Analysis of Daily Application of Indoor Positioning Technology Based on TDOA

Shuhong Yi *

Department of Communication Engineering, Northeastern University at Qinhuangdao, Qinhuangdao, China

* Corresponding author: zhaoxr@stu.xmu.edu.cn

Abstract. As a matter of fact, under the background of the rapid development of the current communication field, positioning technology is an important and valuable research direction in recent years. At the same time, indoor positioning is a relatively new and popular research topic of positioning technology contemporarily. With this in mind, this paper proposes to apply TDOA (Time Difference of Arrival) positioning technology to the positioning of indoor personnel in actual scenarios. In addition, this study attempts to apply TDOA positioning technology to the practical problems of personnel search as well as rescue in disaster scenarios. According to the analysis, the feasibility of these schemes is systematically analyzed and discussed. Moreover, the current defects as well as prospects are demonstrated at the same time. Overall, these results shed light on guiding further exploration of positioning technology.

Keywords: Location technology, TDOA, Indoor personnel location.

1. Introduction

With the rapid development of mobile communication equipment and continuous breakthroughs in positioning technology, indoor positioning technology has made great leaps and has a tendency to be popularized in various industries. It will increase with people's demand for daily travel positioning, and it will also increase with the rapid development of various fields such as industry and commerce. For example, in places such as large shopping malls and office buildings, people will be troubled by complex indoor environments, and navigation based on indoor positioning technology can provide people with a very accurate and efficient experience. Users can use the navigation solution based on indoor positioning technology to easily find target stores, offices and products. This can greatly help users reduce time and effort to find the positioning target point. In addition, with the rapid development of IOT, industrial robots equipped with indoor positioning technology can also perform well in terms of performance. For example, through real-time positioning technology, users can realize the whole process of production tracking in industrial workshops, and industrial robots equipped with positioning equipment can provide real-time feedback on the position of products and other various data [1].

With the continuous development of indoor positioning technology, the current positioning solutions of indoor positioning technology include but are not limited to WiFi, Bluetooth, and infrared ranging. However, in different actual scenarios, complex indoor environments will interfere with positioning signals to a certain extent, making the final positioning results greatly affected in terms of timeliness and accuracy. In comparison, the TDOA positioning technology based on multiple base stations can obtain better anti-interference ability through modulation and demodulation, so the indoor positioning based on TDOA has become a research hotspot. As far as the positioning algorithm is concerned, Chan conducted in-depth research on the Chan algorithm. The Chan algorithm estimates the distance between each base station and each positioning device terminal through the quadratic weighted least square method, and has good positioning performance [2].

Based on the latest research results, Kim Jonghoek proposed a scheme based on TDOA target tracking filter to reduce the NLOS error in the clutter environment. The scheme is based on the wireless communication system of radio signal to track the moving target, and discusses how to reduce the NLOS error while tracking the moving target in only TDOA measurement. It is proposed

to track mobile communication devices based on TDOA measurements in an unknown mixed LOS/NLOS workspace, and the results show that the proposed filter significantly reduces the NLOS error of TDOA-only measurements while running fast. Xu and Zhang proposed an improved combined weighted TDOA indoor two-position positioning algorithm, which improves the positioning accuracy of edge targets in the positioning area. The key point of the method is to use the target position estimation result and its estimated Cramereau lower bound value, design the weight of two weighting steps, and obtain the final positioning result through the two-step combination weighting algorithm. The proposed algorithm effectively reduces the original The error of the combined weighting algorithm in locating objects located at the edge of the locating area.

Based on the excellent performance of TDOA technology in indoor positioning, this paper analyzes the application of TDOA indoor positioning technology in indoor navigation of large buildings and large-scale industrial production tracking scenarios. The basic principle of TDOA positioning is introduced, and the basic steps of TDOA positioning are explained in detail. Then, using actual application data, the positioning performance of TDOA indoor positioning in actual scene applications was analyzed in detail, and the excellence of TDOA indoor positioning technology in indoor personnel positioning was verified.

