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Spatio-Temporal Constrained Trajectory Tracking for Emergency Care

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Abstract: High-precision trajectory tracking facilitates high-quality medical care. In this paper, a trajectory tracking and alarm system constrained by time and space norms are designed based on the emergency scene. The location data are collected based on the UWB positioning platform, and the K-means clustering filter and TDOA solve the location. The horizontal positioning accuracy is less than 30cm. Furthermore, the rules of space and time were set up according to the requirements of admission, and the emergency patients were monitored through the statistical information of location, path, time, and so on, and the abnormal behaviours or abnormal areas were alerted. The simulation results show that the system can realize the basic functions of real-time viewing of the position, moving track, and alarm of emergency patients and can effectively meet the needs of hospital emergency patients' fine management service.

1. Introduction

The application of real-time assistant positioning and navigation technology in medical monitoring can effectively alleviate the imbalance of medical needs and reduce the conflict between doctors and patients [1,2]. Many researchers in indoor location scenes have used Ultra Wide Band (UWB) technology because of its excellent characteristic of the high-frequency band and wide bandwidth, which has a good ability to suppress indoor multipath interference [3]. Specifically, UWB sensor-based devices are used to track, measure, and record pedestrian movement distances and information in 3D as a new type of motion recording data. The research of human motion data editing, analysis, and recognition attracts many scholars' and researchers' attention.

In this paper, we design an emergency patient tracking method and system based on UWB, and use the UWB technology to analyze the patient's motion process, can better realize the real-time view of the position of emergency patients, the movement of the track and the reception of abnormal alarm functions.

2. System Design

As shown in Figure 1, the system design includes rule management, clustering algorithm location calculation, positioning system, alarm system, and other modules. Firstly, the rule management module establishes the service flow and activity rules of emergency patients, then the location system collects the location information and obtains the original location data package. Then using a clustering algorithm to filter and calculate the original data of the location information collection module, the location error is obtained, and the location error is calibrated with the experimental environment. The location tracking module uses the location algorithm to calculate the location information and obtain the location data and then obtains the two-dimensional coordinate location data (Loc Data) to realize the location calculation. Finally, according to the result of location tracing and the management rules, the root alarm discriminant module can judge whether or not the behaviour and state of emergency patients accord with the management rules. If they do not accord with the management rules, the abnormal point alarm can be realized through the algorithm.

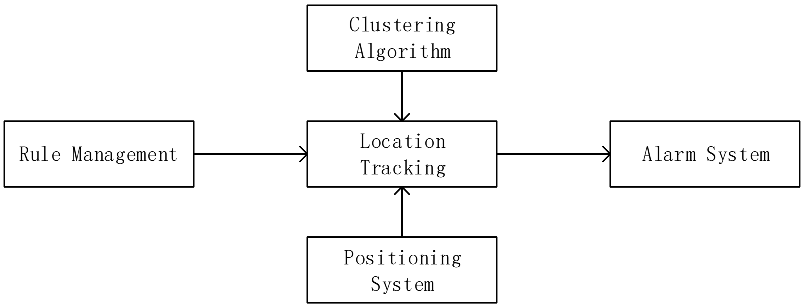

Figure 1: System design drawing.

The overall flow of the system is as follows, according to Figure 1:

(1) rule management module: make the emergency service flow and activity rules of emergency patients.

(2) location system: the UWB-based driver location system collects the location information and obtains the original location data packets.

(3) clustering algorithm: the outliers are detected by the clustering algorithm, and the location error is obtained by calculating the location information data collected by the location system. According to the error, the positioning error is calibrated in the experimental environment, and the positioning accuracy of the positioning system is judged to meet the requirements of indoor positioning error < 30cm.

(4) location tracking module: the raw data is filtered by the clustering algorithm, through location algorithm, such as the TDOA algorithm, which solves the location information, obtains TDOA location data, then two-dimensional coordinate positioning data (LocData) is obtained by solving the problem, and precise position tracking is realized.

