

Research On Vision Based SLAM Technology For UAV

Zhaoyun Xu *

School of Energy Power and Mechanical Engineering, North China Electric Power University,
Beijing, China

* Corresponding Author Email: 120221350105@ncepu.edu.cn

Abstract. The application of Simultaneous Localization and Mapping (SLAM) technology in the field of UAVs is becoming more and more extensive and in-depth. This paper reviews its rapid development and breakthroughs in recent years, lists some problems that can still be improved, and prospects the development of SLAM technology in the future. The SLAM technology is a powerful and highly flexible technology, whose application in Unmanned Aerial Vehicles (UAVs) can improve their operation safety and autonomous work ability. This paper lists some current research results which show the application of SLAM technology based on vision in UAVs plays a key role in obstacle avoidance, positioning and path planning. At the same time, in order to further enhance the help of vision based SLAM technology to UAVs, many emerging technologies are introduced to integrate with it. This paper reviews the impact of integrating SLAM technology based on vision with GPS positioning technology, inertial measurement technology and other technologies on UAVs during operation as well. The relevant research in this paper will play a significant role in the application of vision based SLAM technology in UAVs and the integration with other technologies.

Keywords: SLAM; Unmanned aerial vehicle; Integrated technology.

1. Introduction

The rapid development of SLAM technology makes it more and more mature. Its functions are more and more powerful, and its application fields are more and more extensive. SLAM technology mainly relies on cameras, rangefinders, odometers and other sensors to collect surrounding data, locate themselves and build environmental maps [1]. Its emergence is closely related to the development of mobile robots, including UAVs. UAVs need to solve the positioning problem in the environment without specific positioning basis, such as indoor places, which requires SLAM technology to play a role [2]. SLAM technology can explore places that are difficult for humans to reach in an efficient and autonomous way, helping UAVs map and locate the environment to complete the scheduled tasks [3]. However, as SLAM technology becomes more and more complex, it faces more and more risks and problems. Therefore, the application of SLAM technology in UAVs need to be continuously improved [4].

This paper first introduces the basic principles of SLAM technology and expounds some of the problems it faces at present and looks forward to the future development of SLAM technology. This paper focuses on the application of SLAM technology in UAVs, including assisting UAVs obstacle avoidance, helping UAV positioning and path planning. At the same time, the problems encountered in the application of SLAM technology in UAVs and the feasible improvement measures are also described. Finally, this paper studies the integration of SLAM technology and other technologies in UAVs, such as GPS system.

2. The basic principles of vision based SLAM technology

The SLAM system is a crucial part of the field of artificial intelligence, which plays a vital role in the movement of robots. Its emergence is to help robots detect environments without GPS signals or unknown environments and construct environmental maps around robots. SLAM technology mainly includes two aspects: mapping and localization. These two aspects complement each other, as determining the robot's positioning in the environment is crucial for map drawing, and having a detailed map at the same time can better determine the robot's position. The operations of detecting

the environment and constructing maps are all independently completed by robots, without the need for manual intervention. In the process of building environmental maps, a series of sensors are involved, such as ultrasonic sensors, laser scanners, red, green blue (RGB) cameras, etc [5].

Its brief working principle is as followed. First, it builds a basic map based on the initial position of the robot, record the robot's starting posture, and set landmarks in the surrounding environment. Next, the robot begins to move and the surrounding environment changes to construct a new map and obtain new landmarks from the new map. Finally, associate the new landmark with the existing landmark and calculate the position of the robot. The SLAM system will repeat the above steps to continuously expand the scope of the constructed map. By constructing an environmental map, robots can be assisted in completing tasks such as obstacle avoidance and path planning [5].

Although SLAM technology has developed rapidly, it still has some problems and has a lot of room for improvement. The most common problem is the uncertainty in SLAM technology, which includes the corresponding error, hardware uncertainty and location uncertainty. The corresponding error is mainly that the robot mistakenly identifies the new landmark as another existing landmark when using SLAM technology for landmark labeling. This often occurs in landmark environments with similar characteristics. The uncertainty of the hardware is mainly caused by the interference of the data collected by SLAM sensor or the problem of the sensor itself, which will make the robot's observation of the surrounding environment wrong. The uncertainty of position is the problem that the robot has when using SLAM technology to locate itself, which is mainly caused by the insufficient number of landmarks or the contradictory measurement distance. These problems of SLAM technology will have a great impact on the motion of robot [3]. With the deepening of related research in recent years, there have arised many new technologies that can improve the problems faced by SLAM technology. These new technologies include but are not limited to selecting more appropriate key frames, applying revolutionary neural network (CNN) to closed loop detection, and using multi-sensor fusion, etc [1].