2. Theoretical Analysis of TDOA

2.1. The Basic Principle of TDOA

When it comes to indoor positioning, the TDOA-based approach is the most common one. The main content of this section is to introduce the basic principle of TDOA-based indoor positioning, which determines the position of the target point by measuring the signal arrival time difference between the target point and each base station [3]. This method usually needs to use at least three base stations to measure to obtain enough information to calculate the coordinates of the target point. The principle diagram of TDOA positioning is shown in Fig. 1.

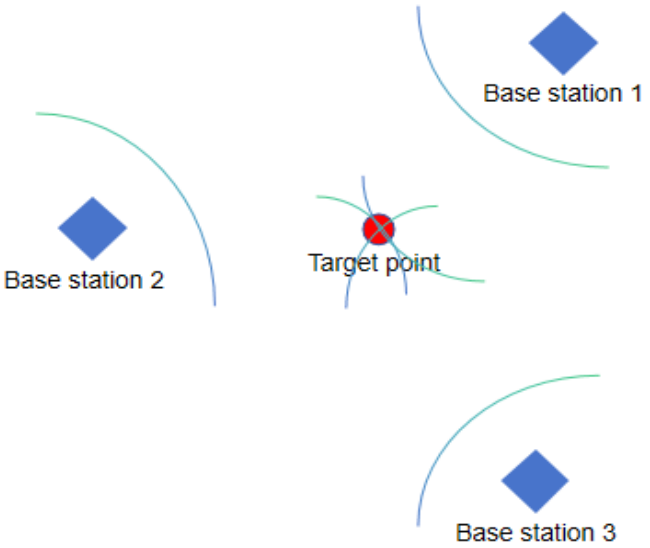

Figure 1. TDOA positioning.

The algorithm model and related positioning algorithm are two main parts, so this chapter briefly introduces the algorithm model and positioning algorithm based on TDOA indoor positioning technology. There are usually two positioning methods involved in indoor positioning, namely, a method that needs to measure a distance and a method that does not need to measure a distance. The method of measuring distance is used for positioning. First, the distance between the target point and each base station must be calculated, and then the coordinates of the target point to be measured are obtained by using the relevant algorithm. Using a method that does not need to measure the distance to perform positioning can rely on many kinds of information, such as the hop count of information

transfer nodes in the positioning network and the positional relationship between each node to obtain the coordinates of the target point to be measured. Generally speaking, there is no need to measure the distance for positioning. The whole process is relatively complicated and highly dependent on the use environment. In the method that needs to measure the distance, RSSI, AOA, TDOA and TOA are generally used to obtain the distance data between the target point and the base station.

The algorithm model of TDOA is to convert the time difference into a distance difference by measuring the signal receiving time difference between the positioning target and each known base station, and multiplying the time difference with the signal speed, thereby establishing one or more hyperbolic coordinate models . The hyperbola takes the positions of any two known base stations as the focus, and the positioning target point is located on a branch line of the hyperbola, and the intersection of the hyperbola and the hyperbola formed by any other two base stations is the positioning The estimated location of the target. The standard TDOA positioning process is as follows:

- Measure the signal reception time difference between the positioning target and the known base station;
- Multiply the received time difference by the transmission speed of the signal (usually the speed of light) to convert it into a distance difference, and then substitute it into a system of equations consisting of multiple hyperbolic equations;
- The equations are solved, and the final value obtained is the position estimation value of the positioning target.

Set the coordinates of the bit target as $(\mathbf{x}, \mathbf{y})$. The coordinates of the base station is $(\mathbf{x_i}, \mathbf{y_i})$, i = 1,2,3.... The distance from the target to the base station is $\mathbf{Q_i}$, i=1,2,3... Then, the distance difference can be expressed as$\mathbf{Q_{i,1}} = \mathbf{Q_i} - \mathbf{Q_1}$. Then according to the geometric relationship of the hyperbola, the system of equations shown in Equation 1 can be obtained:

$$\begin{cases} \sqrt{(\mathbf{x_2}-\mathbf{x})^2-(\mathbf{y_2}-\mathbf{y})^2}-\sqrt{(\mathbf{x_1}-\mathbf{x})^2-(\mathbf{y_1}-\mathbf{y})^2}=\mathbf{Q_{2,1}} \\ \cdots \\ \sqrt{(\mathbf{x_i}-\mathbf{x})^2-(\mathbf{y_i}-\mathbf{y})^2}-\sqrt{(\mathbf{x_1}-\mathbf{x})^2-(\mathbf{y_1}-\mathbf{y})^2}=\mathbf{Q_{i,1}} \end{cases} \quad (1)$$

In the equation system Eq. (1), $\mathbf{x_i}$, $\mathbf{y_i}$, $\mathbf{Q_{i,1}}$ are known values. Therefore, the result obtained after solving the equations is the estimated coordinate value of the positioning target [4].

