INDOOR VISIBLE LIGHT LOCALIZATION METHOD BASED ON EMBEDDED ARTIFICIAL INTELLIGENCE

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ABSTRACT:

This paper proposes an indoor visible light location method based on embedded platform and optical frequency image recognition technology with artificial intelligence, which can effectively improve the location effect in complex indoor environment. By transplanting the artificial intelligence (AI) based image classification algorithm into the embedded platform, this method uses a forward neural network to analyse the position information coming from the coded optical frequency image received by a camera, and then the positioning results can be obtained. In view of the "motion state" and "occlusion state" that are most likely to fail in traditional visible image localization, we specially supplement the training set of relevant characteristic optical frequency images to enhance the robustness of the method. According to the track and positioning results of the moving platform receiver, the proposed method can provide accurate and reliable navigation and positioning and has stronger anti-interference ability compared with the traditional light intensity or light image positioning methods.

1. INTRODUCTION

1.1 Background Description

In recent years, as people's demand for location information continues to increase, traditional positioning methods, such as global positioning navigation system, communication base station positioning, radio frequency sensing, etc. have good performance in outdoor and open conditions, but the application effect is not ideal in indoor, underground and other environments with weak wireless signals, or even cannot be used at all. Because power attenuation, such as loss of signal, the traditional method based on radio frequency location and positioning does not apply to indoor environment. At the same time, the use of indoor LED light source as the sender, with light as a carrier of the positioning methods have been proposed, which aroused the interest of the researchers. Compared with the traditional positioning technology based on the wireless signal, the visible light location technology has high positioning accuracy, not occupy the communication frequency resource advantages, therefore is regarded as a very promising indoor positioning navigation solutions, can be widely used in coal mine, shopping malls, underground parking. Currently, the main existing indoor visible light positioning scheme is divided into two types. One is the use of photoelectric diode induction intensity, according to the triangulation method to obtain relative coordinates. Another is based on light blinking time interval of coding regions, and then at the receiving end by decoding results for location information.

1.2 Existing Defects

At present, lot of the existing visible light localization methods are based on decoding the stripe image captured by the camera, then the position is determined according to the results. However, most of the current decoding schemes are based on the analysis and recognition of the flicker stripes image itself. This process has obvious defects, because in the process of positioning, the image collected by the camera may not be a completed, and the stripes containing address information may be incomplete or wrong. Therefore, if the light is partially blocked during transmission, or is distorted due to the structure of the camera itself, it is difficult for traditional decoding methods to resolve. So, these traditional methods have the defects of weak anti-interference ability, narrow positioning range and inability to complete dynamic positioning. They can only be implemented in the experimental environment and are difficult to be used in our daily life.

1.3 Innovation Points

To solve these problems, we propose a regional localization scheme based on embedded artificial intelligence image classification algorithm, and carry out field tests in a typical indoor environment. The DSP chip is used to change the flashing frequency of LED lights, and the digital images of optical frequency at different frequencies are collected as address codes at the receiving end. Then the TensorFlow framework is used to train and fit the symbol images of different frequencies, and the weight model for visible light image recognition and analysis is obtained. The model is transplanted to an embedded platform, and the neural network is used to analyse the received optical frequency fringe image containing location information, and the location is determined by comparing it with the address library. Experimental results show that the proposed method can significantly improve the robustness and application range of visible light indoor positioning function, and can better complete address recognition and trajectory fitting under strong light background and dynamic. Uses embedded artificial intelligence image classification algorithm to recognize images of different optical frequencies. The strong robustness of neural network classification algorithm greatly improves the decoding success power when the image at the receiver end is partially occlusion, which is more conducive to the application of indoor visible light localization. Even if the received optical frequency image is partially blocked, or the image is distorted due to the moving state of the receiver, the location can still be carried out. After the conclusion of the final experiment and data summary and analysis. The results show that the system is successful and effective in indoor positioning and navigation applications.

2. METHODS AND ALGORITHMS

2.1 Hardware structure of platform

As shown in Figure 1, our transceiver system consists of two parts, including "optical frequency signal transmitter" for sending visible light signals, and "optical frequency address acquisition analyser" for receiving signals. The "optical frequency signal transmitter" includes a power supply boost circuit, a control circuit, and a modulation circuit. In practice, the optical frequency signal generator at different positions will regularly send a constant frequency optical signal to the nearby area as the address code. Correspondingly, as the receiving end of the "optical frequency address acquisition analyser", through the OV7670 camera, optical frequency images are collected, and then the normalized and adjusted image matrix is transmitted to the local neural network weight model, and according to the output probability distribution results to analyse the address information.

