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Research on AR Positioning System Based on Kalman Filtering Algorithm

Enhan Chen[1,a], Qi Zhang[1,b], Ning Mao[1,c], Jinxiu Li[1,d], Guwei Li[1,e,*]

[1]*Artificial Intelligence College, Zhejiang Dongfang Polytechnic, Wenzhou, China*
[a]*364940760@qq.com*, [b]*2731832296@qq.com*, [c]*1097658283@qq.com*,
[d]*18357655299@163.com* ,[e]*3168897@qq.com*
**Corresponding author*

Abstract: *This study focuses on the application of the Kalman filtering algorithm in the AR positioning system. It elaborates on the principles of both and constructs the corresponding system model. Verified by cases such as indoor AR navigation and industrial AR-assisted assembly, as well as indoor and outdoor experiments, this algorithm can significantly improve the positioning accuracy and system stability. However, complex noise and sensor failures will affect its performance. In the future, it is planned to integrate advanced algorithms, optimize the hardware, and customize scenario solutions to facilitate the development and widespread application of the AR positioning system.*

Keywords: *Kalman, Algorithm, AR*

1. Introduction

Augmented Reality (AR) technology has developed rapidly in recent years. By skillfully integrating virtual information with the real world, it brings users an immersive experience. In numerous application scenarios, such as intelligent navigation, industrial inspection, education and teaching, medical assistance, etc., precise positioning is a key prerequisite for the AR system to function effectively. For example, in intelligent navigation, AR technology needs to determine the user's position and orientation in real time and accurately to provide accurate navigation guidance. During industrial inspection, accurate positioning is required to precisely correspond the virtual information of the equipment with the real equipment, assisting workers in efficient detection. However, in practical applications, AR positioning systems are often disturbed by various types of noise, such as sensor measurement noise, environmental factor interference, etc., making it difficult for the positioning accuracy to meet the requirements. As an efficient state estimation method, the Kalman filtering algorithm has shown significant advantages in processing noisy data and improving system accuracy. Introducing it into the AR positioning system is expected to effectively filter out noise, improve positioning accuracy, enhance the stability and reliability of the AR system, and promote the in-depth application of AR technology in more fields. Therefore, studying the AR positioning system based on the Kalman filtering algorithm has important practical significance. Foreign research on AR positioning systems and the Kalman filtering algorithm started relatively early and has achieved fruitful results both in theory and practical application. Many scientific research teams and enterprises have actively explored and applied the Kalman filtering algorithm to different types of AR positioning systems. For example, some studies focus on AR positioning in complex indoor environments[1]. By fusing data from multiple sensors through the Kalman filter, the positioning accuracy has been effectively improved. Relevant research in China is also developing rapidly. Universities and scientific research institutions have successively launched research projects, focusing on the optimization and innovative application of the Kalman filtering algorithm in AR positioning, and attempting to combine it with cutting-edge technologies such as deep learning to further improve the system performance. Although there have been many studies, there is still a need for in-depth exploration in aspects such as the adaptive adjustment of the parameters of the Kalman filtering algorithm in different complex environments and the deep integration with other advanced positioning technologies. There are certain research gaps, which provide directions for subsequent research.

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2. Principles of AR Positioning System and Kalman Filtering Algorithm

2.1. Overview of AR Positioning System

2.1.1. Principle of AR Positioning System

The AR positioning system mainly relies on a variety of sensors to collect data. Common sensors include Inertial Measurement Unit (IMU), Global Positioning System (GPS), cameras, etc. After the sensors obtain information such as the position and attitude of the user equipment, the system uses specific algorithms to process and analyze these data, so as to accurately calculate the position and orientation of the equipment in the real world. Then, according to the calculation results, the virtual information is accurately superimposed on the corresponding position of the real scene to achieve the fusion presentation of virtual and real[2]. For example, when a user uses an AR navigation application, the GPS sensor in the mobile phone provides approximate position information, the IMU sensor senses the attitude change of the device, and the camera captures the surrounding environment images. The system fuses these data through algorithms to determine the user's position and display accurate navigation indication arrows and other virtual information on the screen[3].

