-based positioning technology is currently the most popular method on the market, and it is widely used in areas such as security surveillance. Image processing technology relies on sensors that can get images, such as cameras and thermal imaging sensors. The commonly used localization method is using two cameras to locate, mark a certain feature point of the target body, obtain the relative position of the target body in two different positions of the camera, and then infer the precise position of the target body through geometric methods.

The most important step in image processing in indoor person localization systems is to subtract the background from the complex image information so that the target person can be highlighted. One approach is to assume that the background of the observed sequence of images is fixed, by setting the original object without moving objects or by processing the photograph through a time median filter [11], but this method is not suitable for scenes with undetermined moving objects in the background.

Another approach is to model each pixel of the background using the Gaussian probability density function, [8] differentiating target bodies with the same characteristics by generating new components. A similar approach is the Gaussian Mixture Model, which utilizes multimodal PDFs [12][13].

Image Processing can provide users with an informative positioning, but it also violates the user's personal privacy.

3.4 Capacitive Sensing Processing

Capacitive Sensing technology mainly uses the capacitance change between two or more electrodes and conductors to work: fixing one electrode conductor in the scene, while using the human body as another conductor, when people move indoors, the change in distance makes the capacitance between the human body and the conductor change, using this to locate and track the target person indoors.

The most important thing in Capacitive Sensing Processing is to obtain an accurate measurement of the capacitance between the target and the electrode conductor, which requires the effects of noise to be eliminated as much as possible. In [14], the authors use a 555-based RC oscillator, which allow the frequency of the system to be related to the distance of the person from the device. They measured the oscillation frequency once per second, and the experiment was successful. But the time to obtain the position each time was long and the system's noise filtering ability was not good, so the error of the experiment was relatively high.

In [15], the authors designed a Caching-Sensor Front-End Interface that cleverly eliminates some of the DC offsets, while adopting a zero-mean additive white Gaussian (AWGN) and a narrow band, using 4^{th} order Butterworth bandpass filter removing the thereby with additive noise. The experimental results show that the stability of the system is good, and the show good sensor sensitivity up to 200 cm for a 16 cm square sensor plate.

Chapter 4

Sensing Technique Comparison

4.1 Accuracy

Accuracy is an important factor in evaluating indoor human localization systems. It represents the degree to which the mean value measured multiple times under certain experimental conditions corresponds to the true value. It is calculated by dividing the number of samples that successfully detected or locate a person in the experiment by the total number of samples. Here, the location means associating the position of the person with a specific area (e.g., [2] associate the position of the person using green square in thermal map) or confirm a specific position of people in test area [10].

In [17], a HOG+IKSVM system use a multi-level version of the HOG descriptor and use histogram intersection kernel SVM based on spatial pyramid match kernel reached a detection accuracy to almost 90 %, and [8] combines background subtraction reached an accuracy almost 97 %. The average detection accuracy of Sensing Using Visible Light has reached about 95 %. And for Pressure Sensing, [10] uses 16 distributed pressure sensors reaching 95 % with 7 mm resolution.

Some Radar [5] techniques can reach 97 % when increasing the transmission power. Neural Networks can effectively classify the Doppler signals and reach an accuracy of 91 % [18]. An ANN identifier can reach accuracy between 82.5 % and 100 % [19]. The average accuracy of the Radar sensing is around 91 %.

UWB sensing can theoretically have a high degree of accuracy, but as the hardware requirements are not fully met by the experimenter, it does not play an absolute advantage in the test. [7] solves the mutual shadowing effect and improve the accuracy of the system. [20] employing the data fusion method to do person short range tracking and got very good result. The average accuracy of UWB sensing is about 90 %.

For Wi-Fi sensing, [4] extracts effective features from the wavelet coefficients and reached an accuracy about 85 %. [21] analysis Principal Component Analysis (PCA), Wavelet Transform (DWT) and Dynamic Time Warping (DTW) and reached an accuracy about 88.9 % to 94.5 %. A Fresnel Zone model can achieve a median absolute error of 10° for direction [22]. The average accuracy of Wi-Fi sensing is about 87 %.

For Infrared sensing, [23] using very cheap sensors array reached accuracy between 70 % to 80 %, [2] made distinction map to distinguish between humans and backgrounds and reached an accuracy range 41.2 ± 28.4 % this large variation is caused by the increase in the number of target people. When the number of people exceeds 5, the accuracy rate will drop a lot. When the number of people in the system is small, between 1-3, the accuracy rate of the system is up to 69.6%. [24] obtains 4 × 4 pixels thermal distributions and reached an accuracy range from 41 % to 100 %. The average accuracy of Infrared sensing is about 82 %.

