A Review of a Brain-controlled Robot Based on the SLAM System

Yizhou Jiang*
Department of Machinery, Shanghai DianJi University, Shanghai, China
*Corresponding author: jyz050628@outlook.com

Abstract. This paper mainly talks about the analysis about the review of a brain-controlled robot based on the Simultaneous Localization and Mapping system (SLAM). Brain robots today as the cutting-edge technology, after combined with the SLAM system, it enables to carry out path planning and intelligently avoid obstacles without human intervention. It can get better positioning accuracy and information transfer after the brain robot combined with the assist of the SLAM system. In this paper, analysis the technical principle of the combination between Brain Computer Interface and SLAM system and put forward brain-computer interface (BCI) do active control and SLAM do assisted strategy. At the same time, according to analysing literature, summarizing the applicable system model, which mainly about SLAM algorithm system, robot system, point cloud scanner, optimization of path planning algorithm and technology application with good performance. This paper examples two applications of brain-controlled robots combined with SLAM system, respectively are the related applications of medical care field and mobile robots, which involve path planning, static obstacle positioning, robot acceleration control and acquisition of map information of the unknown environment. As a combination of two cutting-edge technologies, it has a good development trend and is worthy of in-depth research.

Keywords: brain-computer interface, simultaneous localization and mapping, artificial potential fields.

1. Introduction

With the development of science and technology, Brain-Computer Interface (BCI) technology has gradually become a research hotspot. Brain Robot as the main application of the BCI, it can control the behavior of robots by interpreting users' Electroencephalogram (EEG) signals that is why it has a wide application prospect. Computing the position of the robot in the map through the simultaneous localization and mapping (SLAM) algorithm, and constructing the map around the robot through the sensor. At the same time, it relies on the environment around the robot to make the corresponding path planning to find the optimal path. The research and development of brain-controlled robot combined with autonomous navigation can be used in many fields, such as the automatic transformation of industrial production lines, the automatic management of logistics and warehousing, or the medical rehabilitation field, intelligent transportation, etc.

Brain-computer interaction today as the frontier technology, is to obtain signals directly from the brain through external devices and convert them into control instructions to realize the interaction with computers or other electronic devices. BCI uses the brain signal generated by thinking intention as the signal source for communication and control, obtains the thinking intention through signal acquisition, signal processing, machine learning and pattern recognition methods, and controls the signal to realize the direct communication with external equipment and control [1].

Autonomous navigation technology can carry out path planning and intelligent obstacle avoidance without artificial intervention to achieve autonomous movement, while the traditional autonomous navigation technology lacks the combination and application of human brain intelligence. Autonomous navigation refers to the mobile robot using sensors to obtain information about the surrounding environment without the assistance of external technology, and being able to independently avoid obstacles and conduct the optimal path planning [2]. Brain control technology, as the human subjective consciousness, often lacks the accuracy in mechanical control, because it is difficult to accurately classify subject commands from neural signals. So combining brain-control technology with the SLAM system can help improve accuracy.

This paper is also an article aimed at the purpose of improving the mobile accuracy of brain-controlled robots, mainly on the introduction of brain-controlled robots and SLAM, technical principles, SLAM technology model, path planning algorithm optimization and application of brain-controlled robots combined with SLAM system.

2. Related technical overview

2.1. Technology Introduction

2.1.1 Introduction of the brain robot

The brain can be divided into multiple regions based on the structure, characteristics, and function of the neural layer. The widely used partial segmentation method is the Brodmann partition, including 52 regions of each hemisphere. Different regions are responsible for processing different information and completing motor memory functions, where the regions related to motor imagination are mainly somatosensory areas and body motor areas, which are overlapping, reversed and related features [3].

Brain robot needs the fusion and adaptation of BCI module and robot multi-layer control module, which needs to be combined with the sensor information of the robot. Through the induction captor which wears it on the head to identify the brain scalp current changes and the flow of blood information. To make the amplification of the weak brain waves and use computers to analyze the intentions of people. Brain-controlled Robot Interface(BCRI) aims to bypass the normal output pathways of the brain (peripheral nerves and muscles) and use the brain signals generated by brain thinking activity to directly control the robot [1]. The control strategy of BCRI is based on Target Selection Strategy(TSS) and Motion Control Strategy(MCS). In which TSS provides high level command control and MCS provides low level fine control.