2.1.2. Key Technologies of AR Positioning System

This technology enables AR devices to build maps in real time through sensor data in unknown environments and simultaneously determine their own positions in the maps. In environments with poor GPS signals such as indoors, SLAM technology is particularly important. For example, the vision-based SLAM algorithm uses the image sequence captured by the camera to extract feature points and match them, so as to calculate the movement trajectory of the device and the structure of the surrounding environment, providing a basis for AR positioning. Different sensors have their own advantages and disadvantages. For example, the positioning accuracy of GPS is good outdoors, but it is easily blocked indoors; the IMU can quickly respond[4] to attitude changes, but it will generate cumulative errors after long-term use. Through the sensor fusion technology, by comprehensively processing the data of multiple sensors, the advantages can be complemented, and the positioning accuracy and stability can be improved. For example, by fusing the data of GPS and IMU and using the Kalman filtering algorithm to estimate the system state, more accurate position and attitude information can be obtained. The computer vision-based positioning method determines[5] the position of the device by analyzing the images collected by the camera, identifying the feature objects or marker points in the scene, and matching them with the pre-stored database. For example, in some AR games, by identifying specific image markers, the game system can accurately locate the player's position and achieve accurate interaction between virtual elements and the real scene[6].

2.2. Principle of Kalman Filtering Algorithm

2.2.1. Basic Concept of Kalman Filtering Algorithm

The Kalman filtering algorithm is a recursive filtering algorithm based on the state space model of a linear system. It assumes that the system state changes over time according to a certain dynamic equation, and at the same time estimates the system state through the observation data. Its core idea is to use the state estimate of the previous moment and the observation value of the current moment to obtain the optimal state estimate of the current moment through specific mathematical calculations[7], and it can effectively process the system data containing noise.

2.2.2. Characteristics and Advantages of Kalman Filtering Algorithm

The Kalman filtering algorithm does not need to store a large amount of historical data. It only needs the state estimate of the previous moment and the observation data of the current moment to perform calculations, which is suitable for application scenarios with high real-time requirements, such as the AR positioning system that needs to update the positioning information in real time. By reasonably setting the process noise covariance matrix and the observation noise covariance matrix, the Kalman filtering algorithm can accurately estimate the system state in the data containing noise, effectively improving the accuracy and reliability of the data, which is crucial for the AR positioning system seriously disturbed by noise[8]. The computational complexity of the algorithm is relatively small, and it can quickly complete the update of the state estimate, meeting the real-time response requirements of the AR positioning system and ensuring that users will not experience obvious delays when using AR applications.

3. Application Analysis of Kalman Filtering Algorithm in AR Positioning System

3.1. Application Scenario Analysis

In AR navigation, users need real-time and accurate positioning information to obtain precise navigation guidance. For example, in a large shopping mall, due to the limited GPS signal, traditional navigation methods are difficult to meet the requirements. AR navigation uses the Kalman filtering algorithm to fuse data from multiple sensors, which can accurately locate the user's position, clearly display the route to the target store on the mobile phone screen, and at the same time, combine the virtual annotations of the surrounding environment to enable users to find the destination more intuitively. In the equipment inspection work in industrial production, the AR system is required to be able to accurately locate the position of the equipment, and accurately superimpose the virtual model, parameter information, etc. of the equipment on the real equipment[9]. Using the Kalman filtering algorithm to improve the positioning accuracy can assist workers in quickly identifying the fault points of the equipment, viewing detailed maintenance instructions, improving the inspection efficiency and accuracy, and ensuring the stable operation of industrial production. In AR education applications, such as the virtual reproduction teaching of historical and cultural sites. When students view the AR display of the sites through mobile devices, the system needs to accurately locate the position and viewing angle of the students. Using the Kalman filtering algorithm to ensure the accurate matching of the virtual scene and the real scene creates a realistic learning environment for students and enhances the learning effect[10].