Ultrasonic sensing reaches an average accuracy of 80 %. [25] using several ultrasonic sensors detect person by analysis the location of head and reached an accuracy about 78 % within an error of 54 mm. [3] using time difference between the first and second reflections to track the indoor human body reached an accuracy about 82 % with a median error of 0.08 m.

Capacitance sensing relies heavily on the design of the circuit, [15] using a Caching-Sensor Front-End Interface and shows very good accuracy results, [9] improving the system and reached an accuracy about 83 %. The average accuracy of Capacitance sensing is about 82 %.

For Zigbee sensing, [6] using NMVPC and EPC method and reached an accuracy around 60 %, [26] using multi–Blind Node model and reached an accuracy around 70 %. The average accuracy of Zigbee sensing is about 65%.

Without considering other issues, from the perspective of accuracy alone, the ordering of techniques above is:

Sensing Using Visible Light > Pressure Sensing > Radar Sensing > UWB > Wi-Fi sensing > Infrared Sensing > Ultrasonic Sensing > Capacitance Sensing > Zigbee Sensing.

4.2 Privacy

Privacy is an important factor in indoor person positioning systems, as the environment may be used in an individual's home, including living rooms and toilets, No one wants their private space to be closely monitored. Sensing Using Visible Light, such as cameras, can directly capture photos and videos in the environment, so they are not suitable for the environments where privacy is emphasized. Other technologies mentioned in this work, such as the way using electromagnetic waves and infrared, can greatly protect the privacy of the person being monitored.

4.3 Power Consumption

Power Consumption refers to the amount of electrical energy consumed by the device during normal operation. In the context of green and low-carbon mainstream, low-power devices are becoming more and more popular with consumers. Moreover, high-power devices also mean more heat generation which can cause drift of electronic components parameters, resulting in a decrease in the accuracy of the system, and even causing irreversible damage such as breakdown, reducing the service life of the equipment.

The power consumption is related to the working principle of the device. For example, power consumption of infrared sensors is usually smaller than the power consumption of Camera. The difference is determined by technical reasons, so we must choose the best technology based on the requirements of the specific scenario when designing the system. Typically, the power consumption of sensors of several sensing techniques in active state is shown in Table 4.3. This is the maximum power consumption when sensor work in active state, the average working power consumption can be greatly reduced by using sensor with very low duty cycles.

Table 4.3 Power Consumption of several techniques in active state.

Sensor	UWB Sensor	Camera sensor	Radar Sensor	Ultrasonic Sensor	Wi-Fi Sensor	ZigBee Sensor	Infrared Sensor
Power Consumption of each sensor	25 mW	150 mW	125 mW	30 mA	220 mW	50 mW	15 mW

4.4 Cost

Cost is relative. The same technique used with different sensors will have different results, because it is related to many factors, such as technical difficulty, yield rate and supplier's monopoly. Even if the same sensor is used, the number of sensors can also affect the accuracy rate and thus the price. For example, in UWB sensing, the use of multiple devices will significantly improve the accuracy. Here are only compared the mainstream procurement methods, such as Amazon and some distributors from the perspective of experimentation, and got the following table:

Table 4.4 Cost of several sensors.

Sensor	UWB Sensor	Camera sensor	Radar Sensor	Ultrasonic Sensor	Wi-Fi Sensor	ZigBee Sensor	Infrared Sensor	Pressure sensor	Capacitance sensor
Average Cost	$180	$80	$50	$200	$18	$13	$20	$8	$10

4.5 Size and Installation Effort

Size and Installation Effort is a problem that cannot be ignored in the indoor human localization system because the indoor space is limited, and we must reasonably arrange the location of the equipment and consider the overall aesthetics and concealment. At the same time, it is necessary to consider the difficulty of installation, such as Pressure Sensing, which requires changing the floor, so it is not suitable for many existing houses. The size of the sensors is typically small. Table 4.5 reports the typical dimensions of several sensor types.

Table 4.5. Size of several sensors.