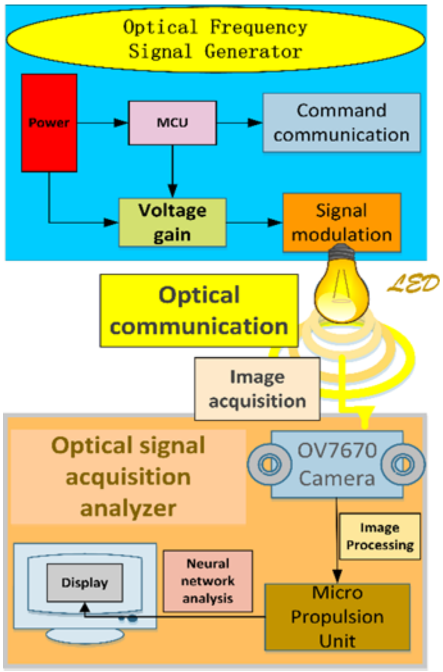

Figure 1. The positioning system hardware structure.

2.2 Address Information And Coding Structure

Under the control of the microprocessor, different LED lamps can blink at different frequencies, and the images of the receiving end corresponding to different flashing frequencies are shown in Figure 2. When LED lights flash at different frequencies, due to the shutter effect of the camera, the stripe images collected by the camera are obviously different in density, brightness and shade. Therefore, we can set the stripe image of some special frequency as the basic code element of the address information, in actual use, only need to let the different locations of lighting source uninterrupted send address information of the corresponding code element string. Receiver can complete the decoding and acquire the regional address information, finish to the process of localization.

In the process of address coding, if the light frequency of 60HZ is selected as one of the basic codes, it is close to the frequency perception range of human eyes, which will make indoor people have a sense of vertigo. If the frequency is too high, it will inevitably lead to the shorter life of the lamp. Finally, optical frequency images of 200HZ, 400HZ, 800HZ and 1600HZ are selected in this paper, corresponding to the basic code of 4FSK. As shown in the figure, the data Frame structure of the visible light positioning and navigation system consists of Start Frame Delimiter (SFD), room number, location number, and End Frame Delimiter (EFD).

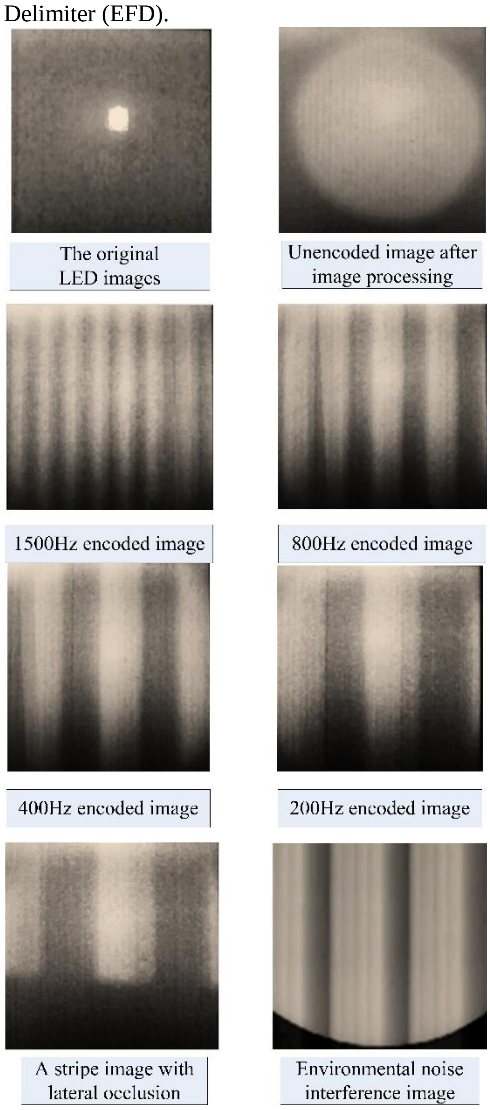

Figure 2. Visible light flashing stripe images

Among them, the data frame is composed of 10 codes, and the start bit and end bit are composed of two letters "A" and "B" mapped from the 800HZ and 1600HZ frequency images. As shown in Figure 3 When the receiving end detects the continuous appearance of "A" and "B", the data bits in the middle will be analysed. The data bit consists of "0" and "1" represented by 200HZ and 400HZ, including the room number used to represent the space and the location number of the area. If an optical frequency signal generator is located in position 2 of Room 1, it will be programmed to blink periodically at the frequency corresponding to the sequence "AB-01-0010-AB", and the other optical frequency signal generator is located in position 3 of Room 2. Then it will be programmed to blink periodically according to the optical frequency corresponding to the sequence "AB-10-0011-AB", each data bit lasts for 5ms, and the total time to successfully encode a complete string of addresses is about 50ms. The address coding method based on the above description can be applied to distinguish and identify 64 location targets, fully meeting the positioning requirements in general indoor scenes. By increasing the coding bits of room number, it can also be applied to shopping malls, hospitals and other larger occasions.

