Application Status and Prospect of Fuzzy Algorithm and Neural Network in Intelligent Control of Forestry Robot

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Abstract. Intelligent control has been widely applied in industrial robot control in recent years, aiming to address control problems such as highly nonlinear models, inaccurate models, and complex task requirements, which are challenging to solve using traditional control methods. Applying intelligent control to the control system of a forestry robot can overcome the disadvantages of traditional control, improve the quality of system control, and significantly improve forestry production efficiency. This paper expounds the research and application status of intelligent control in forestry robot control in recent years, analyzes the shortcomings and problems existing in the current application, and puts forward relevant suggestions, which can provide ideas for the subsequent research of intelligent control in forestry robot control field, assist the optimization and application of related technologies, and further play the supporting role of intelligent control in forestry industry development..

Keywords: Fuzzy Algorithm, Neural Network, Intelligent Control, Forestry Robot, Robot Control.

1. Introduction

With the transformation of the global forestry industry towards high efficiency, ecology, and precision, traditional forestry equipment relying on manual operation has struggled to meet the multiple challenges of modern forestry. On the one hand, there are problems such as complex terrain, changeable climate, and dense vegetation in the forest operation environment, which put forward extremely high requirements for the environmental adaptability of equipment; On the other hand, forestry production tasks have been expanded from single harvesting to seedling transplanting, forest inspection, ecological restoration, and other full-chain scenarios. The functional shortcomings and automation limitations of traditional equipment are becoming increasingly prominent, which not only restricts the improvement of production efficiency but also intensifies the contradiction of forestry labor shortages due to the high manual operation intensity and high risk coefficient.

The emergence of forestry robots provides the core technology path to solve the above problems, and intelligent control technology is the key to determining the operational ability of forestry robots. Compared with traditional control methods, intelligent control, such as neural networks and fuzzy algorithms, can effectively deal with the problems of high non-linearity, inaccurate models, and strong interference in forestry operations, realize high-precision operation of robots in complex scenes through autonomous perception, decision-making, and execution, and significantly improve the automation and intelligence level of forestry production.

However, there are still three core limitations in the current research and application of intelligent control technology for forestry robots. Firstly, the synergy between environmental perception and decision-making is insufficient, and existing systems rely on a single sensor to obtain environmental information. In scenes with insufficient understory light and severe vegetation occlusion, it is easy to experience blind perception, which can lead to decision-making delays or misjudgments. Second, the versatility and robustness of the control algorithm need to be improved. Most algorithms are designed for specific operation scenarios. When the scene changes, a large number of parameters need to be adjusted, which makes it difficult to achieve "plug and play" functionality. Moreover, in extreme weather conditions, the algorithm's stability decreases significantly. Third, the degree of technology transformation and industrialization is relatively low. Domestic research focuses on laboratory prototype verification, but the reliability, maintenance costs, and adaptability to existing forestry production processes of robots are not sufficiently considered, which makes it difficult for most technical achievements to meet the large-scale application needs in actual production. As a result, a significant gap exists with international, mature products.

Developed countries laid out forestry robot technology earlier; North America and Europe have realized automatic operations such as forest harvesting and skidding, while Japan is leading in the field of complex terrain refinement operations. Although China started late, it has developed rapidly in recent years and has introduced intelligent harvesting equipment, forest fire prevention robots, and other innovative technologies.

These limitations not only restrict the further development of forestry robot intelligent control technology but also put China under double pressure from "technical bottleneck" and "international competition" during the process of forestry modernization. Under this background, it is of great significance to carry out systematic research on intelligent control technology of forestry robot: from the theoretical level, it can fill the gap of coordination mechanism of intelligent control algorithm under multi-sensor fusion, enrich the theoretical system of robot control under complex scenes; from the application level, it can break through the limitations of existing technologies, develop intelligent control schemes more suitable for forestry scenes in China, and promote technology from laboratory to industrialization; From the strategic level, it will help to enhance China's core technology competitiveness in the field of forestry robots, reduce dependence on international advanced technologies, and provide technical guarantee for the realization of forestry modernization and the goal of "double carbon".

Based on this, this paper takes "intelligent control technology of forestry robot" as the research core, aiming at systematically sorting out the application status of intelligent control technology such as neural network and fuzzy algorithm in forestry robot, deeply analyzing the limitations and challenges of current technology, clarifying the future research direction and technical path, and providing comprehensive theoretical reference and practical guidance for the optimization design, algorithm improvement and industrial application of intelligent control system of forestry robot.

