Research and Realization of Firefighter Positioning System Based on Inertial Navigation

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***Abstract*—The fire scene environment is diverse, especially the pattern of large buildings is complex. When a fire occurs, after firefighters enter the scene for rescue, real-time positioning of firefighters is of great significance to ensure the safety of firefighters and on-site command and deployment. Two challenges faced by fire positioning systems include positioning in indoor environments and the fusion between positioning coordinates and the internal structure of buildings. This paper designs a firefighter positioning system for indoor environment based on inertial navigation, including four parts: single-person positioning device, positioning terminal, data transfer service system and monitoring terminal. The system supports indoor high-precision positioning and rapid modeling of any building, so that the on-site commander can grasp the position information and all motion trajectories of each firefighter in the fire field in real time, which has a strong reference value for the on-site command center to make fast and accurate command and decision-making.**

***Keywords*—inertial navigation;firefighters;indoor;positioning**

I. INTRODUCTION

With the rapid development of China's economy and the diversity of residents' production activities, urban buildings are gradually developing towards the direction of super high-rise and large-scale. In recent years, fires have occurred frequently all over the country, and the causes of fires have been constantly changing, coupled with the lack of a unified infrastructure for building structures, making rescue tasks more difficult and dangerous[1]. When firefighters enter a complex and unfamiliar building, it is difficult to use the indoor positioning system of firefighters at the present stage to locate the firefighters in real time, and the on-site command center cannot judge the exact location and status of the firefighters[2], which cannot provide necessary guarantee for the life and safety of firefighters. Therefore, it is extremely urgent to design a system that can accurately locate the firefighter's position and path in the complex and changeable fire environment.

At present, the mainstream indoor positioning technologies at home and abroad mainly include wireless positioning technology based on pre-networking, directional measurement technology based on radio and ultra-wideband positioning technology[3]. Due to extensive attention and research on indoor positioning technology, the positioning accuracy of these positioning technologies at this stage has been very high, and some even reach the centimeter level. However, these indoor positioning technologies need to deploy a large number of equipment in buildings in advance, and the technical cost is extremely high; Some also rely on the original network equipment of the building, so they are not suitable for sudden fire environments. The inertial navigation technology can be applied to the fire rescue positioning because of its characteristics of being free from the influence and interference of the external environment, having good stability, and being able to complete the navigation autonomously[5].

Erhard Schubert et al. used wireless sensing technology to adjust the attitude of the received signal, re-evaluate the optimal position of the wireless sensing technology and the antenna to effectively locate the indoor firefighters[4], but the positioning accuracy is limited by the building structure. Duke University developed an indoor positioning system for firefighters, Un-LOC[5], based on inertial navigation technology and landmark idea, which achieved high-precision positioning and real-time tracking of the location of indoor firefighters.However, the system does not have a host computer with friendly interface and real modeling function. China's Bauc Intelligent Technology Co., Ltd. has developed a firefighter individual positioning device based on inertial navigation,which has won the bid for the fire rescue and rescue equipment project, but the trajectory of the individual soldier's movement is very vague and the modeling effect of the building is not ideal[6].

This paper proposes an indoor positioning system for firefighters based on inertial navigation technology. Compared with the existing indoor positioning systems for firefighters, it has an intuitive and friendly human-machine interface,which can recognize the movement posture of firefighters in real time and can quickly model any building.

II. THE TOTAL DESIGN OF SYSTEM

A. The composition of the firefighter positioning system

The firefighter positioning system based on inertial navigation is mainly composed of four parts: single-person positioning device, positioning terminal, data transfer service system and monitoring terminal. The single-person positioning device of the firefighter positioning system is fixed on the feet of the firefighters by wearing, and works autonomously after being turned on.It communicates with the mobile phone terminal through Bluetooth to obtain the absolute position coordinates provided by GNSS on the mobile phone terminal, and turns the integrated indoor and outdoor seamless positioning results are returned to the mobile phone after fusion and calculation with MEMS. The positioning results of the sensor of the single positioning device are transmitted to the mobile device through Bluetooth transmission, and then the mobile device packages the data and sends it to the data transfer service system through 4G or WIFI. The data transfer service system receives and saves the data and sends the data to the on-site command center. The on-site command center conducts command and decision-making through the movement trajectory and personnel status of the firefighters observed by the monitoring terminal.

