Environmental Interference Mitigation and Anti-LED Blocked using ANN with Memory Module in 3D Indoor VLP Systems

Zicai Cao, Mengfan Cheng, Qi Yang, Deming Liu, Lei Deng

School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan, 430074, China, denglei_hust@mail.hust.edu.cn

Abstract *A novel deviation-correction algorithm named memory-artificial neural network is proposed in the ANN-based 3D indoor visible light positioning system for environmental interference mitigation and anti-LED blocked. The average positioning error of 1.04cm and 2.89cm is experimentally achieved under environmental interference and LED-blocked, respectively.*

Introduction

With the fast development of 5G-mobile communication, the demand for precise indoor positioning services and location-based applications is increasing rapidly [1]. The visible light positioning (VLP) based on light-emitting diodes (LED) is a potential solution for not only stable transmission link and immunity to electromagnetic interference but also the advantages of high position accuracy, low cost, and compatibility with building illumination system [2]. The most used scheme in the VLP system is the received signal strength (RSS) technique which estimates the distance to LEDs by the light intensity attenuation factor [3]. Recently, the introduction of machine learning (ML) is saving complicated models calculation in the RSS scheme, contributing to lower algorithm complexity. Typically, an artificial neural network (ANN) combining with the RSS-based VLP system has the advantages of high accuracy, low complexity, and low cost. An ANN-based VLP system is used to achieve positioning with a diffuse channel [4]. In our previous work [5], by using two-layer ANN technique, a 3D positioning system with an average positioning error of 0.9cm has been successfully demonstrated.

However, as a typical supervised-ML, the join of ANN brings the RSS-VLP system not only the advantages, but also inherent shortcomings such as being susceptible to the environment, depending on the database, and insufficient flexibility. Since the robustness which indicates the ability of the system to resist interference such as power fluctuation, channel disturbance, surrounding light, LED blocked, etc, rather than high precision gradually becoming the focus of VLP research, ANN gets less attention. Recently, proposed solutions mainly include fusion network which needs to train multiple classifiers [6], and reinforcement-learning which requires complex iterations [7], but none of them has achieved high accuracy. To achieve both system robustness and high positioning accuracy, we extend our previous work [6] and propose a novel 3D ANN-RSS indoor VLP system called memory-ANN which allows ANN to get database-memory mechanism to improve its robustness to environment. The average positioning error of 1.04cm and 2.89cm is experimentally achieved under environmental interference and LED-blocked respectively in a unit volume of 0.6×0.6×0.8m^3.