2.1.2 Introduction of the SLAM

SLAM is a technology for simultaneous positioning and map construction, which is a key technology to solve the autonomous navigation of robots in unknown environments. The system can use lidar and other devices to scan the surrounding environment during the robot moves, estimate its own position in real time while building a map of the surrounding environment, and plan the optimal path with the help of specific algorithms. SLAM system mainly includes five modules: sensor data reading, front-end processing, back-end optimization, loop detection and map construction. The current mainstream SLAM system is mainly divided into visual SLAM, laser SLAM and SLAM system based on multi-sensor visual laser combination [4]. This paper mainly focuses on multi-sensor combined laser SLAM system.

2.2. Brain-controlled robot combined with the SLAM

2.2.1Technology principle

In terms of brain-controlled robot control, the first operation is signal collection. There are two sorts of techniques which are invasive and non-invasive. Electroencephalogram (EEG), which is the most popular technology in BCI because of its implementation accuracy, cost and non-invasive nature. However, due to the low accuracy of multi-class neural signal classification using brain signals alone, it is not enough to accurately control the robotic system. To overcome these shortcomings of the BCI system, a hybrid system is introduced, where the control of the robot by the BCI is assisted by the SLAM. The robot builds an unknown environment map based on the visual SLAM algorithm, and has a low-level movement control strategy for obstacles. When the operator uses the SLAM scans around, you can get a map of the surrounding environment. At the same time, the robot transmits the real-time map to the operator as visual feedback to select a precision command. The obstacle boundary will flicker at different frequencies, and the operator chooses according to the image [5].

The brain-controlled robot combining SLAM technology and EEG-APF method can reach the target point in the free environment with obstacles, and the automatic navigation requires a combination of particle filtering and artificial potential field method. In the Brain-Machine Interface (BMI)system architecture, there are four submodules: EEG classification, motion planning based on APF, SLAM and visual feedback. APF regards the environment around the robot as a virtual potential field, in which the target point generates attraction, making the robot move to the target point, and the obstacles produce repulsion force to prevent the robot from colliding with the obstacles.

2.2.2 SLAM system model

The model of SLAM is achieved by the 2D SLAM algorithm of Google Cartographer. This algorithm integrate with the robot system iClebo Kobuki Turtlebot 2 and use Microstrain's 3DMGX5-25 as the Inential Measurement Unit(IMU), also use the Velodyne LiDAR's PUCK VLP-16 as the point cloud scanner. Together, these components constitute the SLAM system for running the SLAM algorithm in the maze environment to help the robot in its localization and map construction [6].

In the article written by Yiliang Liu and other scholars, the model for the indoor application of SLAM system. SICK laser sensor is used to collect environmental data, and a comprehensive sound range r and Kinect sensor are used to obtain robot positioning. The observation model for the laser is $\varphi\mathrm{i} = (\mathrm{Li}, \alpha\mathrm{i})$. Using APF simulate the robot environment of the virtual potential field, and also attracts the target point of the robot to attract the robot to move to the target point. On the contrary, the repulsive force is generated to prevent the collision between the robot and the obstacle. Finally, the gravity and repulsive force of the robot are combined to make it move along the two directions of the gradient of the total potential field function to reach the target point [7].

2.2.3 Path planning algorithm optimization

The brain-controlled robot combined with SLAM system involves simultaneous positioning and map construction. It can be built based on RTAB-MAP, realizing real-time positioning and map construction in five steps: sensor data processing, visual odometer, back-end optimization, loop detection and map construction. Local map construction can use Red, Green, Blue, Depth(RGB-D), lidar and wheeled odometer. For the three-dimensional map, the three-dimensional point cloud which provided by RGB-D can be directly used to realize the creation of three-dimensional map. For the two-dimensional map, the two-dimensional point cloud of lidar is to realize the creation of two-dimensional map through the two-dimensional beam model [2]. In SLAM, the optimal path planning is very important. In the global path planning, the algorithm A can be used, while the algorithm A has some problems such as strong dependence on the heuristic function, insufficient search performance, etc. The heuristic function h * (n) can be changed to:

$$\begin{cases} h^*(n) = w(n)^* h(n) \\ w(n) = e^{1+\frac{h_{ng}-h_{sn}}{h_{sg}}} \end{cases} \tag{1}$$

This (1) is the improved algorithm A [2]. In view of the accuracy of the outer end odometer of the robot and the precision improvement of subsequent loop detection, it can be achieved by improving the graph optimization laser scanning algorithm and frame matching optimization. During the construction of the front-end attitude graph, the task of the laser sensor is to estimate the global attitude of the thermal robot in the world coordinate system.