1) Single-person positioning device: The single-person positioning device is a wearable module based on MEMS, which is connected to the positioning terminal through Bluetooth. The single-person positioning device calculates the current position of the person in real time through the combination of the GNSS data on the positioning terminal and the inertial data of the MEMS module mounted on the device, and sends it to the positioning terminal in real time through Bluetooth

2) Positioning terminal: The positioning terminal is bound with the single-person positioning device, communicates with the single-person positioning device through Bluetooth, and uploads the position information obtained from the single-person positioning device to the data transfer service system.

3) Data transfer service system: The positioning terminal uploads the location and other information to the data transfer service system through wireless signals (4G, WIFI, etc.), and then the data is sent to the monitoring terminal by the data transfer service.

4) Monitoring terminal: The monitoring terminal can monitor the specific coordinate position information of each positioning terminal in real time and make scheduling.

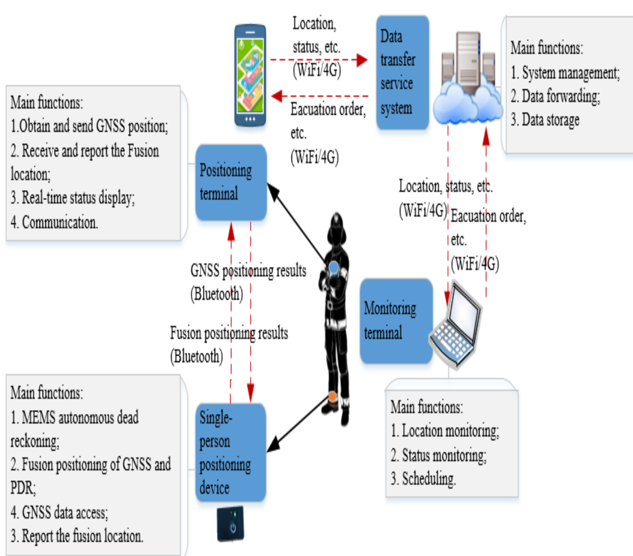

Fig. 1. Schematic diagram of the composition of the firefighter positioning system.

III. THE SOFTWARE DESIGN OF THE SYSTEM

A. Single-person positioning device

The single-person positioning device is mainly based on inertial navigation positioning technology and multi-source fusion positioning technology. It provides continuous positioning for firefighters in indoor and underground areas where GNSS is unavailable, so as to realizes seamless indoor and outdoor positioning for firefighters in complex urban environments.

Inertial navigation system is an autonomous navigation system that does not rely on external information and does not radiate energy to the outside. It does not require external help or be interfered by external signals, and has the advantages of high autonomy, good real-time performance and strong reliability[7]. The basic principle of inertial navigation is based on Newton's laws of mechanics, and the spatial coordinate datum (navigation coordinate system) is established by using the output of gyroscope. Integrate the acceleration measured by the accelerometer twice, convert it into the navigation coordinate system through the transformation matrix, and finally determine the motion parameters of the carrier such as the velocity, yaw angle and position[8]. The principle flow chart of inertial navigation is shown in Fig2 :