From the past development process of SLAM and the problems it faces now, the future of SLAM technology will mainly focus on the research and development of new and unconventional sensors and deep learning capabilities. The research and development of sensors can improve the accuracy of SLAM technology for robot positioning and better detect the color direction around the robot. At the same time, the introduction of unconventional sensors can improve the robot's ability to perceive the surrounding environment and obtain more information about it. The ability of deep learning will make SLAM technology more intelligent and better deal with more complex situations through autonomous learning of previous scenarios [2].

3. The practical application of vision based SLAM technology in UAV

By using SLAM technology, UAVs can observe their surrounding environment, including the detection of nearby obstacles. However, SLAM technology itself cannot change the motion of UAVs. Therefore, the real-time data collected by SLAM technology can help the UAV avoid obstacles in the flight process, so as to increase the safety of UAV operation. At present, the commonly used obstacle avoidance method based on SLAM technology is the artificial potential field method. Its working principle is to regard the movement of UAV in the environment as a movement in a virtual human workshop, in which obstacles generate repulsion force on UAV and the target exerts a gravitational pull-on UAV, so as to achieve the purpose of changing the movement of UAV to avoid obstacles. However, when the resultant force between the obstacle and the target at a certain point is zero, the UAV cannot move. Therefore, the obstacle avoidance algorithm can be improved by redesigning the target potential field and obstacle potential field function. A potential field function based on the distance between UAV and target, the Euclidean and Mahalanobis distance between UAV and obstacle is designed. The deflection angle of UAV during obstacle avoidance is determined by using the relationship between the negative gradient of potential field function and UAV speed vector, so as to achieve the purpose of obstacle avoidance through maneuver [6].

SLAM technology based on vision can play a important role in UAV navigation and path planning tasks as well. In open space such as outdoors, GPS positioning and navigation system is a reliable solution. But in the complex indoor environment, GPS is not as reliable as SLAM system based on UAV itself. Through vision-based SLAM technology, the image of the surrounding environment can be collected, and the related targets can be projected, and then the target can be set as the surface to help UAV locate. The computer vision algorithm is used to extract the feature points of the target and record the landmark, so as to determine the relevant spatial position of the UAV. At the same time, with the aid of altimeter, rangefinder and other equipment, it can better help the UAV know its position and speed in space and plan the path to the target [7].

However, using vision-based SLAM system of UAV for positioning and path planning also has some defects. Without the participation of GPS and other technologies, UAVs' observation of the surrounding environment through SLAM technology is limited. However, the observation of the surrounding environment can be expanded by using the formation flying of UAVs and integrating the data collected by SLAM technology for calculation, so as to better complete relevant tasks. The experimental data shown in the Table 1 indicates that monocular SLAM with a cooperative target can more accurately determine the position of the UAV [7].

Table 1. Total Mean Squared Error for the estimated position of the UAV [7]

Method	MSEX (m)	MSEY (m)	MSEZ (m)
Monocular SLAM	9.1325	3.6424	0.0642
Monocular SLAM with a cooperative target	5.5552	1.9708	0.0367

However, there are also some problems in the cooperative operation of multiple UAVs using SLAM technology, the most obvious of which is the delay caused by the processing time of data and the pressure on the server caused by a large amount of data processing. For the cooperative operation of fewer UAVs or the observation of a small range of environment, these effects can often be ignored, but with the increase of the number of UAVs and the increase of space environment, its impact will gradually begin to appear. Especially in the information transmission and exchange between multiple UAVs, it often takes a lot of time. In order to reduce the impact of these problems, researchers can use a more powerful ground station or a more powerful server to reduce the communication time and strengthen the data processing ability [8].