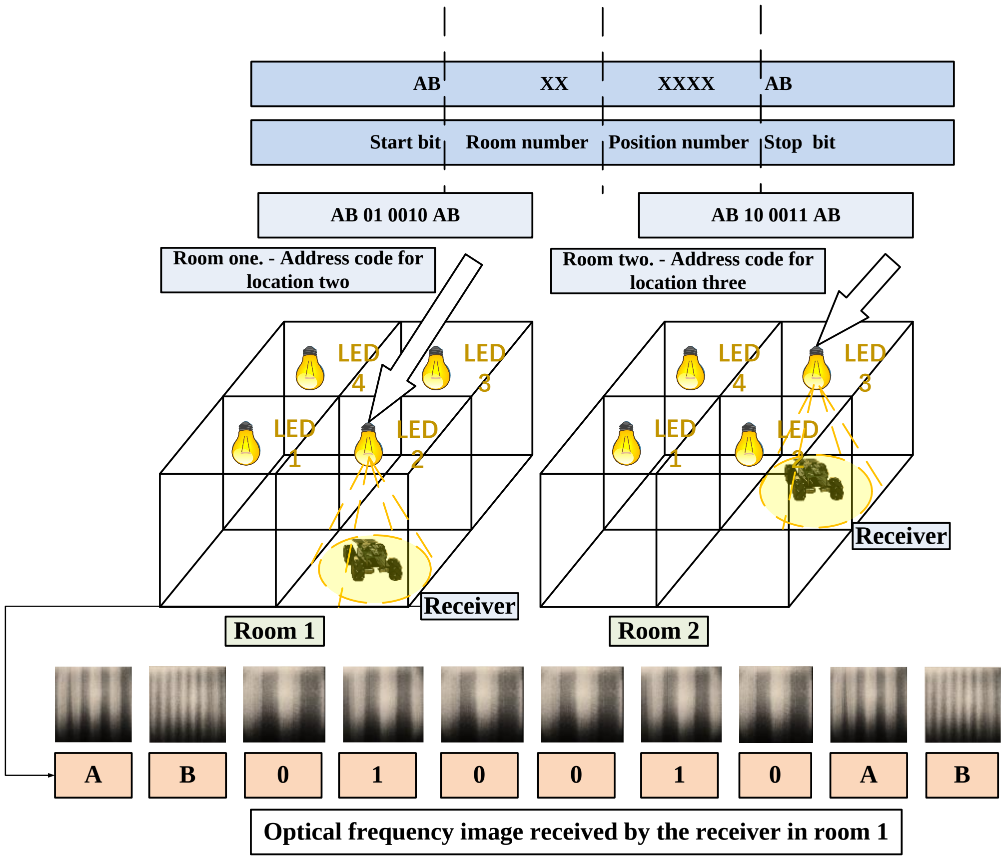

Figure 3. The encoding format of the location data frame

Compared with the modulation method based on OOK, It is obvious that matrix images with different frequencies represent the basic symbols with greater anti-interference and migration ability in different environmental backgrounds. The process of symbol parsing and recognition of optical frequency image, as well as the migration process of neural network model to the receiving end, will be introduced in the next section

2.3 Principle And Construction Of Neural Network

We choose deep neural network as the basic network structure of stripe image recognition. The deep neural network consists of simple sensory neurons. According to the weight of the neurons and the real value of the input nodes, the nonlinear activation function is used to generate the output. This concept can be expressed by equation:

$$\boldsymbol{y} = \varphi\left(\sum_{i=1}^{n} w_i x_i + b_i\right) = \varphi(\boldsymbol{w}^T\boldsymbol{x} + \boldsymbol{b})$$

$\boldsymbol{x}$ is the input vector, $\boldsymbol{w}$ is the vector of weights, φ is the activation function, and $\boldsymbol{b}$ is the deviation.