(5) alarm system: according to the result of location tracking and combined with management rules, we can judge whether the behaviour and state of emergency patients accord with the management rules.

3. Key Technologies

3.1. Rule Management

An Act is a legal act or a violation of a rule, which, under reasonable conditions, is judged to be “Out of bounds” if it does not comply with that rule, the violation is judged when the relevant time limit is not met after crossing the boundary (generally no more than 25 minutes), and when the boundary is not crossed, the violation is judged according to the trajectory of the relevant act.

3.1.1. Rule-making

According to the arrangement of the behaviour of the emergency patients in Table 1, the activities of the emergency patients can be roughly divided into the above several regions, and the emergency patients in each region may pass by if the patient stays in an area for too long or ceases to observe an abnormal condition and gives an alarm, in addition, the patient can trigger the alarm manually. Then, the experiment can be divided into several regions in the coordinate system, each region to collect a state of data.

Table 1: Example of an alarm rule.

Location Area	Alarm Rules	Alarm Standards	Cause of Alarm
Emergency Room	Emergency time to 30 minutes as the standard, delayed 5 minutes to end location data collection	Time: Alarm if time out Non-automatic: manually triggered the alarm	Time-out alarm: Stay too long in the area Non-automatic alarm: The patient's physical discomfort and inconvenient movement can trigger the alarm automatically
Rest Area	Time and space are not limited; the patient can automatically trigger the alarm	Non-automatic: Manually triggered the alarm	Non-automatic alarm: The patient'sphysical discomfort and inconvenient movement can trigger the alarm automatically
Office Area for Medical Staff	Space: not for patients	Space: After performing error calibration, if the point in the area, the alarm	Out-of-bounds alarm: Out of patient range or into the danger area

3.1.2. Out-of-Bounds Judgment

The point in the polygon can be used to judge whether or not an emergency patient has crossed the boundary. When an emergency patient appears in a specific polygon in a fixed period (when it is a clocking area), the clocking function can be realized by calling relevant commands. When emergency patients are in a polygon for a long time, the correlation algorithm is used to detect the time-out.

Method:

(1)determined by the sum of the areas, if the area of the triangle composed of the label and the polygon sides and the area of the polygon is equal to the area of the polygon, the label is inside the polygon;

(2) determined by angle whether the sum of the angles between the label and all sides is three hundred and sixty degrees or, if it is three hundred and sixty degrees, within the polygon [4-5];

(3) determination by introducing a ray from the label, which is used in this system when the number of points where the ray intersects the polygon is an odd number and an even number is an external number[6], see Figure 2:

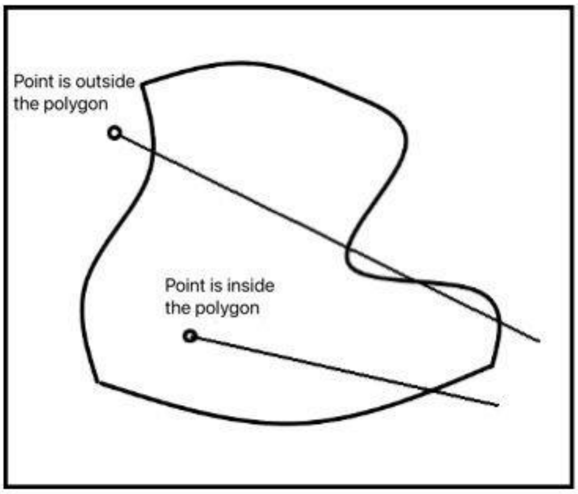

Figure 2: Schematic diagram of radiographic method.

3.2. Positioning System

The system uses the division positioning system for location information acquisition. Each employee wears a tag that constantly sends out location packets collected by base stations in the company's location system and then uploaded to a data-processing server, as shown in Figure 3.