4. The integration of vision based SLAM technology with other technologies in UAV

SLAM technology based on vision can help UAVs perceive their surroundings during flights. However, SLAM technology can only detect the environment in a small range around UAVs. Therefore, some other technical means and vision-based SLAM technology can work together to better help UAVs monitor the surrounding situation, so as to achieve better obstacle avoidance, better path planning or better cooperative flight.

The use of altimeter can improve the accuracy of UAV position estimation. To test this point, it is assumed that a control system exists which can maintain UAV target tracking and impose poor initial conditions on the landmark states. The experimental results in the Table 2 and Figure 1 show that in three repeated experiments under different initial error conditions, the UAV with altimeter can both better estimate the position of UAV [7].

Table 2. Mean Squared Error for the estimated position of the target (MSEXt, MSEYt, MSEZt) and the estimated position of the UAV (MSEXc, MSEYc, MSEZc) [7]

		MSEXt(m)	MSEYt(m)	MSEZt(m)	MSEXc(m)	MSEYc(m)	MSEZc(m)
With Altimeter	$\sigma_a = 1$ m	0.0075	0.0187	0.0042	0.0045	0.0151	0.0033
	$\sigma_a = 2$ m	0.1214	0.2345	0.0302	0.1170	0.2309	0.0219
	$\sigma_a = 3$ m	18.9603	3.0829	0.9351	18.9578	3.0790	0.8962
Without Altimeter	$\sigma_a = 1$ m	0.0178	0.0139	0.0153	0.0145	0.0105	0.0207
	$\sigma_a = 2$ m	1.7179	0.4689	0.2379	1.7078	0.4686	0.2084
	$\sigma_a = 3$ m	80.9046	12.8259	7.3669	80.9000	12.8185	6.9981