In practical application, deep neural network is usually composed of multiple nodes. Since a single perceptron can be represented as a directed linear function, it will be used as a component of the basic network. The network parameters we will use include the number of layers in each part of the network, the number of nodes in each layer, and the weight coefficients between adjacent layers. Technically, the input signal passes through the input layer, the hidden layer and the output layer to form the final analysis result, which is represented by equation:

$$\boldsymbol{x} = f(\boldsymbol{s}) = \boldsymbol{B}\varphi(\boldsymbol{A}\boldsymbol{s} + \boldsymbol{a}) + \boldsymbol{b}$$

For the training process of the network, we need to collect and classify the image with different coding conditions in the form of "data-label", and input them into the entrance of the network. During the training, the weights and biases (A, B, a and b) are adapted to be the optimal values respectively according to the pairs as (s_i(t), x_i(t), i=1,2,3, ⋯⋯;n). Moreover, the way to optimize feature is depend on reconstruction error as equation：

$$\sum_t \| f(s_i(t)) - x_i(t) \|^2$$

2.4 Data Acquisition And Model Training

As mentioned above, we use the neural network classification algorithm to replace the traditional fringe threshold algorithm and array parsing method. Therefore, in order to get the neural network model matching with the environment, we collected different kinds of optical frequency fringe images at different positions in the experimental room as the training set. In order to enhance the recognition ability of the classification network, we also collect additional images with defects, including "lateral occlusion" and "partial occlusion". On the basic principle of neural network, this article is based on Google Tensor training open source framework - Flow and its application Keras function interface, designed and implemented for different optical frequency image analytical framework, the depth of the neural network as shown in the figure below. As shown in Figure 4, The neural network, including image pre-processing, input layer, the connection layer, Dropout layer, and the results of the output layer.

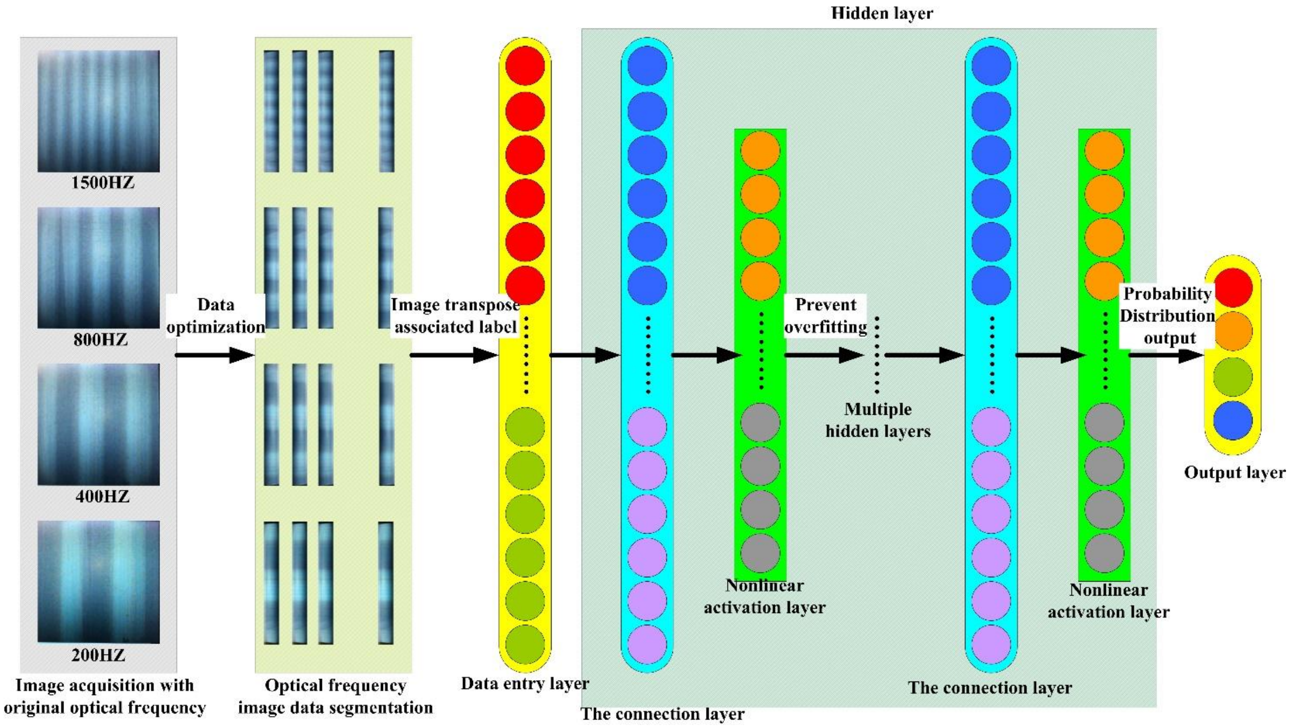

Figure 4. Deep neural network architecture

First, in the image pre-processing, need for two different test site, acquisition of six types of optical frequency image to do classification and after corresponding label on, in the form of hot code alone said. In order to enhance the robustness of the method of neural network and the generalization ability, so as to improve the light of the special circumstances parsing the success rate of frequency algorithm, this paper included in the training set optical frequency image types mainly include:

1. Optical maps of 200HZ, 400HZ, 800HZ and 1600HZ at different heights in the two experimental sites;
2. Space background and full background light frequency images at different heights in the two experimental sites;
3. Incomplete images with occlusion and partial missing appear in the transverse or longitudinal optical frequency images;
4. Partially occluded or partially missing images appear in the corners and edges of optical frequency images;

Secondly, according to the above formula, the partial image of the scanning direction of the shutter of the extended camera has almost the same optical frequency information as the complete optical frequency image. Accordingly, if a complete image of a light frequency matrix, the distribution of 240 x 240 pixels, just need to choose one over ten of the vertical direction as a training set, according to the section on data pre-processing and normalization method is introduced in the formula, in order to facilitate neural network training, is it needed to this part of 240 x 10 to distinguish between the size of the image matrix normalized, Unify its pixel size from the colour format of [65535,0] to the range of [1,0]. After repeated iteration and training, finally, the complete network model is transformed into machine language and transplanted to MPU for subsequent application tests.

2.5 Transplantation Of Neural Networks

After completing the network training and verifying successfully, the network model needs to be transplanted from THE PC to the embedded platform at the receiving end. First of all, under the open source framework, the optical frequency image parsing model successfully trained and verified is saved as a file in .h5 format. Then, the embedded development and configuration platform launched by STMICROELECTRONICS is used to select cube-AI transformation tool kit and send the complete network model into it for parsing. Each layer network contains the number of neurons, and neural network proportional coefficient between adjacent layers all converted to the C language in the form of a database, and then the weight data and the second chapter introduces the optical positioning receiver hardware driver software integrated in full, the part to ensure that the data conversion accuracy, image acquisition and application function such as address resolution between the compatibility and stability. In actual use, the data collected by the camera will be fed into the image parsing function interface in real time by Direct Memory Access (DMA). Its output part is the same as that of the PC, which is a probability array containing six categories. Then, the part with the largest probability weight can be obtained by sorting and retrieving. After ten consecutive parsing, it can correspond to the optical frequency address coding information received by the vehicle, and then get the location of the region

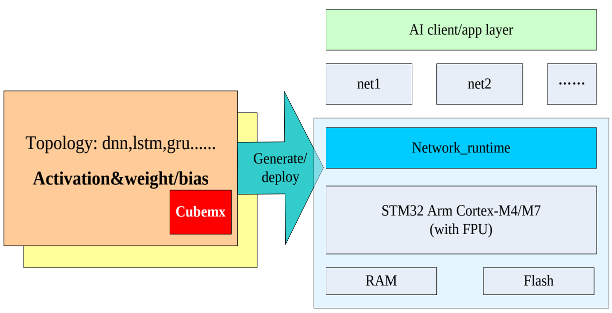

Figure 5. Neural network transplantation process

Due to the parsing process, the embedded artificial intelligence network conversion tools will be based on the embedded chip for transplantation have storage space, to a certain proportion of the weight of the model parts of compression. Therefore, this section further compares the analysis results of the same test set between the complete network model on PC side and the embedded network model after transplantation. The test results are shown in the figure below, output by Softmax function. In the test set composed of 20 groups of images with different optical frequencies, the analytical results of any image matrix of the two networks are almost the same, and both can accurately identify the corresponding fringe frequency of the test image, and the probability evaluation results corresponding to the correct optical frequency classification. Far higher than the other five misclassifications. The process is shown in Figure 5.

3. EXPERIMENTAL AND RESULTS

3.1 Introduction about experimental site

Compared with the previous visible light positioning experiment, which could only be applied in a narrow environment without interference from other light noises, we chose a wider room as the test site to verify the positioning effect of the scheme proposed in this paper.

As shown in Figure 6, the experimental site is 14 meters long, 8 meters wide and 2.8 meters high. We installed lighting sources in different areas of the room. The light source is composed of CKS32 microcontroller and CMOS amplifier circuit, and the corresponding position information can be modulated to the emitted light by changing the on-off time interval of the LED lamp. The hardware platform of the receiving end includes STM32 controller and OV7670 camera. By capturing the high frequency flashing illumination light through the camera, the stripe image with intersecting light and shade can be obtained.

Figure 6. Experimental scene diagram

The receiving device is placed on a four-wheeled vehicle composed of STM32 microcontroller and L298N motor controller that can realize the function of real-time positioning and trajectory fitting under the state of motion. The receiving platform is shown in Figure 7.