2.2. Theoretical Analysis of TDOA Positioning in Large Indoor Places

The equipment of the indoor positioning system mainly includes a location information integration server, multiple indoor base stations, and mobile communication equipment of users. The user's mobile communication device is used to receive the positioning signal sent by the base station, and feed back its own position information to the base station. Each indoor base station sends and receives positioning signals to the user's mobile device, measures the transmission time and signal strength of the signal, and sends this type of information to the location information integration server. The server estimates the position of the mobile terminal through the transmission time and signal strength of the signal. After the final result is obtained, it is sent to the user's mobile device through the base station, and finally meets the user's use requirements. In large shopping malls, users want to go to the target location through mobile phone navigation. First, the user searches for the target location on the mobile phone for navigation, and then the base station receives the location information of the mobile phone and sends the user's location and target location to the server, and the server will plan the optimal navigation based on the user's location and the indoor map model Finally, the mobile phone will guide the user to the target location, thus completing an indoor positioning and navigation.

In the intelligent logistics delivery workshop, the staff who want to track the location of the goods only need to load a positioning device on the intelligent delivery robot. Similar to the above, the signal interaction between the positioning device, base station, and server will quickly display the location

information of the robot's cargo to the staff, so that the staff can visualize and control the operation process of the entire workshop.

3. TDOA-based Indoor Personnel Positioning System

3.1. Classic Positioning Algorithm

The Taylor series expansion method is a recursive algorithm that needs to determine the initial position of the target point, so this algorithm is often used in combination with other algorithms. The Taylor series method is to determine the real coordinates by continuously correcting the estimated value of the coordinates of the target point by infinite approximation. This method must choose an appropriate initial point, otherwise there may be a situation where it cannot converge. Let the coordinates of base station i be $(\mathbf{x_i}, \mathbf{y_i})$, distance is $\mathbf{d_i}$. According to the distance between the target point and the base station, the following equation can be obtained:

$$d_i = \sqrt{(x_i - x_{tag})^2 + (y_i - y_{tag})^2} \tag{2}$$

Simplifying and yielding:

$$\mathbf{k_i}^2 = \mathbf{x_i}^2 + \mathbf{y_i}^2 \tag{3}$$

$$d_i = {k_i}^2 - 2x_i x_{tag} - 2y_i y_{tag} + {x_{tag}}^2 + {y_{tag}}^2 \tag{4}$$

According to the positioning method of TDOA, the distance difference between the target point and different base stations and the selected reference base station can be expressed as the following:

$$d_{i1} = d_i - d_1 = \sqrt{(x_i - x_{tag})^2 + (y_i - y_{tag})^2} - \sqrt{(x_1 - x_{tag})^2 + (y_1 - y_{tag})^2} \tag{5}$$

Performing Taylor series expansion on the initial coordinates of Eq. 4, $(\mathbf{x_0}, \mathbf{y_0})$. After removing the second-order and higher-order components, the following equation 5 can be obtained:

$$\varphi = \alpha - G\beta \tag{6}$$

$$\beta = \begin{bmatrix}\Delta x \\ \Delta y\end{bmatrix},\ G = \begin{bmatrix}(x_1-x_0)/d_1-(x_2-x_0)/d_2 & (y_1-y_0)/d_1-(y_2-x_0)/d_2 \\ (x_1-x_0)/d_1-(x_3-x_0)/d_3 & (y_1-y_0)/d_1-(y_3-x_0)/d_3 \\ \cdots & \cdots \\ (x_1-x_0)/d_1-(x_n-x_0)/d_n & (y_1-y_0)/d_1-(y_n-x_0)/d_n\end{bmatrix},\ \beta = \begin{bmatrix}d_{21}-(d_2-d_1) \\ d_{31}-(d_3-d_1) \\ \cdots \\ d_{n1}-(d_n-d_1)\end{bmatrix} \tag{7}$$