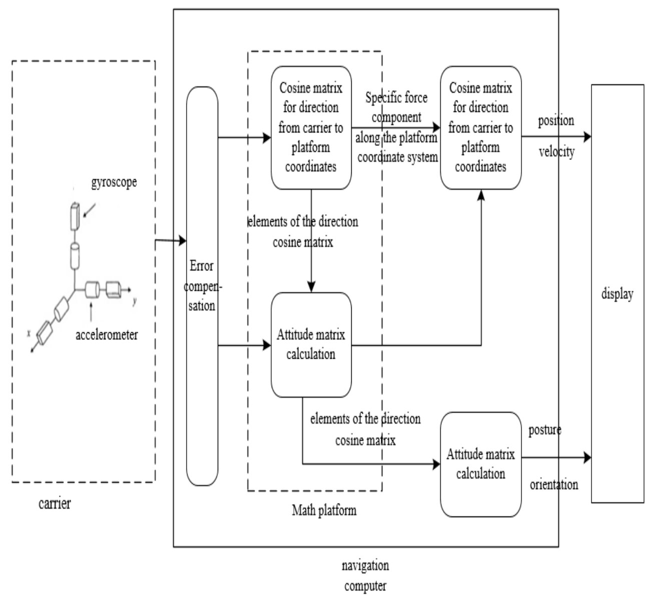

Fig. 2. Flow chart of inertial navigation principle.

It can be known from the working principle of the above inertial navigation that the pedestrian position obtained by the inertial navigation is calculated by integrating the acceleration continuously, so the positioning accuracy is poor for a long time. In addition, the precision that can be achieved by inertial navigation is also related to the precision of the device used and the environment. In the effective time, it is usually meter-level precision. Therefore, the performance of inertial navigation alone is poor, and it is a relative positioning method. Without the assistance of other means, the absolute position of personnel cannot be determined autonomously, so this method cannot be used alone.

This system uses a navigation method combining inertial navigation system and pedestrian dead reckoning algorithm (PDR).It is a navigation and positioning method that mainly uses the motion law of pedestrians in the process of traveling (step length/step number detection, zero velocity correction, building heading constraints, etc.) to constraint recursive divergence problem in the process of inertial navigation system,so as to obtain pedestrian posture and position. The principle of the PDR algorithm is to take the pedestrian's current position P(x0, y0) as the starting position, and calculate the next moment's position according to the pedestrian's movement direction θ and step size d.In this way, the position Pk(xk,yk) at the pedestrian's time K can be calculated by iteration. The principle of PDR is shown in Fig 3.

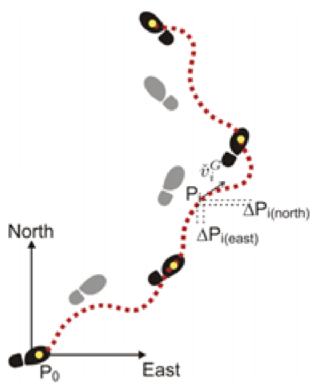

Fig. 3. The principle diagram of pedestrian dead reckoning algorithm.

The inertial sensor is fixed to the body (placed on the feet, legs and other parts.), and the method of inertial calculation method is adopted to calculate the incremental position by inertia recursion for each step in the process of moving. The pure inertia recursive algorithm mainly includes three stages: zero-velocity detection, zero- velocity update, and inertial solution. The zero-velocity detection stage mainly uses the original output of the three-axis accelerometer and the three-axis gyroscope, which is realized by the method of threshold detection; The zero-velocity update stage uses the observational velocity to be zero, and then combines H ∞ filtering to achieve; In the inertial calculation stage , if the current carrier is in the zero- velocity stage, it is corrected by methods such as zero-velocity correction to constrain the accumulated inertial error; otherwise, only inertial recursion is performed to output reliable position information. The pseudocode of the PDR algorithm is in Algorithm 1:

The coordinate system used by the pedestrian dead reckoning system is usually the carrier coordinate system. The conversion from the carrier coordinate system to the geographic coordinate system is realized through coordinate transformation,and the time system used generally directly outputs the accumulated time of the system. The system output parameters generally include velocity, position and posture information.