Sensor	UWB Sensor	Camera sensor	Radar Sensor	Ultrasonic Sensor	Wi-Fi Sensor	ZigBee Sensor	Infrared Sensor
Average Size	20*10*3 mm	20*10*10 mm	20*15*8 mm	150*10*10 mm	30*20*10 mm	20*20*10 mm	20*40*10 mm

The installation of these sensors can be divided into three types:

On the ceiling:

Infrared Sensing: Infrared sensor can be installed in the central area of the ceiling of the room with a certain height, and the sensor's sensing range is a cone with the sensor as the fixed point. The installation complexity of infrared sensor is low because there is no need to change the structure of the house, and it is suitable for many existing houses. For example, in [2], the sensor is installed in the ceiling of the office at a height of 2.7 m.

Sensing Using Visible Light: The sensor of this technique can be installed around the ceiling, because this sensor has a good sensing distance, the sensor installation complexity is low, we do not need to make special modifications to the room, so it is suitable for most existing rooms. For example, in [8], the camera is installed in the one side of the ceiling of the meeting room, one side of the ceiling of the library, and on the ceiling at the end of the corridor.

ZigBee Sensing: The positioning system using ZigBee is usually composed of a set of sensors. They are usually installed at a certain distance around the ceiling. The installation complexity of the sensor is low, we do not need to make a special modification of the room, so it is suitable for most of the rooms. For example, in [6], the 42 reference nodes sensors and 3 blind nodes sensors were installed on all sides of the ceiling of the room, covering the path that a person might pass through.

Wall-mounted:

Ultrasonic Sensing: The Ultrasonic sensor can be installed on the wall around the house, near the height of the human body, and as far away from the furniture as possible, the installation complexity of the sensor is low and it also can be moved easily, so it is very suitable for layout in existing rooms. For example, in [3], the sensor is installed on the one side of the opposing wall.

Capacitive Sensing: The Capacitive sensor can be installed on the side of the wall that near the person, near the height of the human body, the installation complexity of the sensor is low and can be moved, which is very suitable for layout in existing rooms. For example, in [15], the sensor is installed near the wall on the table with a height near the height of human body.

Wi-Fi Sensing: The Wi-Fi sensors can be installed around the wall of the room, the installation complexity of the sensor is low and can be moved, which is very suitable for layout in existing rooms. For example, in [4], the three sensors were installed in three different corners of the office.

Radar Sensing: The Radar sensor can be installed around the wall of the house and try to keep the antennas in an open place, the installation complexity of the sensor is low, and the system also can be moved, so it is very suitable for layout in existing rooms. For example, in [5], the sensor is installed on the table which near the wall of the room.

UWB Sensing: The UWB sensors can be installed around the wall of the house and try to keep the antennas in an open place, the height is also important, when the sensor is installed too low, person's shaking legs can have an impact on the accuracy of the system. The installation complexity of the sensor is low, and the system, so it is very suitable for layout in existing rooms. For example, in [7], the two UWB sensors are installed on the desk near the wall with a height around 1 m.

Floor-mounted:

Pressure Sensing: The Pressure sensor needs to be installed on the floor of the room, this method requires the use of a special floor or make the pressure sensors cover the floor, the installation complexity of the sensor is high, and the room needs to be renovated. For example, in [10], the 16 distributed pressure sensors were installed covered the floor.

4.6 Noise Immunity

Noise Immunity is primarily related to the sensing technique. I evaluate several sensing methods based on the Noise Immunity, denoted by noise rejection level. It is ranged from 1 to 5, the higher the level the better the noise rejection capability this technique has for the main interference factors:

Level 1:

Infrared Sensing: this is because sensors are often affected by other heat sources in the room, such as sunlight, various heating devices, and pets. In [2], the experimental area is the office, when they draw the distinction map, the author needs to consider the heating of the floor by the sunlight near the window, the heat of the PC and printer on the table, and the heating of the seat when the person leaves the chair, these all influence will break down the accuracy of the system.

Level 2:

Ultrasonic Sensing: Ultrasonic sensors need to receive reflections from the target body, which will be affected by other furniture or walls in the room. In [3], the author did the experiment between two opposing walls, if a furniture like a chair is placed between the walls, then in the static experiment, the system will mistakenly identify the reflection of the chair as a person, and during the dynamic experiment, the trajectory of the person tracked by the system will jump and offset in the furniture position, which will have a great impact on the results of the experiment.

Capacitance sensing: The inductive capacitance of the human body is affected by the temperature, humidity, and conducive bodies in the room. In [27], the author shows the effect of the humidity of the surrounding atmosphere on capacitive sensors by test the sensor results for different humidity.

Level 3:

Sensing Using Visible Light: the lighting intensity of the room and the moving objects of non-targets can have impact. In [8], the author did an experiment in the library, when the light of the library is off, the system cannot recognize target person in such a low light, and in the office experiment the system can recognize moving person, but if there some object with similar characteristics like robots, the system may have mistaken.