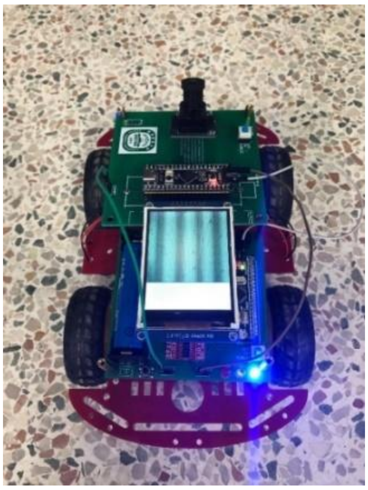

Figure 7. Receiving terminal platform

3.2 Experimental results

After setting up the scene, we first tested the performance of regional positioning in the static condition of the receiver. As mentioned above, firstly, we encode the optical frequency signals of "corner area", "corridor area" and "empty area" separately. Then, the embedded platform that has been transplanted with the optical frequency address image neural network parsing algorithm is used to analyse the received optical frequency address images of different regions, and the corresponding decoding results are compared with the actual location region, the results are as follows.

As shown in Figure 8, when receiver is in relatively empty reception area, when the distance light beacon receiver's height is 1.8 meters, the receiver address information contained on an image of a light frequency of parsing the success rate can reach 100%, the average resolution time consuming to 45ms. When the height of the optical beacon was adjusted to 2.0 meters, the analytic success rate of the receiver was classified again, and the final analytic success rate could still reach 100%, and the average analytic time was 47ms. When the distance between the optical beacon and the receiver is adjusted to 2.2 meters, the receiver can still resolve the address information in the visible light image completely, and the average parsing time is 51ms. Finally, in order to test the method under the background of strong ability of static positioning, keep the receiver under 11 light beacon lighting range, opened the curtains and the room window at the same time, make whole room environment fully bright, and keep the sender and the receiver distance visible light is 1.8 m, under this premise, parsing takes 45ms at the receiving end, The overall parsing success rate is 100%

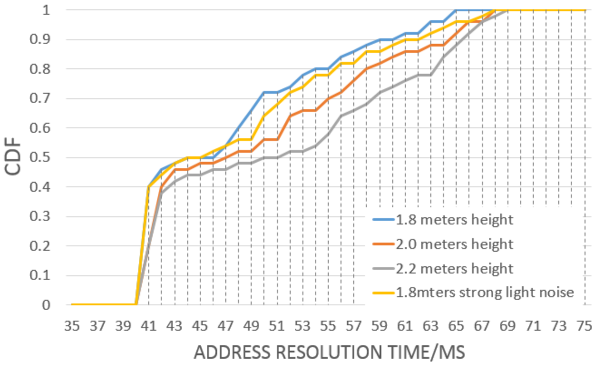

Figure 8. Middle region location time & resolution success rate

Secondly, as shown in Figure 9, when the receiver is in the receiving area at the edge of the branch, in order to test the ability of the system to analyse and locate the light frequency image with slight defect, it is placed under the edge of the obstacle, so that the receiving end can collect the received image with edge defect. Referring to the test and evaluation process in the previous section, the optical frequency address resolution results when the optical beacon is 1.8 meters away from the receiver (including the results in dim environment and bright environment), 2.0 meters away and 2.2 meters away from the receiver are counted. When the distance between the sending and receiving ends is 1.8 meters, the success rate of positioning can reach 100% in dim environment and bright environment, and the average consumption time of parsing is 47ms and 50ms respectively. When the distance between the transceiver and receiver is set to 2.0 m, the positioning performance of the system is similar to that of the system when the distance between the transceiver and receiver is 1.8 m in the bright environment. The average parsing time is 49ms, and the overall success rate is 100%. Finally, the distance between the transceivers was extended to 2.2 m. Among the 50 sets of test results in this round, two sets of data were resolved incorrectly. Among the remaining 48 sets of correctly resolved results, the average resolution time was 53ms, and the overall resolution success rate was 96%.