Algorithm 1: The PDR Algorithm

Input: The angular velocity and acceleration measured by the IMU and the initial position P_0 of the pedestrian;
Output: Pedestrian's position P_k at time k;
t←1;
Initialize the location parameters of pedestrians;
while $t<=T$ **do**
  for $t<=T$ **do**
    Get the acceleration of the x, y, z axis at this position;
    Stores the value of the wave crest that meets the threshold value;
    Calculate the time difference between adjacent wave crests;
    If the time difference meets the threshold, the number of steps is incremented by one; Get the number of steps n;
  end
  for $i<=n$ **do**
    Convert the magnetometer measurements M_x^b,M_y^b,M_z^b to the navigation coordinate system; Calculate heading angle, $\psi_i = \arctan(Mx/My) + \psi_0$
  end
  Get the position at time K
  $X_k = X_0 + \sum_{i=1}^{n} d_i \sin\psi_i$, $Y_k = Y_0 + \sum_{i=1}^{n} d_i \cos\psi_i$
end

Since the pedestrian motion law (zero velocity correction stage) is combined to constrain the accumulated error of the inertial sensor, the reliability of the output positioning result can be guaranteed for a long time.

B. Positioning terminal

The positioning terminal is mainly responsible for communicating with the single-person positioning device, obtaining the position information of the single-person positioning device in real time, and uploading the location information of the positioning terminal to the public network server at a certain frequency. The functions of the positioning terminal mainly include: Bluetooth communication, data upload, command reception and real-time position display of the terminal. The functional structure of the positioning terminal is shown in Fig 4.

The fire rescue environment is often accompanied by chaotic wireless communication, which greatly affects the network communication of fire rescue work. Therefore, the network communication in the firefighter positioning system has become a difficult point for the positioning terminal. Aiming at this problem, the system realizes the short-distance data exchange between the single-person positioning device and the positioning terminal by using Bluetooth. The network communication between the positioning terminal and the data transfer service system is realized by using the network communication design based on TCP. The communication method is TCP protocol, and the bottom layer uses WLAN and 4G. In addition, considering that the actual situation of the fire scene is relatively complex and bad, the common network equipment is often destroyed and the power equipment stops working normally, so it is possible to place several signal relay devices with batteries at intervals of 50m or 100m at the fire scene to realize the normal communication between the positioning terminal and the data transfer service system.

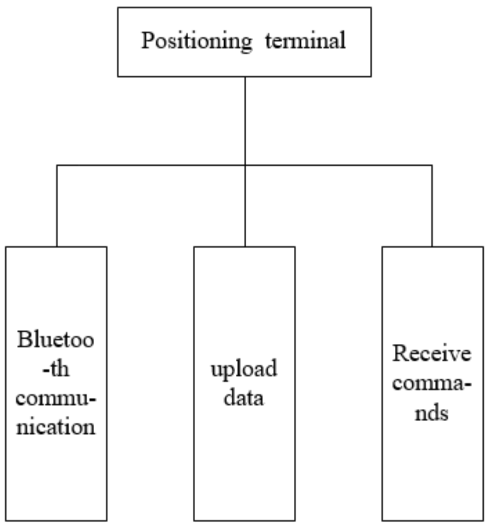

Fig. 4. Functional structure diagram of positioning terminal.

C. Data transfer service system

All data sent by the positioning terminal is first transmitted to the data transfer service system, and then distributed to the monitoring terminal by the data transfer service system. Similarly, the relevant commands sent by the monitoring terminal are also sent to the data transfer service system first, and then forwarded to the relevant positioning terminal by the data transfer service system.