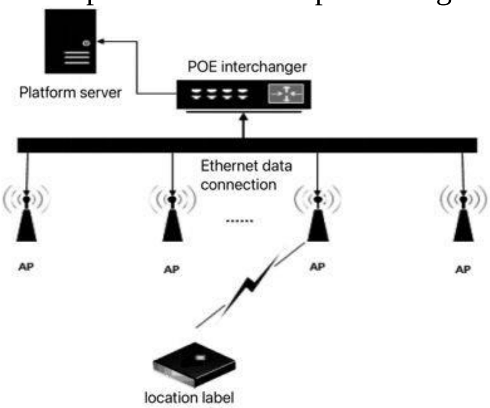

Figure 3: Location information collection.

The functions of the components are as follows:

(1) Tag: Normally, the tag is dormant. After vibration, it sends location packets according to the specified frequency. The positioning accuracy is 10-30cm, the refresh rate is 0.5-50HZ (adjustable), and the battery life is more than two months (1HZ). The system uses a wristband label.

(2) Base Station (AP): it is fixed in the closed space or open area on the spot and is used for real-time interaction with the high-precision positioning tags worn by the production personnel to realize high-precision personnel positioning. When the base station receives the location packet, it saves the received system time TICK (40-bit integer, 1.0/499.2e6/128.0 seconds per TICK, 4.69 mm) and sends it to PC solution software through the network. The master base station sends the synchronization packet according to the frequency and sends the time of sending the synchronization packet to the computer solution software. The indoor positioning base station is used in this design.

(3) Poe switches: with Poe Exchanger, the Base station can be powered by Ethernet data lines. It must support the 802.3af power supply standard to enable the sensor to operate at 7W power.

(4) Ethernet: Current Systems Use Wired Ethernet, where each sensor is connected to an Exchanger for data transmission.

3.3. Clustering Algorithm

The system uses the K-means algorithm to detect outliers and then fuses the location data to reduce the location error. The k-means algorithm is an iterative clustering algorithm that takes distance as a similarity index. It calculates how many classes there are in a given data set, the number of classes is K, and the centre of the class is the cluster centre, which is the mean of all the values in the class. The European distance is chosen for the similarity index for a given data set X and the number of classes K. The purpose of clustering is to minimize the sum of squares of K classes [7]:

$$J = \sum_{k=1}^{k} \sum_{i=1}^{n} ||x_i - u_k||^2 \tag{1}$$

The flow of the K-means algorithm:
(1) Randomly select k centroid;
(2) Calculating the Euclidean distance between each sample and the centre of mass;
(3) Classify the samples into the cluster with the nearest centroid;
(4) Find the mean value of each cluster and classify it again;
(5) The number of iterations reaches the end of the algorithm. Otherwise, go back to step (2).
The correction process using the k-means algorithm is as follows:
(1) Collecting more than 5 minutes of location data;
(2) K-means and Kalman filter clustered the data to obtain measurement coordinates;
(3) The measured coordinates are compared with the actual coordinates, and the formula obtains the error value;
(4) Repeat the process several times and compare the variation of the error value.

3.4. TDOA Algorithm

The location tracking module uses the TDOA algorithm to filter raw data after the clustering algorithm and gets the actual coordinates, that is, two-dimensional coordinate data. This data is in LOC format. The flow is shown in Figure 4 below.

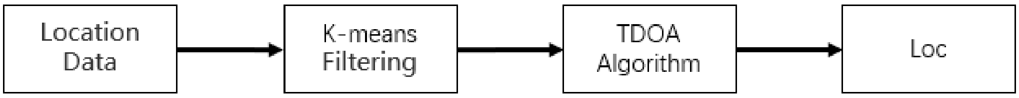

Figure 4: The process of position calculation.

TDOA (Time Difference of Arrival) is a method to deduce the relative position Of the target relative to the reference base station by solving nonlinear hyperbolic equations based on the distance between the reference base station and the target [8]. Because the speed of electromagnetic waves is known and constant, the distance and time of flight can be converted to each other, and if the time of transmission is expected (or the interval is known), then the flight time and the arrival time of the signal can be converted to each other, so the corresponding distance can be obtained by measuring the difference between the arrival time of the signal sent by the tag and the arrival time of the base stations [9].