Finding the weighted least squares solution to Equation 5 yields Equation 6 as follows:

$$\beta = (G^T Q^{-1} G) G^T Q^{-1} \alpha \tag{8}$$

Here, $\mathbf{Q}$ is the covariance matrix of the TDOA measurement value. According to the above equation, the initial value of the next iteration can be obtained, and then the initial value is resubstituted into Equation 4, and the above steps are repeated. Recurse until the sum of $\Delta\mathbf{x}$ and $\Delta\mathbf{y}$ is less than the initially set limit value. Eq. 9 can then be obtained as follows:

$$x_0' = x_0 + \Delta x, y_0' = y_0 + \Delta y \tag{9}$$

At this time $(\mathbf{x_0}', \mathbf{y_0}')$ is the final target point coordinates.

In the TDOA positioning scene, the Chan algorithm is more commonly used. The Chan algorithm is a solution that uses the method of maximum likelihood estimation to realize positioning. If the distance error of the signal measurement presents a Gaussian distribution, then the calculation amount

of the Chan algorithm is higher than that of other algorithms. Said smaller, relatively higher positioning accuracy. The research scope of the Chan algorithm usually involves the scenario of three or more base stations. This section will solve the positioning scenario in the case of three base stations [5]. The positions of the three non-collinear base stations are known, and their respective coordinates are $A = (x_1, y_1)$,$B = (x_2, y_2)$,$C = (x_3, y_3)$,The position of the target point is to be solved, set as $H = (x_s, y_s)$. The distances between the target point and all base stations are recorded as d_1,d_2,d_3,Let $d_i = \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2}$,i=1,2,3..., Establish hyperbolic equations 8 as follows:

$$\begin{cases} d_2 - d_1 = \sqrt{(x_2 - x_s)^2 + (y_2 - y_s)^2} - \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2} \\ d_3 - d_1 = \sqrt{(x_3 - x_s)^2 + (y_3 - y_s)^2} - \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2} \end{cases} \tag{10}$$

Simplifying as follows:

$$\begin{cases} d_{21} + d_1 = d_2 \\ d_{31} + d_1 = d_3 \end{cases} \tag{11}$$

Square both sides and subtract ${d_1}^2$ from each to obtain Equation 10 as follow:

$$\begin{cases} {d_2}^2 - {d_1}^2 = (d_{21} + d_1)^2 - {d_1}^2 \\ {d_3}^2 - {d_1}^2 = (d_{31} + d_1)^2 - {d_1}^2 \end{cases} \tag{12}$$

After expansion, Eq. (13) is obtained as follows:

$$\begin{cases} (x_2 - x_1)x_s + (y_2 - y_1)y_s = -d_1 d_{21} + \frac{({k_2}^2 - {k_1}^2 - {d_{21}}^2)}{2} \\ (x_3 - x_1)x_s + (y_3 - y_1)y_s = -d_1 d_{31} + \frac{({k_3}^2 - {k_1}^2 - {d_{31}}^2)}{2} \end{cases} \tag{13}$$

Here, ${k_i}^2 = {x_i}^2 + {y_i}^2$,i=1,2,3... Let matrix

$$A = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \end{bmatrix},\ X_S = \begin{bmatrix} x_s \\ y_s \end{bmatrix},\ B = -\begin{bmatrix} d_{21} \\ d_{31} \end{bmatrix},\ C = -\begin{bmatrix} {k_2}^2 - {k_1}^2 - {d_{21}}^2 \\ {k_3}^2 - {k_1}^2 - {d_{31}}^2 \end{bmatrix} \tag{14}$$