Principle

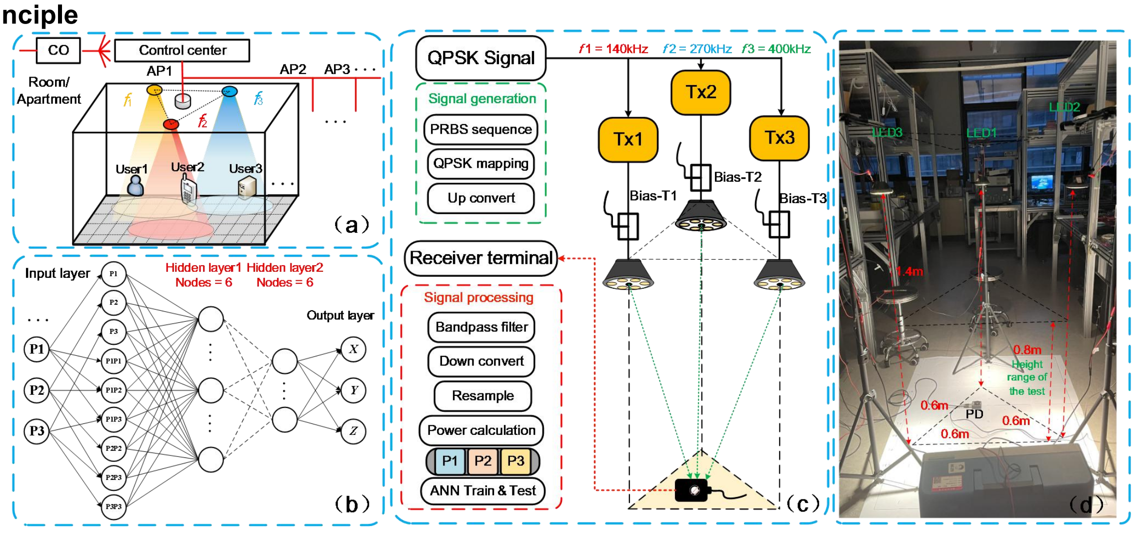

Fig. 1: (a) Typical 3D indoor VLC system. (b) The used ANN models. (c) Experimental setup. (d) The VLP system testbed.

978-1-6654-3868-1/21/$31.00 ©2021 IEEE

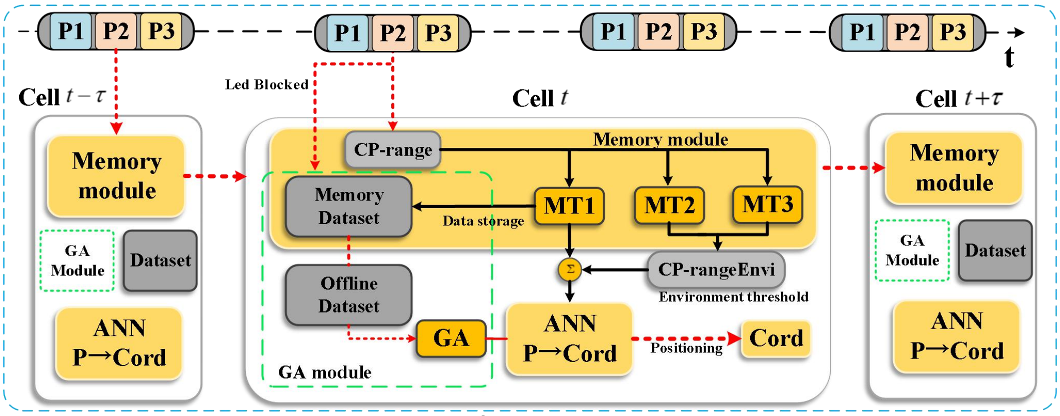

Fig. 2: The block diagram of the proposed Memory-ANN algorithm.

As shown in Fig. 1(a), the central office (CO) connects the core network-data transmission to the user's terminal via the fiber local area network, and the control center can deliver various services to the access point (AP) located at individual room [8]. In our VLP system, each LED is modulated by identification (ID) signals at different carrier frequencies. Subsequently, the received signal strength information from three LEDs is captured as the input parameters of ANN for coordinates estimation. As shown in Fig. 1(b), our original ANN structure is composed of 9 input layer nodes which represent input parameters from the original RSS of three LEDs, 2 hidden layers with 6 nodes and 6 nodes respectively, and 3 output layer nodes.

Fig. 2 shows the principle of the proposed memory-ANN. Each cell contains an original ANN structure accompanied by a memory module and a Genetic algorithm (GA) module. A well-trained ANN can map the corresponding coordinates from the RSS information (P1, P2, P3). In every processing period, the cell receives the RSS information at that moment, calculates the coordinates (positioning), and then updates the memory module. The memory module is mainly divided into three parts: MT1, MT2, and MT3. MT1 is used to store the RSS information for subsequent moments and save data to build an online database. Both MT2 and MT3 are selectively derived from the calculated 'difCP' curve over time which represents the mathematical characteristics in signal strength conversion between adjacent test moments, and they will keep updating during the positioning process. By learning and observing the continuous changes of these parameters between test moments, the cell can finally identify whether the transformation is induced by the detector movement or environmental interference. After that, the cell will choose to block the data or input it to the original ANN. Besides, the GA module is used to deal with the LED-blocked situation. ANN-RSS system is dependent on the database, when an LED is blocked by an object, the information of the signal cannot be obtained, so the positioning of ANN fails. When it happens, M-ANN can fuse the offline database from the simulation model and the online database in the memory module, and then the GA module can obtain the similar mathematical features of the database and search the data efficiently which the M-ANN may need most at that time (the missing data).