2. Forestry robot intelligent control

Forestry robots can be categorized into three types: forestry ecological robots, forestry industrial robots, and forestry special robots [4] according to their application scenarios. In recent years, in addition to the design of the robot's mechanical structure, the intelligence level of forestry robots has also begun to receive attention, and related research has been carried out in intelligent control. To face the complex and changing working environment, research on forestry robots focuses on vision detection systems and mechanical structure design, including walking mechanisms and actuators. In contrast, research on control systems primarily focuses on open-loop or simple PID closed-loop control, and the study of intelligent control algorithms is not sufficiently in-depth.

2.1 Forestry Ecological Robot

Forestry ecological robots are primarily used in areas such as logging, tending, seeding, and forest protection. They primarily operate in outdoor environments, such as forests and woodlands, where uncertainties, including terrain and climate, pose significant challenges to precise control.

To overcome the time-varying parameters, uncertainty, and non-linearity of the electro-hydraulic proportional position control system of a forestry harvesting robot, Guo Xiuli, et al.[5] designed an RBF neural network controller based on a fuzzy adaptive Kalman filter. This controller enables the robot arm to automatically perform multifunctional operations such as positioning, felling, and stacking wood, effectively avoiding hazards during the harvesting process. Experimental results show that efficiency is 10-15 times higher than manual control. Jennifer, et al.[6] introduced a reinforcement learning strategy into a forestry lifting robot and performed reinforcement learning control of the operating arm, and the success rate of grasping reached 97%; after adding the reward function to the energy optimization objective during the learning process, the energy consumption was significantly reduced, and the success rate of grasping was maintained at 93%, which indicated that the method was robust to environmental disturbances and uncertainties. Aiming at the shortcomings of traditional agroforestry seeding robots, such as low seeding efficiency and qualification rate, and poor uniformity, Wang et al.[7] designed a dual-closed-loop fuzzy PID control algorithm to achieve high-precision speed control of the motor. In a seeding experiment, when the theoretical seeding speed ranged from 0 to 34 r/min, the motor response time was 0.51 s shorter than conventional PID control, the speed error was less than 0.35%, and the average planting interval qualification rate exceeded 95.81%. Ghamry, et al.[8] Using a particle swarm optimization algorithm, the control system for multiple UAVs used in forest firefighting is optimized. While considering control input constraints, the optimal control input is calculated to avoid potential collisions during the UAV’s movement, thereby effectively completing forest fire prevention tasks. Zhang, et al.[9] studied a multi-sensor information fusion detection system for firefighting robots. During the detection process, they utilized a BP neural network to integrate the feature layer and fuzzy control, thereby combining the decision layer. Test results showed that the training run time was 0.0276 seconds and the mean square error was 0.0013, indicating good accuracy and essentially meeting the required detection accuracy. To improve the path tracking accuracy and driving stability of a spraying robot, Ren et al.[10] proposed a dual deep Q-network (DQN) navigation path tracking control algorithm. This algorithm significantly reduced lateral deviation, achieved high path tracking accuracy and driving stability, and improved the efficiency of irrigation and pest control.

2.2 Forestry Industry Robots

Forestry industry robots are primarily used in forestry production and processing, including lumber, furniture, and wood component manufacturing, as well as the harvesting of economically valuable fruit trees. Improving the robot's control algorithm can enhance production and processing efficiency, improve product quality, and increase wood utilization.

To improve the efficiency and quality of wood component grinding processing by a grinding robot, Zhang Lianbin, et al.[11] designed an improved fuzzy neural network controller for grinding trajectory tracking. Simulation experiments demonstrated that the controller achieved a tracking error of ± 0.01 mm, enabling effective startup control and high-precision curve trajectory tracking.

Zheng Liping, et al.[12] employed BP fuzzy control to achieve the specific control requirements of speed and pressure during wood bending. This improved the efficiency of the bending speed and bending force convergence to the ideal state, reduced oscillation, and achieved higher control accuracy, enabling optimal control of pressure and speed. Xu Qiang, et al.[13] A PID control based on iterative learning is used for a spraying robot. The PID constitutes the inner loop, and the iterative learning controller is the outer loop.