When the TDOA algorithm measures the distance, the time the same packet arrives at different base stations is different [10]. The process for measuring distance is as follows:
(1) Continuously sending out positioning data packets from the label;
(2) Then the base station receives the location data packet sent by the tag and records the time

received by base station 1 as t1 and the data received by base station 2 as t2;

(3) t1 and t2 are subtracted to get td;

(4) In general, there are more than four locating base stations, and more than three groups of results can be obtained by repeating the process as mentioned above;

(5) Finally, the actual coordinates are obtained by solving the related equations.

Here are the equations involved.

$$\sqrt{(x_0-x_1)^2+(y_0-y_1)^2}-\sqrt{(x_0-x_4)^2+(y_0-y_4)^2}=v(t_1-t_4) \quad (2)$$

$$\sqrt{(x_0-x_2)^2+(y_0-y_2)^2}-\sqrt{(x_0-x_4)^2+(y_0-y_4)^2}=v(t_2-t_4) \quad (3)$$

$$\sqrt{(x_0-x_3)^2+(y_0-y_3)^2}-\sqrt{(x_0-x_4)^2+(y_0-y_4)^2}=v(t_3-t_4) \quad (4)$$

4. Experiment and Analysis

4.1. Experimental Environment

The test environment for the experiment is located in the laboratory and is an area of 10m × 8m, the environment shown in Figure 5.

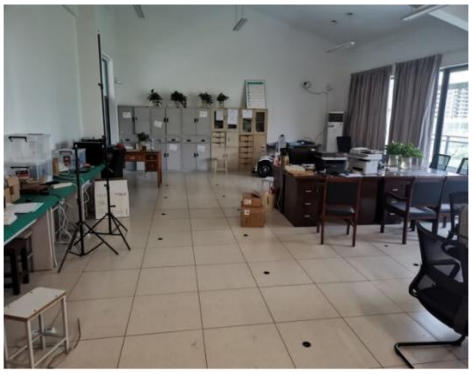

Figure 5: The experimental site.

4.2. Experimental Process

The experiment was designed as shownin Figure6below:

(1) The experimental site was divided into areas to simulate the hospital scene.

- Area 1: emergency room
- Area 2: Lounge
- Area 3: Director's office

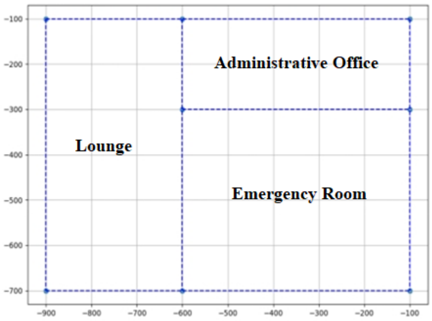

Figure 6: Area division interface diagram.

(2) Carry on the experiment to the alarm function of the system.

- The location data of different states in each region are collected respectively.
- The positioning data is imported into the alarm module.
- Analyse the alarm results.

4.3. The Results of The Experiment

4.3.1. Error

When collecting data, the location error should be considered, and the buffer zone should be set in the designated area of the experimental site. According to the location error calculated above, the buffer zone should be set to the maximum error of 0.3 m of the label to avoid false alarms caused by position errorand improve the reliability of the alarm.

4.3.2. Alarm function

Running interface, tag tracking, and alarm status of each status as follows:

(1) State of emergency: In the emergency department, the patient left the emergency area and crossed the boundary, the track was red, and the timeout behaviour occurred when the emergency time was more than 30 minutes, the track of the timeout part was purple. The interface is shown in Figure 7:

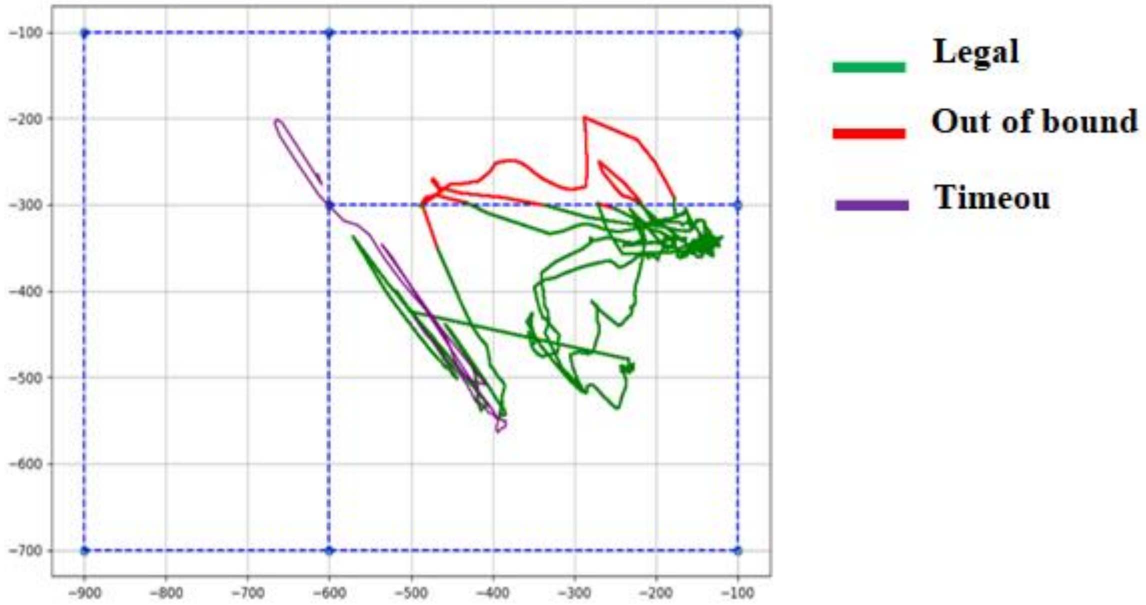

Figure 7: Track and alarm of behaviour data in emergency department.

(2) State of rest: Most of the activity happened in the restroom. Data collection about a minute after the patient left the restroom, into the emergency room, resulting in cross-border behavior, trajectory in red, as shown in Figure 8 Reliability.