According to the following equation 12, solve the coordinates of the target point $H = (x_s, y_s)$:

$$X_S = A^{-1} d_1 B + A^{-1} C \tag{15}$$

TDOA positioning requires all base station nodes to maintain time synchronization, while the terminal node and all base station nodes can be out of time synchronization. The distance $\boldsymbol{d_1}$ between the target point and the base station A is unknown. So, the position of the target point calculated by $\mathbf{H} = (\boldsymbol{x_s}, \boldsymbol{y_s})$. Include the unknown $\boldsymbol{d_1}$ which can be calculated as follows

$$d_1 = \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2} \tag{16}$$

3.2. System Analysis

After natural disasters such as fires and earthquakes, how to quickly evacuate the untrapped people and how to quickly complete the tasks of searching and rescuing the trapped people is an important research direction of indoor positioning today, which can greatly reduce the disaster losses. At present, the mainstream indoor positioning system is generally applicable to rescuers, and the specific indoor

positioning system for disaster victims can almost be called blank. Under traditional conditions, since the location of indoor disaster victims cannot be obtained through the positioning system, all rescue plans are only based on the active search of search and rescue personnel. Such rescue plans are only under anticipated conditions and cannot be used as the only reference for rescue [6, 7]. If the indoor positioning system can be adapted to the victims and search and rescue personnel, then a better response plan can be proposed, so developing a positioning system for the victims can minimize casualties. Based on the current positioning technology and rescue plan, the schematic diagram of the positioning system equipment is shown in Fig. 2.

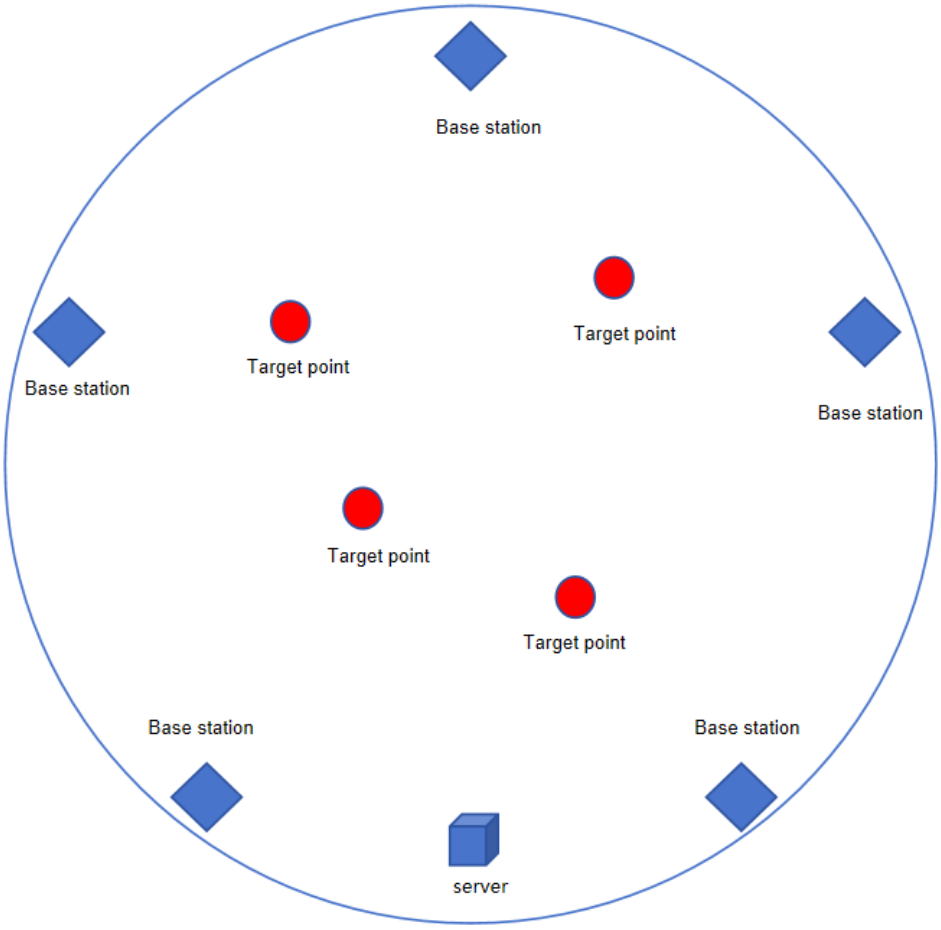

Figure 2. Diagram of the positioning system equipment

The equipment functional requirements of the indoor disaster victim positioning system can be divided into the following aspects:

- A common portable communication device. Smart watches, mobile phones, etc. carried at any time can help quickly locate indoor disaster victims. In order to obtain the real-time location information of the victims, the system needs to use the mobile communication device as the target to be located. Through the signal transmission between the mobile communication device and the base station, the positioning system can locate the victims indoors in real time.
- Multiple indoor base stations. As the communication device between the base station and the target to be positioned, its quantity, stability, and distribution position all have high requirements. In terms of quantity, after a disaster, some base stations may be damaged and unable to operate, so it is necessary to arrange multiple base stations indoors in advance. In terms of stability and distribution location, the indoor environment will change greatly due to disasters, so the distribution locations of base stations need to be relatively scattered, so that they can cover a larger area and locate all the targets in the entire room.
- Positioning system integration server. First of all, the system server, as the brain of the entire positioning system, undertakes the tasks of calculating target location information, simulating rescue

and evacuation routes, and sending plans. Then, the server needs to have an indoor map model of the entire disaster scene to facilitate the planning of evacuation and rescue plans.

Table 1. Advantages of Practical Application of Indoor Personnel Positioning System

	Traditional evacuation, search and rescue methods	Positioning system evacuation, search and rescue methods
Response time	5-10 minutes to reach the indoor scene	Immediate response
Map model	Original model	Original Model + Sensor Updates
Program planning time	1-3 minutes artificial planning	Server real-time planning
Search device	Thermal imaging, night vision, etc.	Precise positioning based on base station
Wayfinding time	Human wayfinding for 3-5 minutes	Update the optimal route in real time
Personnel coverage	Unknown	Full coverage

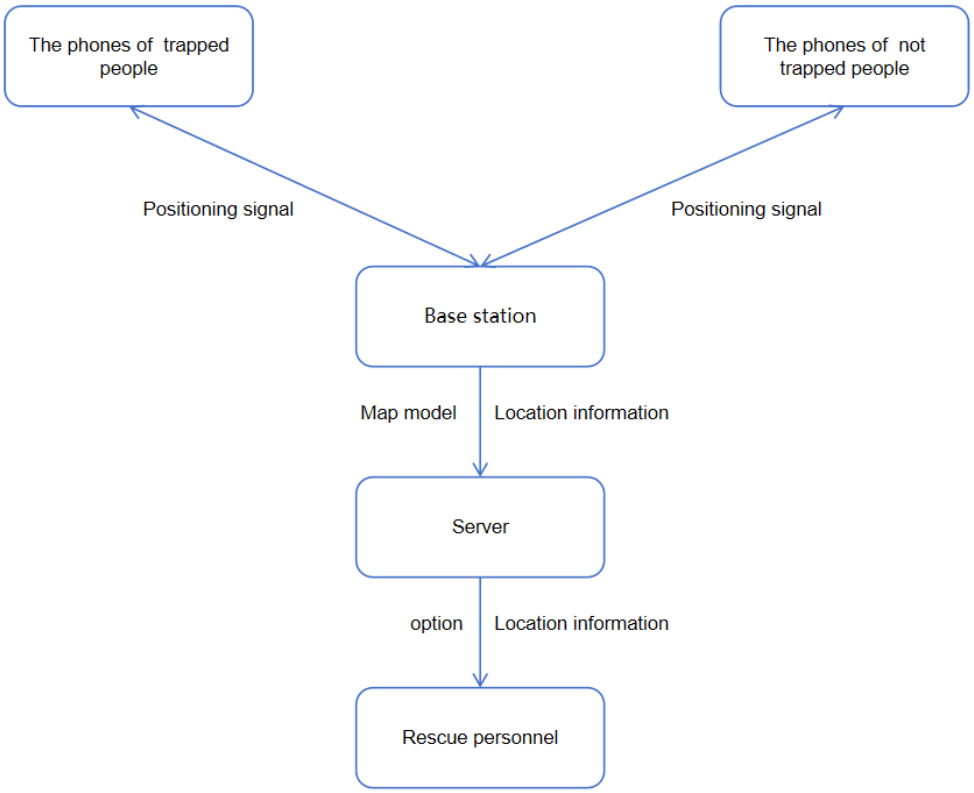

Figure 3. Diagram of the flowchat.