By converting the current frame point cloud into a global coordinate system, and using the Correlative Scan Matching (CSM) to get the position position of the current frame point cloud. The back-end optimization uses the sparse attitude adjustment method to detect whether the robot returns to the historical position, and compares the similarity between the current frames and the historical frames to form a circular trajectory [8].

The execution process of the algorithm A, first start the search, then initialize the open and clean node group, then add the initial point extended nodes to the open group, then save into the close group, and remove the starting point from the open group, judge whether the open group is empty, if the open set is not empty, continue to the next step. The nodes in the open group iterate g (n), f (n) and the parent node n-1 update. And get the node with the smallest f (n) value: find the node with the lowest value of the cost function from the current open collection. Save the node in the clean group, delete it from the open group, and then join it in the open group. If the target point is not reached, return to step 5; otherwise proceed to the next step. And determine whether the target point is reached. If the target point is reached, the algorithm ends [9].

2.2.4 Process flow of a brain-controlled robot combined with SLAM

According to the Fig. 1, the technology starts from the SLAM system, by the lidar, can easily get the two-dimensional beam model and get the two-dimensional map of the surrounding environment. Meanwhile, A algorithm is used to analyze the map to obtain the optimal path planning. After the obtained map information is transmitted to the operator, the operator uses BCI to send advanced commands to actively control the robot and then combines the optimal path and map construction provided by SLAM to effectively assist obstacle avoidance.

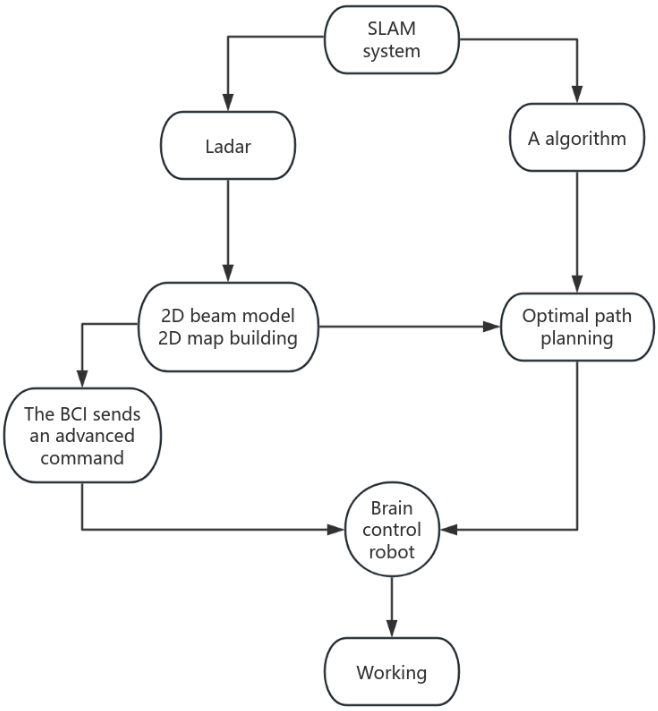

Fig. 1 Flow of a brain-controlled robot combined with SLAM

2.3. Technology Application

2.3.1 Application in the medical care field

Literature proposed by scholar Wang and other scholars presents a good application of brain-controlled robot combined with SLAM system and makes study about the real-time positioning and map creation of brain-controlled wheelchair [10]. The image is acquired by the relatively installed camera, and the positioning of static obstacles is completed through image correction, obstacle segmentation, contour extraction and fitting, the camera plane to the ground plane and the contour intersection on the ground plane [10]. In terms of path planning, Voronoi diagram and Dijkstra algorithm are used for path planning to ensure that the planned path is the safest and relatively short. The experimental results show that this method is effective in the combination of BCI and SLAM system, and the brain-controlled wheelchair system is mainly composed of brain control system and autonomous positioning and navigation system. The brain control system is responsible for processing the user's EEG signals and selecting the target location; the autonomous positioning navigation system is responsible for generating the selected destination according to the environmental information and completing the positioning and navigation. This literature presents a series of improvement methods and innovative points, which provides theoretical support and technical reference for the future practical application of brain-controlled wheelchair.