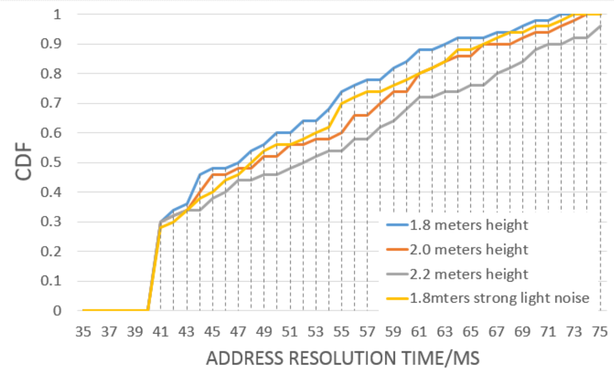

Figure 9. Edge region location time & resolution success rate

In addition to testing the system performance under the condition of complete image and slight defect of image, this experiment also evaluates the system localization ability under the condition of large defect of corner time-frequency image. When the distance between the optical beacon and the receiver is 1.8 m, the overall success rate of the analysis is decreased compared with the first two cases due to the large defect of the image, and the highest is 94%. When the distance extended to 2.0 m, the resolution success rate further decreased slightly to 92%, with an average resolution time of 57ms. Finally, when the height gap between the receiver in the corner and the sender reaches 2.2 meters, the received image quality is not ideal, but the final parsing success rate is 88%, as shown in Figure 10.

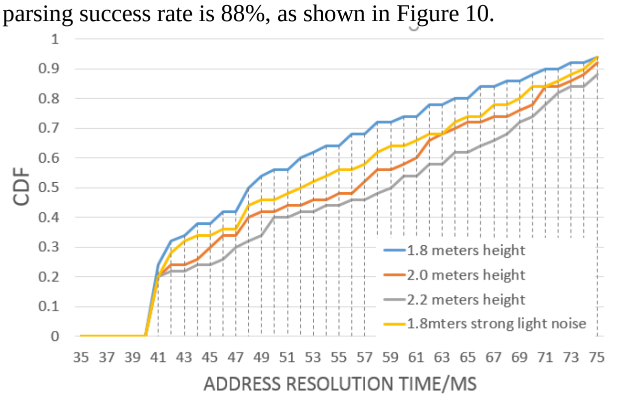

Figure 10. Corner region location time & resolution success rate

The above experimental results show that the system has good anti-interference and accuracy for regional target positioning in static state, and can be used in practical complex indoor situations. In addition, in order to further verify the system's tracking and navigation ability of dynamic targets, multiple routes were planned in the two test sites above to evaluate the real-time resolution ability of optical frequency parsing algorithm for dynamic and fuzzy images. As shown in Figure 11, three routes are planned in blue, red and orange respectively. The blue route, which is a straight route, is no. 3, no. 7, No. 11, No. 15 and No. 19 optical beacon, is used to verify and count the performance results of the scheme under the state of straight driving. Similarly, the red line from the beginning of the 13th light beacon, 8, 5 beacon light, then turn to the left 90 degrees, along a straight line driving all the way to the no. 1 beacon light, then turn left 90 degrees by 6 light beacon its final destination, this line contains two 90 degrees of corner, is mainly used for detection of this set of system when turning the corner location and tracking performance. Finally, the orange route is more complex than the red route, consisting of three 90-degree corners, and is ultimately used to evaluate the results of the combined application under complex road conditions.