Radar Sensing: walls and furniture can interfere with the propagation of electromagnetic signals. In [18], The authors found that some variables in the environment such as furniture, moving objects, etc. will have certain changes in the Doppler waveform, which will affect the results of the experiment.

ZigBee Sensing: drift and signal multipathing are the main influencing factors. In [6], when the system's estimation of the blind node position is unstable, then in the positioning program, the position of the target will drift from one place to another, which makes the positioning system shows a wrong result.

Level 4:

Wi-Fi Sensing: walls and furniture can interfere with the propagation of electromagnetic signals. In [21], the system detects the phase difference between the sinusoidal instantaneous amplitude waveforms of different receiving antennas to detect the target person, and when furniture that can affect signal propagation appears in the environment, the received signal of the antenna changes, affecting the results of the system

Level 5:

UWB Sensing: The mutual shadowing effect is the main influencing factor. In [7], when a moving object appears near the antenna, it will produce a relatively large dead area in the monitoring area, and in this time the system wants to locate a target person is in this area, the UWB system will not detect that target person.

Pressure Sensing: Furniture and weighty objects such as pets can cause the system to make mistakes. In [10], the experiment shows that weighty objects on the sensor will incorrectly triggers the switch, the system may not recognize the difference between the target person and weighty objects, then will show a wrong result.

4.7 Activity Detection

In the indoor person localization system, we not only need to know the location of the person, but sometimes we also need to know the behavior of the monitored person, such as in medical monitoring, we need to record the behavior to conduct a more comprehensive analysis.

Sensing Using Visible Light does best in activity detection. It can provide data information by recording photos and videos. The main method is recognizing the regions of interest in a video scene, tracking and analyzing the trajectory of a target person to do activity detection. [28] detect activity using trajectory analysis. First, they reconstructed and represented target trajectories to symbol sequences (the target person suddenly accelerates and runs, or one target person suddenly approaches and overtakes the second target person), and then they use Markov model to build the transition probability matrix, this matrix may help to analyze the behavior of target person, last detected the behavior by voting the results come from individual camera nodes. This method shows a high detection rate of 93.7 %.

Infrared Sensing can analyze the activity of the target person based on the change in heat. [23] detects the activity by recognizing the temperature change based on the events (e.g., the target person opening the refrigerator, the target person cooking the meal, the target person taking a shower). First, recognizing the time independent and time dependent, then generate feature vectors (e.g., maximum of the temperature change in the segment, mean and maximum of the temperature in the segment, position of the largest temperature difference), last detect the activity by fusing the parallel events. The experiment shows an accuracy between 70 % to 80 %.

Ultrasonic Sensing can analyze the speed of the target person based on the frequency change of the return signal, [29] used customized multiple ultrasonic sensors to detect activity. First, pre-processing the ultrasonic signal based on the features of the environment, then identifying the primary activities to classify data into known labels or state (sitting, standing, or walking) for machine learning, here the author use Decision Tree, last, recognizing the activities through some features using Hidden Markov Model (HMM). The experiment has achieved a high activity recognition accuracy up to 90 %.

Wi-Fi Sensing can analyze the behavior of the target person based on the change of the RSSI and CSI signals. [30] quantitatively correlate CSI dynamics and human activities, in the experiment, they use CSI-speed model and CSI-activity model to detect the activity, first model quantifies the correlation between the dynamic CSI and the speeds of movement, and the second model quantifies the correlation between the movement speeds of different human body parts and a specific human activity. The experiment shows an accuracy of 96 %.

Radar Sensing can analyze the behavior of the target person based on the change of the electromagnetic signal. [31] use a multi-dimensional feature learning method to detect activity. First, they get the spectrums of range-Doppler, Doppler, the azimuth angle, and the elevation angle based on the reflection wave from the target body, then use fixed frame-length sliding window method to represent the activity of target body, last use convolutional neural network (CNN) to improve the system. The experiment shows an accuracy range from 86.7 % to 91.7 %.

4.8 Summary

Each technology has its own advantages and disadvantages, and the designer of the system needs to combine the actual situation and select the required technology and technical parameters based on the different requirements of different cases. Table 4.8 summarizes the main findings.