3.2. Construction of AR Positioning System Model Based on Kalman Filtering Algorithm

The architecture of the AR positioning system based on the Kalman filtering algorithm mainly includes a data collection module, a data processing module, and a display module. The data collection module is responsible for collecting various types of sensor data, such as the acceleration and angular velocity data of the IMU, the position data of the GPS, and the image data captured by the camera. The data processing module preprocesses the collected data, removes outliers and noise, and then uses the Kalman filtering algorithm to fuse the data, estimate the state of the system, and obtain accurate position and attitude information. The display module fuses and displays the virtual information and the real scene according to the processed results and presents them to the user. The various modules cooperate with each other to realize the functions of the AR positioning system.

4. Case Studies

4.1. Indoor AR Navigation System Based on Kalman Filtering

A shopping mall has introduced an indoor AR navigation system based on the Kalman filtering algorithm, aiming to improve the shopping experience of customers. The system locates by fusing the data of Bluetooth positioning beacons, IMU, and cameras. Without the Kalman filter, due to environmental interference and sensor noise, the positioning error is relatively large, and customers often cannot accurately find the route. After introducing the Kalman filtering algorithm, by fusing and processing the sensor data, the noise is effectively filtered out. The experimental data shows that the positioning accuracy has been improved from the original average error of 2 - 3 meters to 0.5 - 1 meter. Customers can find the target store more smoothly when using AR navigation, significantly improving the accuracy and stability of the navigation.

4.2. Positioning Application in Industrial AR-assisted Assembly

An automobile manufacturing enterprise has adopted an industrial AR-assisted assembly system in the engine assembly process. The system uses the Kalman filtering algorithm to fuse the data of visual sensors and laser rangefinders to provide precise assembly guidance for workers. Before using the Kalman filtering algorithm, due to the complex assembly environment, the sensor data is easily disturbed, resulting in inaccurate positioning and a relatively large assembly error, and the defective product rate is relatively high. After applying the Kalman filtering algorithm, the positioning accuracy has been greatly improved, and the assembly error has been significantly reduced. According to statistics, the defective product rate of assembly has been reduced from the original 5% to less than 1%, effectively improving the assembly efficiency and product quality.

4.3. Case Comparison and Analysis

By comparing the two cases, it can be found that in different application scenarios, the Kalman filtering algorithm can significantly improve the performance of the AR positioning system. The indoor AR navigation system pays more attention to real-time performance and positioning accuracy to meet the needs of users to quickly and accurately find the destination; the industrial AR-assisted assembly system has extremely high requirements for positioning accuracy and stability to ensure the accuracy and reliability of the assembly work. In the indoor navigation case, the algorithm mainly deals with the fusion of data from multiple low-precision sensors and noise suppression; while in the industrial assembly case, it needs to deal with the interference problem of data from high-precision sensors in a complex environment. Both cases show that by reasonably adjusting the parameters of the Kalman filtering algorithm according to the characteristics of different application scenarios, its advantages can be fully utilized, and the performance of the AR positioning system can be improved.

5. Experimental Verification and Result Analysis

5.1. Experimental Design

5.1.1. Experimental Purpose and Environment Setup

The purpose of the experiment is to verify the effect of the Kalman filtering algorithm on improving the accuracy of the AR positioning system. The experimental environment is set up as follows: A mobile device equipped with an IMU, GPS, and camera is used as the AR positioning terminal; experimental sites are set up indoors and outdoors respectively. The indoor site simulates a complex shopping mall environment, and multiple Bluetooth positioning beacons are arranged; the outdoor site is selected in an open area to ensure good GPS signals. By conducting experiments in different environments, the performance of the algorithm is comprehensively evaluated.

5.1.2. Experimental Data Collection and Processing Method

During the experiment, the sensors of the mobile device are used to collect data such as position and attitude. The data is recorded every 0.1 seconds, and each experiment lasts for 10 minutes, and a total of 10 groups of experiments are carried out. The collected data is preprocessed through a data processing program written in Python to remove obvious outliers. Then, the AR positioning system without and with the Kalman filtering algorithm is used to process the data respectively, and the positioning results are calculated.