2.3.2Mobile robot application

Literature proposed by Liu Y and other scholars which mainly uses the brain-computer interface system framework based on steady-state visual evoked potential combined with SLAM system, and the combination of artificial potential field method and EEG signal to establish the relationship between EEG signal intensity and potential field strength, so as to obtain the movement command of barrier-free trajectory [11]. And conducted related experiments, where participants control the mobile robot through brain signals by looking at the flashing screen. This experiment shows that the system can effectively identify the EEG signals of the participants and transform them into the movement command of the mobile robot, resulting in high accuracy navigation control. This article proposes the semi-autonomous BRI control strategy, combines Steady-State Visual Evoked Potential(SSVEP), Microsatellite Instability(MSI) classification algorithm and SLAM technology, realizes the mobile robot navigation and control in the uncertain environment; through the relationship between the robot control law and the strength of the APF, the brain signal can directly determine the acceleration of the robot, which greatly improves the control accuracy of the robot. In the unknown corridor environment, a multifunctional (BRI) embedded with SLAM function is proposed to obtain information on odometer, disappearing point and door panel, and accurately locate the robot. By using the landmark images, the accumulated attitude error of the range meter can be reduced when positioning the thermal robot [11].

3. Discussion

As the cutting-edge technology in the field of science, the brain-computer interface technology applied by the brain-controlled robot has high usability and redevelopment. But as a robot technology controlled by the human brain, it is difficult for a robot to move itself to a precise position in the space under BCI control in the response stage after receiving the processing signals. This requires an improvement, so use the combination of SLAM systems can well improve the accuracy of the robot during movement.

Auxiliary navigation also with a problem is in navigation will force users to calculate the direction, the active influence in the auxiliary process, for the solution to the problem is to update the auxiliary control, guide the user without constraint the user, to guide the user to the direction of the calculation rather than forcing him to the direction [12].

Brain control robot combined with SLAM system, can improve the accuracy of robot obstacle avoidance, because brain control robot as human brain control robot, the autonomous movement of the robot in the targeted situation requires an effective obstacle avoidance function. And combined with SLAM system, through the whole environment scanning of laser radar, get the position of obstacles, using artificial potential field method for the optimal path planning, and achieve good autonomous obstacle avoidance effect. At the same time, BCI combined with SLAM can assist to control the brain-controlled robot, understand the surrounding map, feedback the map information to the operator, and can still achieve accurate autonomous movement in the dark environment beyond the human eye.

However, the combination of brain-controlled robot with SLAM system also has some defects. In SLAM system, visual SLAM performs poorly in low light or untextured scenes, while laser SLAM may lead to performance decline due to the influence of light outdoors.

This problem can be solved by the combination of visual SLAM and laser SLAM.In addition, SLAM system will also have cumulative errors in the process of long-term operation of large-scale scenarios, which needs to be corrected by mechanisms such as loop detection, but these mechanisms may not completely eliminate the errors, so how to effectively reduce the error is the future research direction.

As shown in Fig.2, according to the statistical analysis of the data, all types of robots in various industries have a large market scale, and their investment ranges from 10 billion to 70 billion yuan. Therefore, the combination of brain-controlled robots with SLAM will have great research prospects.