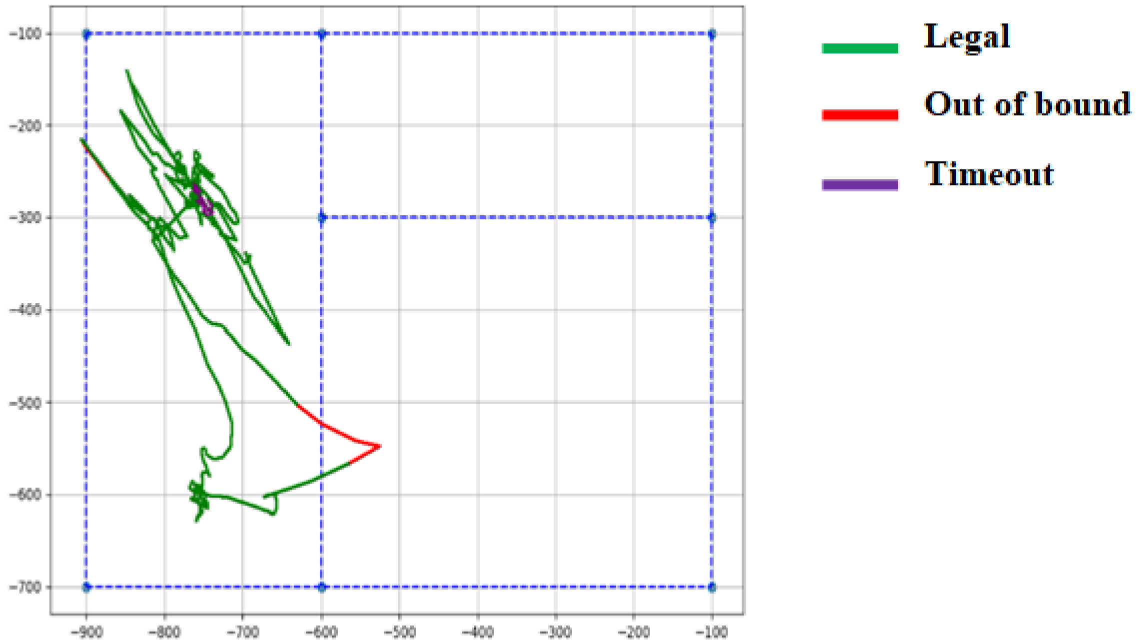

Figure 8: Break room behaviour data track and alarm.

(3) State of face consultation: Most behaviors that happened in the department are legal. Face-to-face time of more than 30 minutes resulted in timeout behavior, and the timeout part of the trajectory is purple; face-to-face time in the emergency area resulted in cross-border behavior and the trajectory is red. See Figure 9.

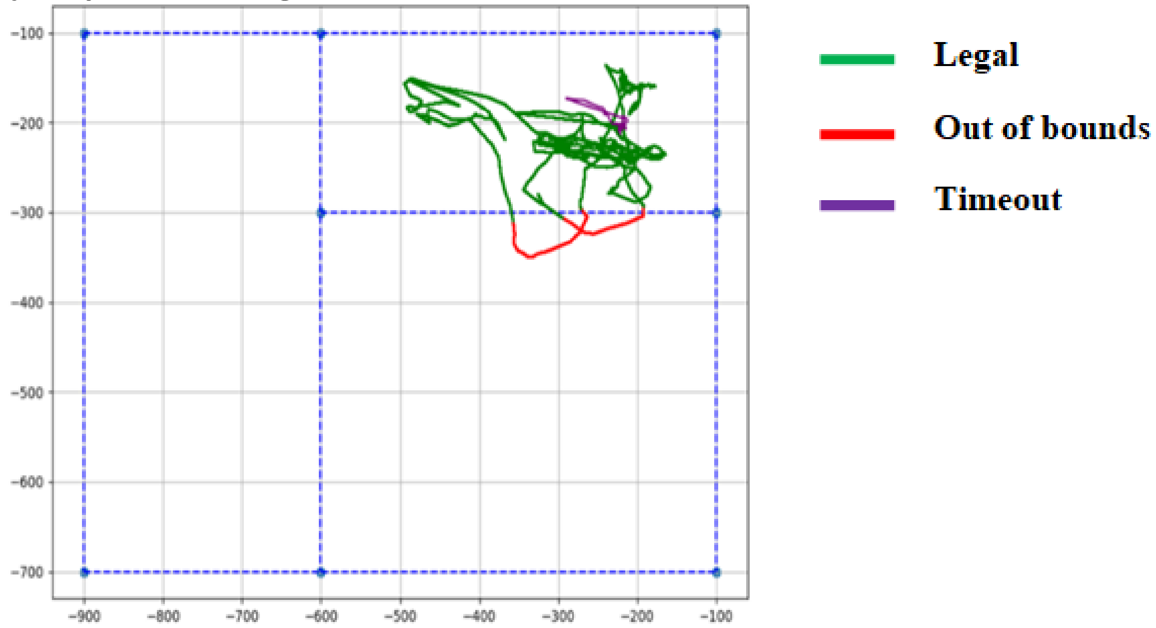

Figure 9: Track and alarm of department behaviour data.

5. Conclusion

To solve the problem that the traditional tracking system for emergency patients lacks an indoor location, a tracking system for emergency patients based on UWB is proposed in this paper. By testing, the system's positioning accuracy is less than 0.3 m, which meets the indoor positioning requirements, comprehensive coverage, low power consumption, support for 24-hour location monitoring, and track tracking. In an emergency, the system immediately alarms and informs the management monitoring centre to meet the hospital's needs for intelligent, efficient, and information-based tracking of emergency patients.

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