Experimental results

Fig. 1(c) illustrates the experimental setup of the 3D RSS-VLP system. In the transmitter, three pseudo-random binary sequences (PRBS) are mapped into three quadrature phase-shift keying (QPSK) ID signals. Then the QPSK signals are modulated with different carrier frequencies of 140kHz, 270kHz, and 400kHz. The transmitted signals are produced by two arbitrary function generators (AFG31000). The generated signals are then combined with DC bias by three bias-tees to drive three LEDs. These LEDs form a triangle and are suspended at the height of 1.4m from the ground which forms a 0.6×0.6×1.4m^3 coverage area. A photodetector (PD) (Thorlabs, PDA36A) with an integrated amplifier is placed within the triangle region for receiving optical signals from LEDs. A digital storage oscilloscope (DSO, Tektronix, DSA725040D) with a sampling rate of 25 MSa/s is used for data capture. Offline signal processing including signal demodulation, power measurement, and ANN training and testing is then performed. Fig. 1(d) presents the photos of our VLP system test bed. In our test, 100 reference points (5×20) within the triangle area with a height of 0cm, 20cm, 40cm, 60cm and 80 cm are selected. At each point, LED powers are captured by 160 times (5×20×160 = 16000) to build a database for training the ANN. We design to add light-blocking materials between the LED and the detector to create environmental interference to test the system performance, and the same number of the signal strength data samples are collected in different disturbed environment scenarios.

978-1-6654-3868-1/21/$31.00 ©2021 IEEE

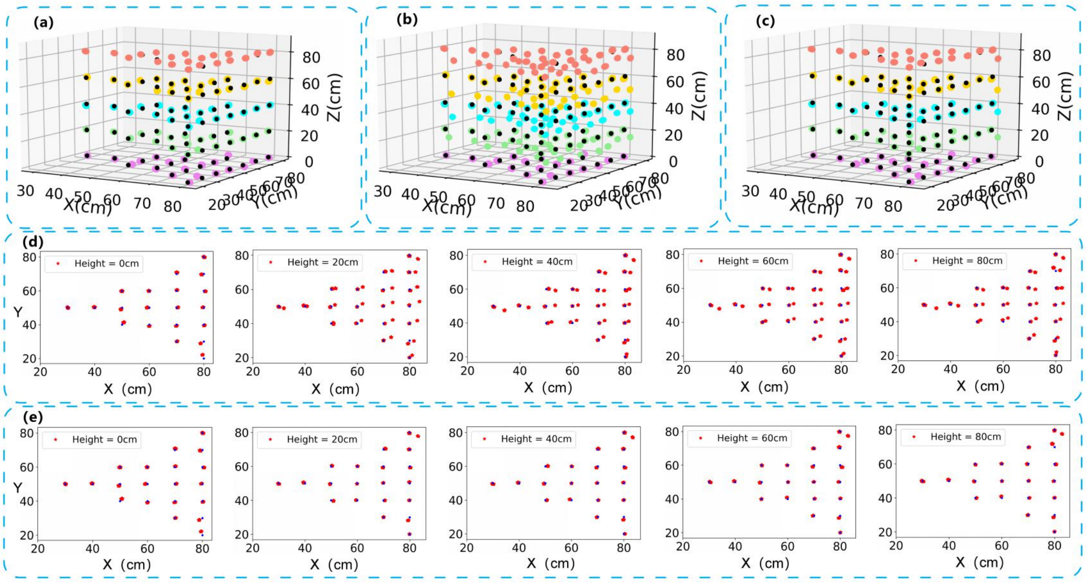

Fig. 3: 3D positioning result without (a) and with (b) the environmental interference, and with the M-ANN (c). 2D view (b) with heights of 0cm, 20cm, 40cm, 60cm and 80cm (d), and 2D view (c) with heights of 0cm, 20cm, 40cm, 60cm and 80cm (e).