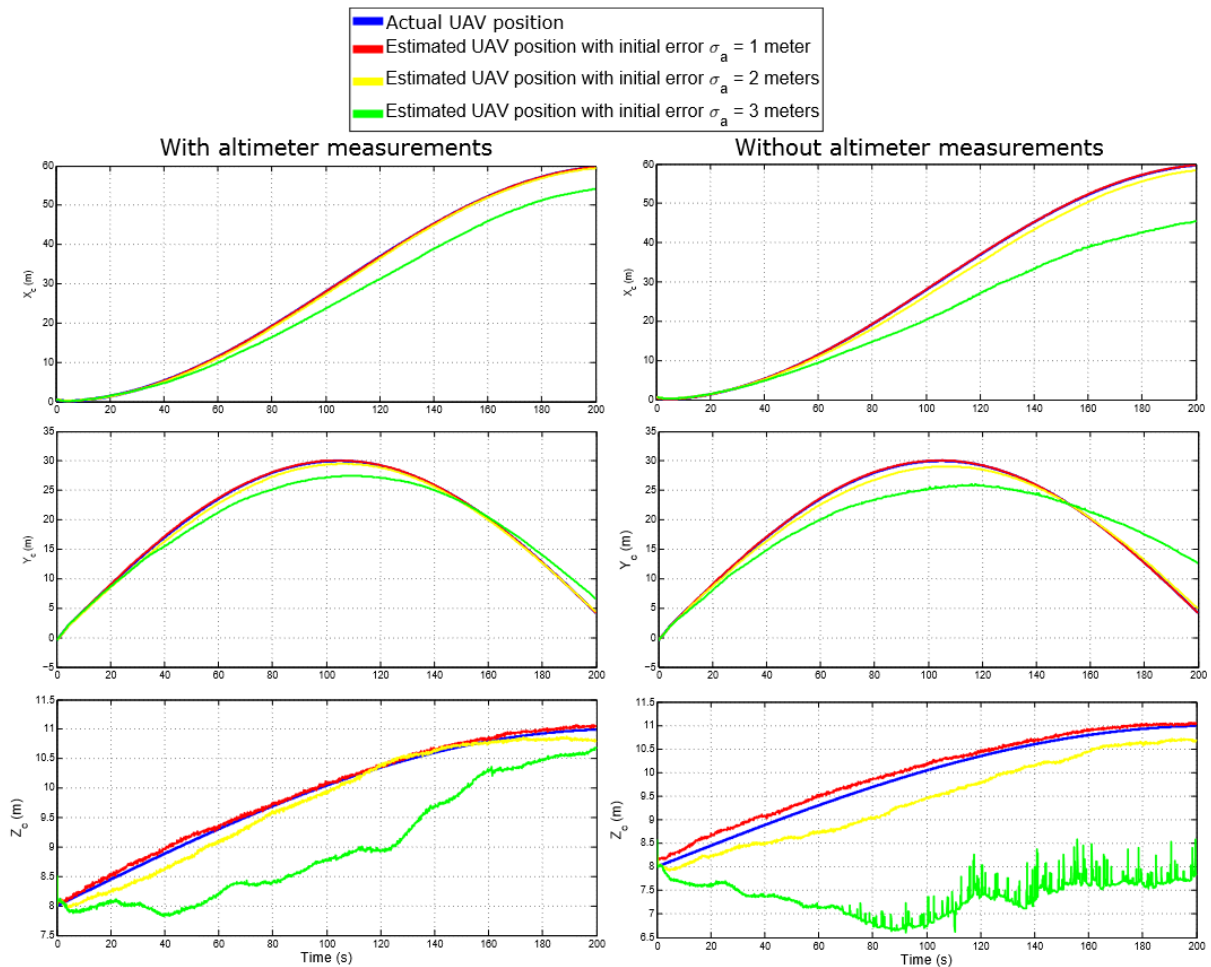


Fig. 1 UAV estimated position [7]

Not only altimeters, but also UAV with anchors or inertial measurements can accurately calculate the estimated position of the drone. The specific experimental data is shown in the Table 3, indicating a significant reduction in the total mean squared error for the estimated position of the UAV when combined with other technologies [7].

Table 3. Total Mean Squared Error for the estimated position of the UAV [7]

Method	MSEX (m)	MSEY (m)	MSEZ (m)
Monocular SLAM	9.1325	3.6424	0.0642
Monocular SLAM with anchors	4.9821	1.8945	0.0394
Monocular SLAM with inertial measurements	4.9544	1.2569	0.0129

The combination of GPS technology and SLAM technology can form a set of adaptive navigation system. Through the mutual switching and cooperation of the two, the positioning accuracy and path planning ability of UAV in indoor and outdoor can be improved. The working principal diagram of mutual cooperation is shown in the Figure 2. When the UAV enters the room from the outside, the space environment becomes more complex, and the GPS signal is weakened due to the shelter of the building. At this time, the UAV switches to its SLAM system for positioning and navigation. When the UAV enters the outdoor from indoor, the environmental situation is just the opposite. At this time, the UAV automatically switches to use GPS system for navigation, while using SLAM system to monitor the surrounding environment and assist GPS system for path planning [9].

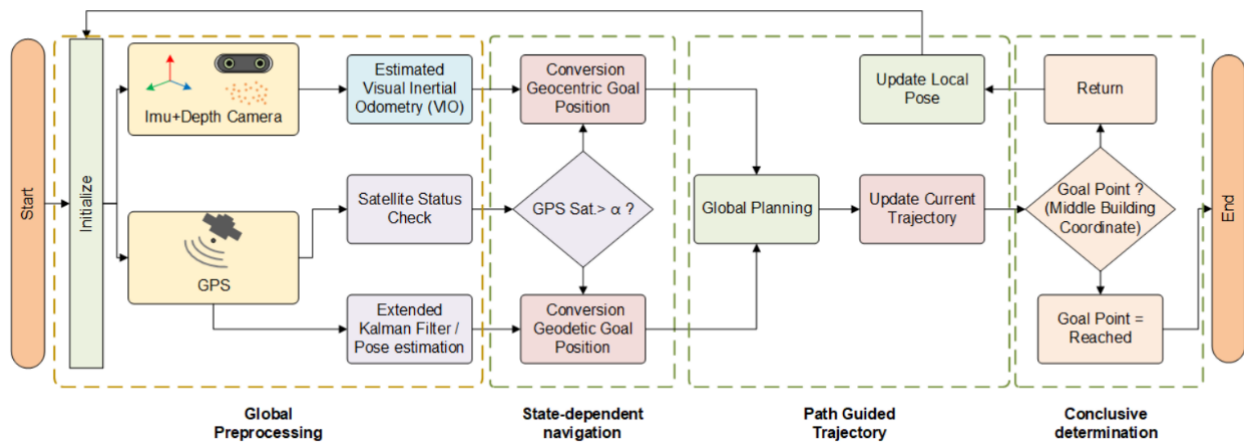


Fig. 2 Pipeline of GO-SLAM with pre-processing, for initializing the GPS and VIO navigation [9]