5.2. Experimental Results and Analysis

5.2.1. Comparative Analysis of Positioning Accuracy

The experimental results show that without using the Kalman filtering algorithm, the average indoor positioning error is 1.8 meters, and the average outdoor positioning error is 0.8 meters; after using the Kalman filtering algorithm, the average indoor positioning error is reduced to 0.6 meters, and the average outdoor positioning error is reduced to 0.3 meters. By comparing the positioning error data with and without the algorithm in different environments and drawing an error comparison line chart (Figure 1), it can be intuitively seen that the Kalman filtering algorithm significantly improves the positioning accuracy of the AR positioning system.

5.2.2. Algorithm Performance Evaluation

The computational efficiency of the Kalman filtering algorithm is evaluated. The results show that when the algorithm processes data, the average calculation time for each iteration is 0.005 seconds, which can meet the real-time requirements of the AR positioning system. At the same time, by observing the stability of the algorithm through multiple experiments, it is found that the algorithm can maintain good performance under different environmental and data conditions, and there are no obvious fluctuations and abnormalities, indicating that the algorithm has high stability.

5.2.3. Result Discussion

The experimental results fully verify the effectiveness of the Kalman filtering algorithm in improving the accuracy of the AR positioning system. However, during the experiment, it is also found that when the environmental noise is too complex or the sensor fails, the performance of the algorithm will be affected to a certain extent. This indicates that in practical applications, it is still necessary to further optimize the algorithm to improve its adaptability to complex environments and its fault tolerance to sensor failures. In the future, it is advisable to consider combining it with other advanced algorithms, such as the particle filter algorithm, to further improve the performance of the AR positioning system.

6. Conclusion

This research deeply explores the application of the Kalman filtering algorithm in the AR positioning system, and conducts systematic analysis and practical verification from multiple aspects. Through the detailed elaboration of the principles of the AR positioning system and the Kalman filtering algorithm, we have a clear understanding of the working mechanisms and internal connections of the two, which lays a solid theoretical foundation for constructing an AR positioning system model based on the Kalman filtering algorithm. In terms of system model construction, the architecture of the AR positioning system based on the Kalman filtering algorithm covers modules such as data collection, processing, and display. Each module has a clear division of labor and close cooperation, ensuring that the system can efficiently fuse data from multiple sensors to achieve precise positioning and the fusion display of virtual and real. Case studies have strongly demonstrated the remarkable effectiveness of this algorithm in different application scenarios. In the indoor AR navigation system, by fusing data from multiple sensors and applying the Kalman filtering algorithm, the positioning accuracy has been greatly improved, providing reliable navigation guidance for users in complex indoor environments and significantly enhancing the user experience. The industrial AR - assisted assembly system, with the help of this algorithm, has effectively reduced assembly errors, improved product quality and production efficiency, highlighting its important value in the industrial field. In the experimental verification section, through carefully designed experiments and tests in different indoor and outdoor environments, the results clearly show that the Kalman filtering algorithm can significantly reduce the positioning error of the AR positioning system. At the same time, it has high computational efficiency and good stability, fully meeting the stringent requirements of the AR positioning system for real - time performance and reliability. However, we must also face up to the problems exposed during the research process. Although the Kalman filtering algorithm has a significant effect in improving positioning accuracy, when faced with extremely complex environmental noise or sensor failures, its performance will be affected to a certain extent. This means that in the actual application and promotion, we still need to continuously optimize the algorithm to further improve its adaptability to complex and changeable environments and its fault tolerance to sensor failures. Looking to the future, with the rapid development of technology, the application prospects of AR technology will become increasingly broad. On the one hand, we can deeply explore the deep integration of the Kalman filtering algorithm with other advanced algorithms, such as the particle filtering algorithm and the deep learning algorithm. By leveraging the complementary advantages of different algorithms, we can comprehensively improve the performance of the AR positioning system. On the other hand, in the research and development and optimization of hardware devices, efforts should be made to improve the accuracy and stability of sensors, providing a better data foundation for the efficient operation of the algorithm. In addition, developing more targeted AR positioning solutions customized to the personalized needs of different industries and scenarios will be the key to promoting the widespread application of AR technology. We believe that through continuous research and innovation, the AR positioning system based on the Kalman filtering algorithm will shine in more fields, bringing more convenience and surprises to people's lives and work, and strongly promoting AR technology to a new stage of development, building a more intelligent and convenient digital future.

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