The data transfer service system must receive the real-time location information of all firefighters in the task state and the relevant commands sent by the monitoring terminal in real time. The amount of data is large and the time is long. Therefore, the data transmission efficiency of the data transfer service system must be guaranteed and improved in the complex rescue environment. In response to this problem, this system adopts high-performance Netty architecture to realize the real-time reception of all firefighter data and forwarding of monitoring terminal commands when implementing the data forwarding function. Netty architecture adopts an asynchronous non-blocking communication framework based on NIO. Compared with the traditional BIO framework, the NIO framework has stronger robustness, function, performance and scalability. It adopts the technology of protocol conversion to solve the problem of inconsistent communication protocols[9]. At the same time, in order to improve the response speed and throughput rate of the system, the data transfer service system uses Redis for high-speed data caching, and uses the method of delayed warehousing to realize the real-time reception, dynamic expression and batch warehousing of large-scale firefighters' real-time positioning information.

D. Monitoring terminal

The monitoring terminal is used to monitor the current position of all firefighters in real time, to view the movement trajectory of a firefighter, to send emergency evacuation commands to all firefighters performing tasks, and to receive help signals sent by firefighters. The monitoring terminal communicates with the data transfer service system through network protocol. The functions of the monitoring terminal mainly include personnel check-in, task start, task end, personnel grouping, personnel track view, building floor management, floor height management, floor plan management, personnel status warning and command management.

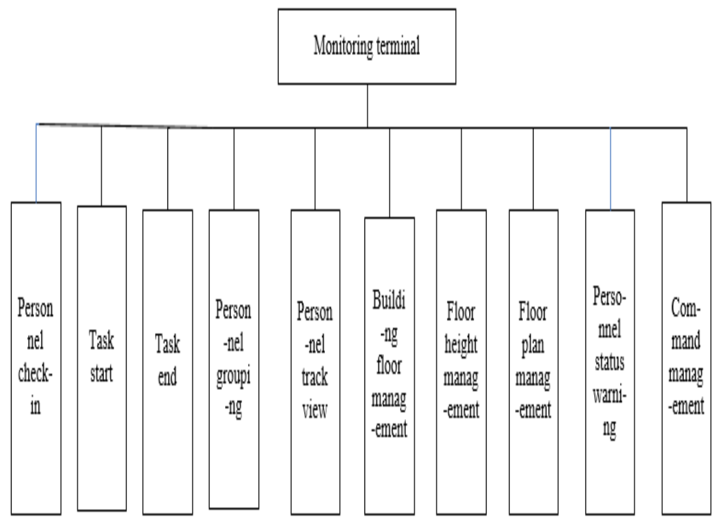

Fig. 5. Monitoring terminal function structure diagram.

Due to the wide variety of buildings , even if the height of different floors of the same building, the plan structure of each floor, and the floors above and below the ground are different,one of the difficulties that the monitoring terminal needs to solve is how to model the building quickly and efficiently. Since each building has detailed 2D design drawings when it is built, the system can quickly model by obtaining the 2D floor plan of the building. The specific process is as follows:
Step 1 Photograph the plan structure diagram of a certain floor of the building through the camera of the monitoring terminal;
Step 2 Automatically trim the edges of the plane structure diagram, or provide the corresponding plane structure picture file by the property management or other personnel;
Step 3 Established the corresponding relationship between the structure map and the GPS map through the steps of panning, rotating, zooming, and fixing in the map in a manual way;
Step 4 The relative coordinates transmitted by the positioning teminal are converted into GPS coordinates by the monitoring terminal to realize the relationship between the positioning

coordinates and the position of the floor plan, and then display the position of the personnel.

IV. Conclusion

This paper combines the inertial navigation positioning technology with the pedestrian dead reckoning algorithm to reduce the time delay error of the inertial navigation.The firefighter positioning system based on this implementation has the function of firefighter indoor and outdoor seamless positioning. The system supports the rapid modeling of any building, and the monitoring terminal can obtain the firefighter's position, status information and the firefighter's movement trajectory in real time. The application of the system can assist the on-site commander to make faster and more accurate decisions, improve the rescue efficiency of firefighters, and reduce the sacrifice of firefighters. It has good application and promotion value.

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