SLAM technology can carry out more accurate positioning and better path planning for UAV with the help of GPS positioning and navigation system, but in turn, SLAM technology can also help monitor the failure of GPS positioning and navigation system. With the increase of the number of GPS positioning and navigation system satellites, the probability of failure also increases. The SLAM system of the robot is used to detect the surrounding environment and calculate its position, speed and other information. At the same time, the calculated information is compared with the information provided by the received GPS signal to determine whether there is a problem with GPS [10].

5. Conclusion

SLAM technology based on vision can effectively and autonomously help UAVs determine their locations and build environmental maps, so as to complete the corresponding tasks. Using SLAM technology in UAVs can help them carry out positioning, obstacle avoidance and path planning, so as to ensure the stability and safety of UAVs operation. However, there is still room for improvement in the accuracy and reliability of SLAM technology. By adding more sensors to SLAM system, strengthening the deep learning ability and introducing neural network, the impact caused by the problems like responding error and uncertainty will be weakened. At the same time, the cooperative

cooperation of multiple UAVs can also better play the role of SLAM technology. In addition to the upgrading and improvement of SLAM technology itself, the integration of other technologies and vision-based SLAM technology in UAVs can also better help them complete their tasks. For example, GPS and SLAM technology are integrated to form an indoor and outdoor adaptive navigation system, which solves the problems caused by poor indoor GPS positioning signal and open outdoor environment which are difficult to detect by SLAM technology. Although SLAM technology has made many breakthroughs in recent years, its potential has not been fully explored, and it will become more powerful, more intelligent and more reliable in the future.

References

- [1] Yalan Chen, Yimin Zhou, Qin Lv, Kranthi Kumar Deveerasetty. A Review of V-SLAM[C], in Proceeding of the IEEE International Conference on Information and Automation, Wuyi Mountain, China, August 2018, 603-608.
- [2] Cesar Cadena, Luca Carlone, Henry Carrillo, Yasir Latif, Davide Scaramuzza, José Neira, Ian Reid, John J. Leonard. Past, Present, and Future of Simultaneous Localization and Mapping: Toward the Robust-Perception Age. *IEEE Transactions on Robotics*, 2016, 32(6): 1309-1332.
- [3] Ryan Xianqian Yuan. Series of advanced SLAM processes and applications[C], in Proceedings of the 2023 International Conference on Machine Learning and Automation, Beijing, China, 2023, 242-250.
- [4] Georges Younes, Daniel Asmar, Elie Shamma, John Zelek. Keyframe-based monocular SLAM: design, survey, and future directions. *Robotics and Autonomous Systems*, 2017, 98: 67–88.
- [5] Hamid Taheri, Zhao Chun Xia. SLAM; definition and evolution. *Engineering Applications of Artificial Intelligence*, 2021, 97: 104032.
- [6] Li Wang, Xu Liu, Hengxin Wang, Xibin Wang. Research on Obstacles Avoidance for UAV SLAM. *Applied Mechanics and Materials*, 2014, 598: 1329-1334.
- [7] Juan-Carlos Trujillo, Rodrigo Munguia, Sarquis Urzua, Edmundo Guerra, Antoni Grau. Monocular Visual SLAM Based on a Cooperative UAV–Target System. *Sensors*, 2020, 20(12): 3531.
- [8] Patrik Schmuck, Margarita Chli. Multi-UAV Collaborative Monocular SLAM[C], in 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, 3863-3870.
- [9] Muhammad Wicaksono, Soo Young Shin. GO-SLAM: GPS-aided Visual SLAM for Adaptive UAV Navigation in Outdoor-Indoor Environments. *TechRxiv*, 2023.
- [10] Sriramya Bhamidipati, Grace Xingxin Gao. Multiple GPS Fault Detection and Isolation Using a Graph-SLAM Framework[C], in Proceedings of the 31st International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2018), Miami, Florida, 2018, 2672-2681.