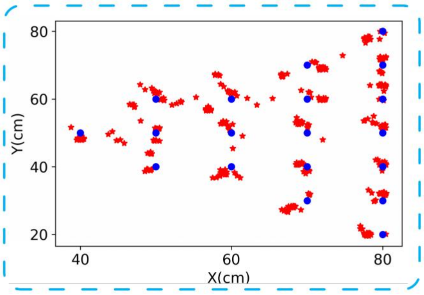

Fig. 4: The positioning result given by M-ANN with GA module when LED is blocked.

Fig. 3(a) shows the 3D positioning result of the original ANN without the influence of environmental interference while the black dots represent real coordinates and the coloured dots represent positioning coordinates in the 3D view figure. The average positioning error is 0.86cm that is similar to the result in our previous work [6]. When we add light-blocking materials to create interference, the accuracy of the original ANN is seriously affected and degrades to 6.14cm as shown in Fig. 3(b). The 2D view of Fig. 3(b) at different heights are shown in Fig. 3(d). The blue dots represent the real coordinates while the red star points represent the calculated coordinates in the 2D figure. With the help of M-ANN, the system can resist the interference and the average positioning error is optimized significantly to 1.04cm. And the 3D positioning result of M-ANN is shown in Fig. 3(c), and Fig. 3(e) shows the 2D view of Fig. 3(c).

Unlike the schemes using image sensors, LED-blocked is fatal to the RSS system. Fig. 4 shows the result given by M-ANN when the LED-Blocked happens. The blue dots represent the test coordinates where we set the LED blocked and the red star points represent the coordinates calculated by the GA module. The numerical results are shown in Table.1, which are the actual coordinates and the average of the coordinates (each cord 20 times) given by the GA module. Finally, we get the average positioning error in the case of LED-blocked is 2.89cm. From the above results, we can see that the proposed M-ANN can still maintain precise positioning while the original ANN fails.

Tab. 1: GA search results(cm)

Real	Cal (mean)	Real	Cal (mean)
（70,30）	(68.13,28.26)	（40,50）	(40.08,48.42)
（70,40）	(69.26,40.18)	（50,60）	(50.66,60.96)
（70,50）	(69.17,52.98)	（60,50）	(58.20,54.47)
（50,50）	(49.05,52.50)	（60,60）	(59.77,62.87)
（60,40）	(59.30,38.42)	（70,60）	(69.84,62.82)
（80,20）	(78.01,20.35)	（70,70）	(71.74,69.50)
（80,60）	(79.87,60.31)	（80,40）	(79.92,40.90)
（50,40）	(49.37,42.30)	（80,50）	(79.11,52.90)

Conclusion

We propose a novel ANN-based deviation-correction algorithm for a 3D indoor VLP system to improve robustness. The memory mechanism is introduced into our original ANN to maintain precise positioning even when environmental changes occur. In our experiment, the M-ANN can achieve precise positioning with the average accuracy of 1.04cm and 2.89cm under environmental interference and LED-blocked respectively. The results show that the proposed scheme can effectively increase the robustness of the RSS-VLP system.

Acknowledgments

National Key Research and Development Program of China (2018YFB1800904).

978-1-6654-3868-1/21/$31.00 ©2021 IEEE

Reference

[1] M. Yasir, et al., Journal of Lightwave Technology, 34(4), 2016.
[2] J. Luo, et al., IEEE Communications Surveys & Tutorials, 19(4), 2017.
[3] N. Chaudhary, et al., 2019 2nd West Asian Colloquium on Optical Wireless Communications, 8770211.
[4] H. Huang, et al., Chinese Optics Letters, 15(5), 2017.
[5] J. He, et al., Optical Fiber Communications Conference and Exposition, 2019, paper Th3I.2.
[6] E. Wong, et al., European Conference on Optical Communication, 2020, paper TU2G-1.
[7] X. Guo, et al., IEEE Photonics Journal, 9(6),2017.
[8] Z. Zhang, et al., Optics Express, 27(16), 2019.