This has high practical application value for achieving high-precision tracking control of the robot along a preset trajectory. Fan, et al.[14] A RBF neural network fuzzy sliding mode controller was designed for the robotic arm of a push-and-shake oil-tea fruit picking robot. This controller effectively eliminated chattering in the robotic arm's joint torques, achieving stable tracking of the prescribed trajectory with a tracking error of less than 0.06 mm. Experimental verification demonstrated that the controller exhibited rapid response, good stability, and strong robustness, improving picking efficiency while reducing flower drop rates. Ma, et al.[15] To reduce environmental interference with a wolfberry-picking robot, a fuzzy control strategy was adopted.

The inputs were the robot's lateral deviation and deflection angle, and the output was the robot's steering strength. Experimental results show that the robot's maximum and average lateral deviations were significantly reduced during operation, demonstrating good robustness and the capability to generally automate wolfberry picking in real-world environments.

2.3 Specialized Forestry Robots

To meet the specific needs of forestry production and management, several specialized forestry robots have emerged, including inspection robots, climbing robots, and field operation robots. They can replace humans in repetitive and dangerous tasks, reducing accidents and improving safety and efficiency.

To minimize damage to the wooden pillars of ancient buildings and improve detection reliability, Liu Cungen, et al.[16] used fuzzy PID control to precisely control the gripping force of a climbing robot's horizontal telescopic joints. A second-order Butterworth low-pass filter effectively reduced noise interference, resulting in a maximum improvement of 51.8% in gripping force control accuracy compared to coupled PD control. Canning, et al.[17] developed a behavioral module decomposition fuzzy logic controller for the navigation of a forest inspection robot. This simple controller enables the robot to autonomously plan its path in a forest environment, minimizing human intervention and enhancing operational safety. Xie, et al.[18] designed a fuzzy controller for the ascending and descending motion of a mountain forest inspection robot. Matlab simulations demonstrated that the robot accurately grasped the straight-line direction and maintained stability while traversing obstacles, thereby demonstrating the feasibility of this approach. Wang Shaohui, et al.[19] used a tree-clearing robot as their research object and designed a sliding mode attitude controller. This, combined with a switching control allocation matrix, addressed the issue of sudden changes in the robot's dynamic model during aerial tree-clearing operations. Experimental results demonstrate that this control strategy effectively mitigates the uncertainty associated with the machine's own inertia and maintains a stable posture during operation. Xu, et al.[20] designed a position and attitude controller based on active disturbance rejection control and a swing angle controller based on the linear SEF method for an aerial pruning robot system equipped with a novel suspended saw. This strategy achieved fast, accurate, and stable flight, effectively suppressing the swing of the payload and residual oscillations after reaching the designated position.

3. Prospects

At the technical level, we will deepen the integration of AI and robotics technology, focusing on breaking through the combination of deep reinforcement learning and digital twins, and improving the decision-making efficiency in complex environments. The integration of Beidou navigation, specialized chassis, and cloud computing technology further enhances the adaptability of robots in complex terrain, such as dunes and steep slopes.

The policy needs to build a closed loop of "technology research and development-standard formulation-market promotion", strengthen cooperation between the government and enterprises, and accelerate the commercialization of technology. Promote international cross-domain collaboration and technology transfer, such as transferring GPS positioning and sensor technology of agricultural robots to forestry to improve the accuracy of mountain operations.

Comprehensive consideration of time and economic cost in practical application and processing production requirements and other factors to ensure good control performance of the system, design algorithms with high cost performance, good robustness, and strong adaptability, reduce the difficulty of engineering implementation, improve the intelligence degree of forestry robots, and promote the industrial upgrading of forestry to automation, unmanned, and intelligent.

4. Conclusions

The development of forestry ecological robots is moving towards a new stage of deep integration of technologies, diversified expansion of scenarios, and improvement of policy systems. Forestry ecological robots achieve operational efficiency by integrating intelligent control technologies (such as autonomous navigation, AI, and multi-sensor fusion). However, it started late, and there are still some shortcomings. First of all, many current application research projects remain at the simulation experiment and laboratory stage. However, good research results have been obtained; they do not account for the actual errors caused by the real environment, software, hardware equipment, network communication conditions, etc. Based on the current state of application research. Second, high costs severely limit the use of large-scale applications. The R&D investment of a single forestry robot generally exceeds 10 million yuan, and the unit cost remains high due to insufficient mass production. The imperfect industrial chain further exacerbates the dilemma. Key sensors, precision reducers, and other core components rely heavily on imports, which poses risks to the stability and technical autonomy of the supply chain. There is still considerable room for optimization and development.