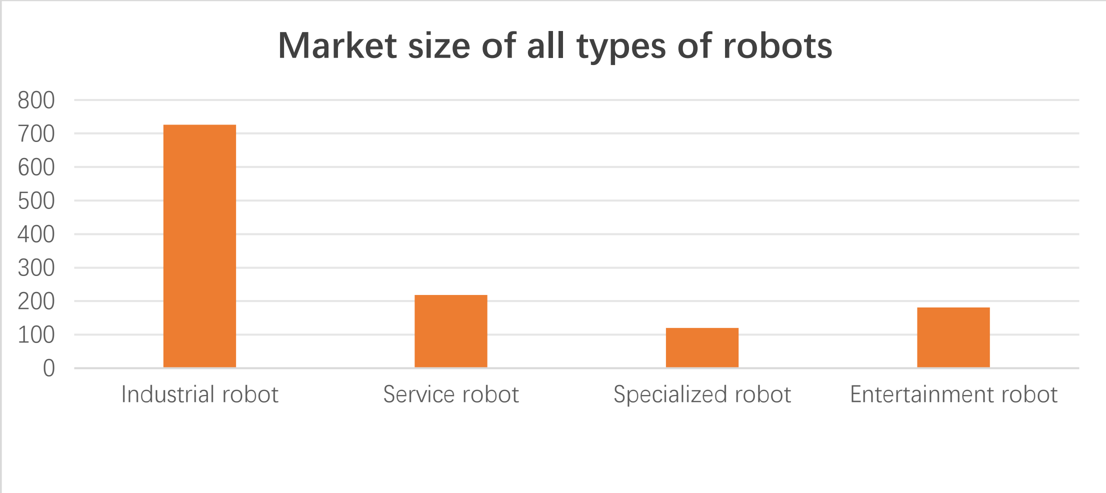

Fig. 2 Investment in the robot market across various industries

4. Conclusion

This paper mainly describes the introduction of brain-controlled robot and SLAM, the technical principle, SLAM technical model, the optimization of path planning algorithm and the application of brain-controlled robots combined with SLAM system. The method of brain control robot combined with SLAM system is mainly to achieve human brain control, and SLAM system is assisted in control to achieve the precise positioning of the robot and environmental information transmission. This is the direct control achieved by BCI module and robot multi-layer control, and the autonomous navigation achieved by hybrid brain-computer interface technology and SLAM system.

The combination of the system with strategies based on target selection and motion control, using hybrid brain-computer interfaces and SLAM technology, improves the control accuracy and enables the robot to navigate autonomously in complex environments. The system also includes submodules such as EEG classification and APF-based motion planning, which realize the complete process from brain signal reading to robot action execution, and make the application of the technology in healthcare and other fields have a great impact.

References

[1] Fu Y F, Wang Y C, Li H Y, Direct brain-controlled robot interface technology. Journal of Automation, 2012, 38(08): 1229-1246.

[2] Liu J W. Development and research of autonomous navigation system for brain-controlled robot. Beijing Jiaotong University, 2023.

[3] Wang F, Zhou C, Hao X, Wang S, Yang G. BCI control system for humanoid robot based on motor imaginary, 2013 25th. Chinese Control and Decision Conference (CCDC), Guiyang, China, 2013, pp. 5140-5143.

[4] Chen L, Luo Z, He Y Z. Review and perspective of visual and laser SLAM development. China test, [2024-11-18]. 1-27.

[5] Su W, Li Z. Brain-computer interface based stochastic navigation and control of a semiautonomous mobile robot in an indoor environment. 2017 2nd International Conference on Advanced Robotics and Mechatronics(ICARM), Hefei and Tai'an, China, 2017, pp. 718-723.

[6] Park J, Choi J W, Jo S. A SLAM Integrated Hybrid Brain-Computer Interface for Accurate and Concise Control. 2019 7th International Winter Conference on Brain-Computer Interface (BCI), Gangwon, Korea (South), 2019, pp. 1-5.

[7] Liu Y, Li J, Li Z. An Indoor Navigation Control Strategy for a Brain-Actuated Mobile Robot. 2018 3rd, International Conference on Advantage Robotics and Mechatronics(ICARM), Singapore, Singapore, 2018, pp. 13-18.

[8] Wang A U, Cong M H, Du M, Zhong Y, Liu H G, Wang D AF. Bio-inspired mobile robot design and autonomous exploration strategy for underground special space. FN Clarivate Analytics Web of Science. ROBOTIC INTELLIGENCE AND AUTOMATION SN. 2754-6969 EI 2754-6977.

[9] Hou Y Y, Chen J R, Wang S C. Research on automatic navigation and obstacle avoidance technology of inspection robot based on laser SLAM. Digital agriculture and intelligent agricultural machinery. 2024, (09):33-35.

[10] Zhang H. Positioning and navigation technology of brain-controlled wheelchair in indoor environment. Institutes Of Technology OF South China. 2015.

[11] Liu Y, Li Z, Zhang T, Zhao S. Brain-Robot Interface-Based Navigation Control of a Mobile Robot in Corridor Environments. IEEE Transactions on Systems, Man, and Cybernetics: Systems. vol. 50. no. 8. pp. 3047-3057.

[12] Petit D, Gergondet P, Cherubini A, Meilland M, Comport A I, Kheddar A. Navigation assistance for a BCI-controlled humanoid robot. The 4th Annual IEEE International Conference on Cyber Technology in Automation. Control and Intelligent, Hong Kong, China, 2014, pp. 246-251.