3.3. Location System

First, the base station sends a positioning signal to the mobile communication device for transmission. Then the server will synchronously update the location information of the target in real time, and then plan the optimal solution based on the indoor map model [8, 9]. Finally, the evacuation and rescue plan are sent to the communication equipment of the victims and rescuers to help evacuation and rescue [10]. The specific process are as follows:

- Positioning signal transmission through multiple indoor base stations and mobile devices of victims to quickly determine the location of victims.
- The map model collected by the sensor eliminates extreme environments, such as high temperature, collapse, flammable and explosive, obstacles and other factors. By excluding such factors, optimal evacuation and rescue routes can be planned.
- Send each evacuation route and rescue route to the mobile devices of the victims and rescuers, so that the untrapped people can be evacuated quickly and the trapped people can be rescued quickly.

The flowchart is shown in Fig. 3 and comparison results are given in Table 1,

4. Conclusion

At present, there are more and more practical applications in TDOA-based indoor positioning. As mentioned above, due to the good performance of TDOA in indoor positioning, such as indoor navigation and visualization of industrial production processes, TDOA positioning systems can be well adapted to these fields. Therefore, I believe that in terms of indoor personnel positioning, TDOA indoor positioning technology can also be well adapted to facilitate people's better production and life. Moreover, with the maturity of technology and the continuous popularization of equipment, TDOA positioning will have better performance in various fields. From the perspective of the development prospect of positioning technology, TDOA positioning technology can also be applied to many fields including smart home and auxiliary guidance for the blind in the future[10]. It can be said that indoor positioning technology will be popularized in people's daily life to a large extent in the future.

References

[1] Li M, Zou F, Wu H, Wang X, Zhang Q. Research on Pedestrian Indoor Positioning Algorithm based on TDOA and Chan Algorithm. Journal of Physics: Conference Series, 2021, 1831 (1): 012024.

[2] Chen Y, Gao W, Zhou Y. FDM-TDOA Indoor Positioning System based on Chan's Algorithm. IEEE Access, 2021, 9: 129965 - 129975.

[3] Li H, Yang R, Li Y, Chen Y. Analysis of the TDOA Algorithm for Indoor Positioning Based on Multiple Ultrasonic Sensors. Proceedings of the 4th International Conference on Communications, Signal Processing, and Systems, 2020, 1 - 6.

[4] Yu J, Zhang H, Li Y. A Hybrid Indoor Positioning Method Based on TDOA using a Single Frequency. IEEE Access, 2020, 8: 95711 - 95720.

[5] Yu S, Li M, Xiao X. Improved Chan Algorithm for Low-Complexity Indoor Positioning. IEEE Communications Letters, 2020, 24 (4): 857 - 861.

[6] Zhang Y, Zheng B, Liu C. Novel Method of Indoor Positioning based on TDOA and Chan Algorithm. The Journal of Engineering, 2020, 19: 4061 - 4065.

[7] Ding J, Lu P. Improved TDOA Algorithm for Indoor Positioning. Journal of Physics: Conference Series, 2019, 1364 (5): 052030.

[8] Zhang X, Wei Z, Zhang Y, Chen X. A New Hybrid Indoor Positioning Algorithm based on TDOA and Chan Algorithm. Proceedings of the 3rd International Conference on Networking, Information Systems & Security, 2019: 279 - 286.

[9] Wang G, Xu R, Wang Y. A High Precision Indoor Positioning Algorithm Based on the TDOA and Chan Algorithms. Proceedings of the 4th International Conference on Mechatronics and Robotics Engineering, 2018: 28 - 34.

[10] Feng Y, Chen L. A Novel Indoor Positioning Algorithm Based on TDOA and Chan Algorithm. Proceedings of the 2018 3rd International Conference on Computer and Communication Systems, 2018: 336 - 341.