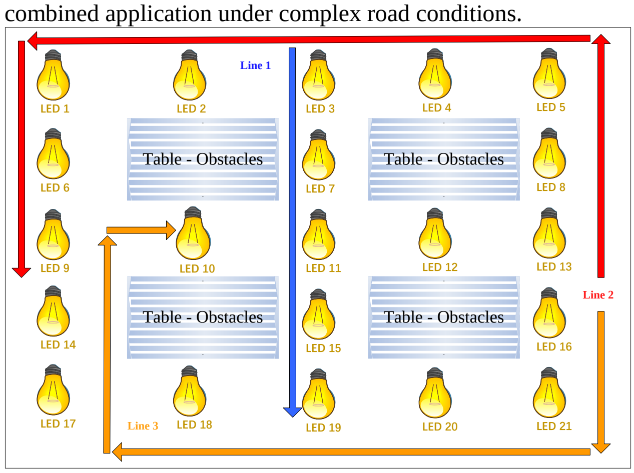

Figure 11 LED light source distribution in site 1

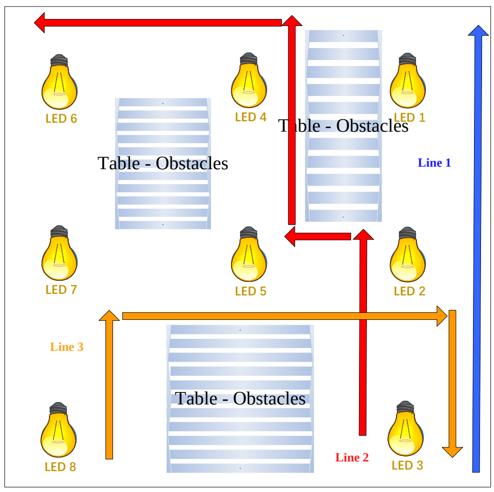

Figure 12.LED light source distribution in site 2

When the car starts from the starting point and successfully passes all cursor nodes on the specified route, and the result of resolving the address of each node is correct, it is regarded as a successful dynamic navigation. Among them, in court 1, vehicles respectively run at a slow speed of 20cm/s and a fast speed of 50cm/s, following the arrows of three routes. For route 1, since there are no path corners or low-light areas, the success rate of the receiving end is 100%, whether it is in slow or fast state. For route 2, which is relatively complicated, the success rate of navigation can still reach 100% if the receiving end passes through each node in turn at a slow speed, while the success rate of navigation is 95% when the receiving end platform passes through the node of route 2 at a fast speed. Finally, for the more complex route 3, the receiver had a 95% and 90% navigational success rate at both speed states, respectively. Referring to similar experimental methods, as shown in Figure 12, three routes were also arranged in Site 2, and the test indexes of each route were the same as those of site 1. The final statistical results, where the success rate of positioning and tracking of the receiving end is 95% when it passes through each node at a slow speed on route 2, which is slightly lower than that of the same comparative experiment in site 1.

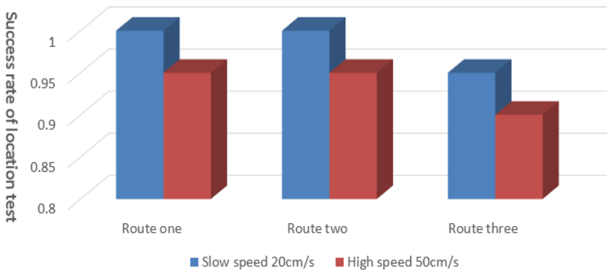

Figure 13.Location test success rate about three routes

4. CONCLUSION

This paper first introduces the basic principle of visible light region positioning, the shutter effect and optical frequency image address coding structure and the basic working mode at both ends are introduced, indicating that the communication positioning method of this system can be realized in principle. On the introduction of the visible light positioning technology based on image sequence coding, on the basis of classification of continue to use Yu Guanine recognition embedded image classification of artificial intelligence method is described, including the basic principle of neural network, optical frequency analysis the structure of the network model, the types of training samples, the network model migration process and transplantation network performance evaluation. The results show that it is feasible to use the embedded artificial intelligence scheme to analyze the collected optical frequency images, and the transplanted network model still retains good classification ability. In the experiment, firstly, the appearance of the two test sites and the location distribution of LED light beacons are introduced, and the positioning or navigation under different heights, different environments and different movement routes are verified and statistically analyzed. Finally, the data conclusions are summarized and analyzed. The results show that the system is successful and effective for indoor positioning and navigation applications.

5. ACKNOWLEDGMENT

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6. REFERENCE

HUANG H Q, YANG A Y, FENG L H, et al. Artificial neural-network-based visible light positioning algorithm with a diffuse optical channel[J]. Chinese Optics Letters, 2017, 15(5): 050601.

KANG Y, KE X Z. Multidimensional coding in visible light communication [J]. China Laser, 2015, 42 (2): 138-144.

WANG T Q, SEKERCIOGLU Y A, ARMSTRONG J. Position accuracy of time-of-arrival based ranging using visible light with application in indoor localization systems[J]. Journal of Light wave Technology, 2013, 31(20): 3302-3308

KESKIN M F, GEZICI S. Comparative Theoretical Analysis of Distance Estimation in Visible Light Positioning Systems[J]. Journal of Light wave Technology, 2016, 34(3): 854-865.

DU P, ZHANG S, CHEN C, et al. Demonstration of a Low-Complexity Indoor Visible Light Positioning System Using an Enhanced TDOA Scheme[J]. IEEE Photonics Journal, 2018, 10(4): 1-10.

STEENDAM H. A 3-D Positioning Algorithm for AOA-Based VLP with an Aperture-Based Receiver[J]. IEEE Journal on Selected Areas in Communications, 2018, 36(1): 23-33.

TRONG-HOP D, MYUNGSIK Y. An in-Depth Survey of Visible Light Communication Based Positioning Systems[J]. Sensors, 2016

ERTAN KAZIKLI, SINAN GEZICI. Hybrid TDOA/RSS based localization for visible light systems[J]. Digital Signal Processing, 2019, 86: 19-28.

Zhang C, Zhang X. Visible light localization using conventional light fixtures and smartphones [J]. IEEE Trans Mob Compute, 2018, 18: 2968–2983

Konings D, Faulkner N, Alam F, et al. Field light: device-free indoor Human localization using passive visible light positioning and artificial potential fields [J]. IEEE Sensors Journal, 2020, 20(2): 1054–1067