Table 4.8: Comparison of Sensing Techniques

Technique	**Infrared sensor**	**Ultrasonic**	**Camera**	**Capacitance**	**Wi-Fi**	**Radar**	**ZigBee**	**UWB**	**Pressure**
Measurement Principle	TOA	TOA	Image process	Capacitance & voltage Calculation	RSSI/ CSI/ AOA/TOA	TOA / AOA	RSSI / AOA / TOA	TOA	Pressure
Accuracy of detect people [note 1]	70% ~ 90%	78%~ 85%	92% ~ 95%	70% ~ 80%	85% ~ 90%	90 ~ 97%	60% ~ 70%	85% - 95%	90 ~ 95%
Privacy	Good for low resolutions	Good	Bad	Good	Good	Good	Good	Good	Good
Installation Difficulty	Easy (Ceiling)	Easy (Ceiling / wall)	Easy (Ceiling / wall)	Easy (wall)	Easy (wall /desk)	Easy (wall)	Easy (Ceiling / wall)	Easy	Difficult (Need to rebuild the floor)

Power Consumption	Low	Low	High	Low	High	Low	Low	Low	Medium
Size of Sensor	Small	Small	Small	Medium	Small	Small	Small	Medium	Big
Activity detection	Hard	Hard	Easy	No	Hard	Hard	No	No	No
Noise rejection Level [note 2]	1 Sunlight, heat, pet	2 Object, wall	3 Light level, moving things	2 Air, temperature, conducive bodies	4 Wall, furniture	3 Wall, furniture	3 Multipath	5 Multipath	5 Furniture, pets
Cost (Sensor)	Medium	High	High	Low	Medium	Medium	Low	High	Low
Covered area per sensor	20 ㎡	15 ㎡	100 ㎡	5 ㎡	100 ㎡	150 ㎡	3 ㎡	50 ㎡	0.5 ㎡

[Note 1] Accuracy of detect people: It is calculated by dividing the number of samples that successfully detected a person in the experiment by the total number of samples.

[Note 2] Noise rejection Level: Range from 1 to 5, the higher level means the better noise rejection capability this technique has. (The main interference factor)

Analysis for Some Typical Application Cases

In the following are analyzed several use cases and the main trade-offs between the various techniques in these specific applications.

A first case is the need to monitor a single person living alone at home. This case is suitable for elderly people living alone or those who need medical care. Since the area is at home, privacy issue is important, so Camera Sensing is inappropriate. Second, the monitoring area is not large, so the UWB technique, Radar Sensing and Wi-Fi Sensing appear to be somewhat wasteful. Then, to improve the monitoring effect, we may need to understand some of the activities of the target person, Pressure Sensing and ZigBee Sensing may locate the indoor person, but they are weak in detecting the activity of a target body, so they are not suitable in this case. Extended exposure to ultrasound can cause harm to the human body, so Ultrasonic Sensing seems not suitable in this case.

So, in this case the most appropriate tracking and monitoring techniques are Infrared Sensing and Capacitance Sensing. UWB and Radar Sensing can also be used if needed by the specific application requirements.

A second case is when several persons must be monitored in public areas. This case is suitable for monitoring malls, public classrooms and conference halls, warehouses, etc. First, the public areas are typically large and with complicated environment usually with surface over 80 ㎡ and with several target bodies and other objects. Infrared Sensing is limited by the sensing range of the sensor, its suitable working area is around 8 ~ 20 ㎡, like [2] working in a small office so it is not suitable here; Capacitance Sensing is also limited in this reason, its suitable working area is 5 ㎡ like [9] working in a small room. Ultrasonic Sensing is not suitable due to the complex environment. Like in [3], with the increase of the target persons, the probability of ultrasonic waves being abnormally reflected increases, and the multipath impact of the signal is obvious, and the results are not good. Pressure Sensing needs to change the structure of the floor [10], but this may be impossible in such a case, so it is not suitable. Second, if the monitoring requires an understanding of the behavior of the target person, ZigBee sensing and UWB techniques may locate the indoor person, but they are weak in detecting the activity of a target body [6][7], so they are not suitable in this case. Finally, referring to the system performance in accuracy with which the system successfully detects and locate a person, camera and Radar sensing reached an average accuracy 95 % and 91 % separately [8][17][5][18] which are better than Wi-Fi sensing with the average accuracy of 87 %, so they are most suitable in this case.