5. References

[1] Chen Sihan, Zhang Changqing. Application of intelligent control in forestry robots[J]. World Forestry Research,2023,36(03):45-50.DOI:10.13348/j.cnki.sjlyyj.2023.0026.y.

[2] Schraick, LisaMarie, Stampfer, Karl, et al.Usability in human-robot collaborative workspaces[J].UNIVERSAL ACCESS IN THE INFORMATION SOCIETY,2025,24(02):1609-1622.DOI:10.1007/s10209-024-01163-6.

[3] ABDELSALAM A, HAPPONEN A, KARHA A, et al. Toward autonomous vehicles and proposals for autonomous vehicle operations[J]. IEEE Access, 2022, 10： 88234−88250.

[4] GIOVANNI C, MAZZETTA F, RENATO V. Design and evaluation of a branch sensing system for a climbing and pruning robot[C].2021 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor). IEEE, 2021: 454-459.

[5] Guo Xiuli, LU Huanin. Design and Research of Harvesting Combine[J]. Mechanical design，2010，27 (8): 14−17, 86.

[6] ANDERSSON J, BODIN K, LINDMARK D, et al. Reinforcement learning control of a forestry crane manipulator[C].2021 IEEE/RSJ International Conference on Intelligent Robots And Systems (IROS). IEEE, 2021: 2121−2126.

[7] WANG W, WU K, ZHANG Y, et al. The development of an electric-driven control system for a high-speed precision planter based on the double closed-loop fuzzy PID algorithm[J]. Agronomy, 2022, 12 (4): 945. DOI: 10.3390/agronomy12040945.

[8] GHAMRY K A, KAMEL M A, ZHANG Y. Multiple UAVs in forest fire fighting mission using particle swarm optimization[C]//2017 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE, 2017: 1404-1409.

[9] ZHANG J J, YE Z Y, LI K F. Multi-sensor information fusion detection system for fire robot through back propagation neural network[J]. PLOS ONE, 2020, 15(7). DOI:10.1371/journal.pone.0236482.

[10] REN Z, LIU Z, YUAN M, et al. Double-DQN-based path-tracking control algorithm for orchard traction spraying robot[J]. Agronomy, 2022, 12 (11)： 2803. DOI： 10.3390/agronomy12112803.

[11] Zhang Lianbin, Ge Zhedong, Jv Mingyuan. Application of an improved neural network in a wood-polishing robot[J]. Forestry machinery and woodworking equipment , 2017, 45 (4): 19−22, 25.

[12] Zheng Liping, Chen Yeye, Yang Cunliang. Theoretical Analysis and Experimental Study on BP Fuzzy Control of Bending Wood Forming Robot[J]. Woodworking machine, 2017 (4): 17−20.

[13] Xu Qiang, Zheng Lei, Ge Lijun. Trajectory accuracy strategy of spray robot based on iterative learning control[J]. scientific and technological innovation and application, 2021, 11 (27): 95−97.

[14] FANG Z Y, LI L J, GAO Z C, et al. Neural network fuzzy sliding mode control design of camellia fruit picking manipulator[J]. Agricultural Mechanization in Asia, Africa and Latin America:AMA, 2021, 52 (1): 2597−2624.

[15] MA Y, ZHANG W Q, QURESHI W S, et al. Autonomous navigation for a wolfberry picking robot using visual cues and fuzzy control[J]. Information Processing in Agriculture, 2021, 8 (1): 15−26.

[16] Liu Cungen, Zhou Yucheng, Liu Xiaoping. CT scanning climbing robot for ancient building wooden pillar[J]. Forest science, 2018, 54 (11): 96-103.

[17] CANNING J R, EDWARDS D B, ANDERSON M J. Development of a fuzzy logic controller for autonomous forest path navigation[J]. Transactions of the ASAE, 2004, 47 (1): 301−310.

[18] XIE Y, XIAO A P, WU J, et al. The structure to a brachiation inspection robot and its fuzzy control for obstacle-negotiation[J]. Applied Mechanics and Materials, 2013, 278/279/280： 622−628.

[19] Wang Shaohui, Yang Zhong, Zhang Qiuyan. Design of Attitude Controller for Tree Obstacle Cleaning Aerial Robot[J]. Journal of instrumentation, 2019, 40 (6): 247-256.

[20] XU H, YANG Z, CHANG L, et al. ARSS: a novel aerial robot performs tree pruning tasks[J]. Discrete Dynamics in Nature and Society, 2020 (3): 1−14.