Another use case is when it is required to monitor safety areas. This case is suitable for monitoring warehouses, industrial plants, garages, etc. Since there are security issues involved, the accuracy and reliability of the monitoring and detection is the most important. Can be ruled out the techniques with reliability and accuracy below 90 %. Considering that in this case the system may need to work in variable lighting conditions or even in the dark, the Camera, which is sensitive to ambient light, is not suitable. Second, the size of such use cases can be rather large, Infrared Sensing is limited by the sensing range of the sensor, its suitable working area is around 8 ~ 20 ㎡, like [2] working in a small office, it is not good to use a lot of sensors in one system to support the area, so it is not suitable here. So, in this case, UWB, Radar and Wi-Fi Sensing are the most appropriate. Pressure sensing can also be used if needed by the specific application requirements if we can change the structure of the floor.

Conclusion

This research focuses on analyzing several typical techniques for Tagless indoor person localization system.

Starting from the principle of each technology, I research the application of nearly fifteen years of the techniques in the field of Tagless indoor person localization system, compared them from several aspects such as Accuracy, Privacy, Power Consumption, Cost, Size and Installation Effort, Noise Immunity and Activity Detection, and obtained the following conclusions.

Infrared Sensing: is a technique which uses infrared radiation, it has an average accuracy around 82 %, very low power consumption, low cost. It can be easily installed in the middle of the ceiling. The main influencing factors are other heat sources in the room, such as sunlight, various heating devices, and pets. It can detect the activity of the target person based on the change in the time to heat up.

Ultrasound Sensing: is a technique which uses ultrasounds, it has an average accuracy around 80 %, low power consumption, high cost. It can be easily installed on the wall around the room. The main influencing factors are the reflection coming from other furniture, persons, or walls in the room. It can detect the activity of the target person based on the change of the reflection.

Wi-Fi-Based Sensing: is a technique which uses RSSI or CSI of the electromagnetic waves, it has an average accuracy around 85 %, high power consumption, medium cost. It can be easily installed around the wall of the room. The main influencing factor is that furniture and other objects may interfere with the propagation of electromagnetic signals. It can detect the activity of the target person based on the change of the RSSI and CSI signals.

Radar Sensing: is a technique which uses reflection of the electromagnetic waves, it has an average accuracy around 91 %, low power consumption, medium cost. It can be easily installed around the wall of the room. The main influencing factor is that furniture and other objects may interfere with the propagation of electromagnetic signals. It can detect the activity of the target person based on the spectrums change of Doppler signals.

Sensing Based on ZigBee Radio: is a technique which uses the electromagnetic waves, it has an average accuracy around 65 %, low power consumption, low cost. It can be easily installed at a certain distance around the ceiling. The main influencing factors are the drift and signal multipathing. It is weak in detecting the activity of a target body.

Ultra-Wide Band Radio Sensing: is a technique which uses electromagnetic waves, it has an average accuracy around 90 %, low power consumption, high cost. It can be easily installed around the room walls. The main influencing factor is mutual shadowing effect. It can detect the activity of the target person based on the change of signals.

Sensing Using Visible Light Processing: is a technique which uses Visible Light Processing, it has an average accuracy around 95 %, high power consumption, high cost. It can be easily installed on the ceiling. The main influencing factors are the lighting level of the room, and non-target moving objects can have an impact. It can detect the activity of the target person by analyzing the video or photos.

Capacitive Sensing: is a technique which uses the electrical capacitance, it has an average accuracy around 82 %, low power consumption, low cost. It can be easily installed on the side of the wall that near the target person. The main influencing factors are temperature, humidity, and conducive bodies in the room. It is weak in detecting the activity of a target body.

Pressure Sensing: is a technique which uses the pressure, it has an average accuracy around 95 %, medium power consumption, low cost. It is hard to be installed without changing the floor. The main influencing factors are furniture and weighty objects such as pets. It is weak in detecting the activity of a target body.

This research may help with the design of the Tagless indoor person localization system. It proposes the best technical options for three scenarios, depending on the possible scenario.

A first case is the need to monitor a single person living alone at home. This case is suitable for elderly people living alone or those who need medical care. In this case the most appropriate tracking and monitoring techniques are Infrared Sensing and Capacitance Sensing.

A second case is when several persons must be monitored in public areas. This case is suitable for monitoring malls, public classrooms and conference halls, warehouses, etc. In this case the most appropriate tracking and monitoring techniques are Sensing Using Visible Light Processing and Radar sensing.

Another use case is when it is required to monitor safety areas. This case is suitable for monitoring warehouses, industrial plants, garages, etc. In this case the most appropriate tracking and monitoring techniques are UWB, Radar and Wi-Fi Sensing.

To my family, they give me the strength to face difficulties.

To Prof. Luciano Lavagno and Prof. Mihai Lazarescu, they give me ideas when I met problems.

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