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Real-Time Object Detection System for Autonomous Robots Using FedGNNs

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Dedication

I would like to dedicate this work to my family, whose unwavering support and encouragement have been the foundation of my academic journey. Their love, belief in my abilities, and constant motivation have inspired me to overcome challenges and pursue excellence in my studies. I am grateful for their sacrifices and for always being by my side, cheering me on every step of the way.

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To all those mentioned above and to anyone else who has been part of my journey, I offer my deepest gratitude and appreciation. This achievement is a reflection of our collective efforts, and I am honored to have had such remarkable individuals in my life.

Thank you.

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Feriel

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Résumé

Le domaine en pleine expansion de la robotique autonome inaugure une ère de progrès technologiques sans précédent, avec le besoin urgent de systèmes d'apprentissage machine décentralisés et sécurisés qui offrent la confidentialité des données et une meilleure efficacité computationnelle. Ces besoins sont encore amplifiés dans des environnements complexes comme les opérations de défense, où les approches traditionnelles de l'apprentissage machine montrent des limites en raison de problèmes de confidentialité des données et de goulets d'étranglement de traitement. Actuellement, nous luttons avec un paradigme qui repose fortement sur des modèles centralisés d'apprentissage machine ou des entrées humaines, tous deux truffés d'inconvénients. Bien que l'intelligence artificielle ait montré des promesses, elle nécessite le partage de données brutes, compromettant ainsi la confidentialité des données et introduisant potentiellement de multiples vulnérabilités de sécurité. En réponse à ces défis, nous présentons FedGNN-DAOD, un cadre novateur qui intègre l'apprentissage fédéré et les réseaux neuronaux de graphes pour améliorer les tâches de détection d'objets et d'association de données dans les robots autonomes. Cette approche permet aux robots d'apprendre à partir de données locales sans sacrifier la confidentialité, et de gérer des données structurées en graphes, améliorant ainsi leur capacité à comprendre leur environnement. Les résultats préliminaires de nos expérimentations soulignent que FedGNN-DAOD surpasse nettement les solutions existantes, en particulier dans les scénarios de défense réels et complexes. Cette avancée non seulement assure la confidentialité des données, mais améliore aussi considérablement les capacités de prise de décision, annonçant une nouvelle ère pour les systèmes robotiques autonomes dans les applications de défense et de sécurité.

Mots Clés :

Apprentissage fédéré, Réseau neuronal graphique,réseau neuronal graphique fédéré, Agent robotique,ssociation de données,systèmes robotiques, Sécurité.

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Abstract

The burgeoning field of autonomous robotics is ushering in an era of unprecedented technological advancement, with the urgent need for secure, decentralized machine learning systems that offer data privacy and improved computational efficiency. These needs are further amplified in complex environments like defense operations, where traditional machine-learning approaches exhibit limitations due to data privacy concerns and processing bottlenecks. Presently, we grapple with a paradigm that relies heavily on centralized machine learning models or human inputs, both of which are fraught with drawbacks. While artificial intelligence has shown promise but necessitates raw data sharing, compromising data privacy and potentially introducing multiple security vulnerabilities. In response to these challenges, we present FedGNN-DAOD. This pioneering framework integrates Federated Learning and Graph Neural Networks to enhance object detection and data association tasks in autonomous robots. This approach allows robots to learn from local data without sacrificing privacy, and manage graph-structured data, enhancing their capacity to understand their environment. Preliminary results from our experimentation underscore that FedGNN-DAOD significantly outperforms existing solutions, especially in complex real-world defense scenarios. This advancement not only ensures data privacy but also drastically enhances decision-making capabilities, heralding a new era for autonomous robotic systems in defense and security applications.

Keywords : Federated Learning, Graph Neural Network, Federated Graph Neural Network, Robot Agent, Data Asoociation, Robotic Systems, Security.

ملخص

المجال المتنامي للروبوتات المستقلة يدشن عصراً من التقدم التكنولوجي الغير مسبوق، حيث يوجد حاجة ملحة لأنظمة التعلم الآلي الموزعة والآمنة التي توفر الخصوصية للبيانات والكفاءة الحسابية المحسنة. هذه الاحتياجات تبرز بشكل أكبر في بيئات معقدة مثل عمليات الدفاع، حيث تظهر الطرق التقليدية للتعلم الآلي قيوداً بسبب مخاوف الخصوصية وعراقيل التحليل. نحن حاليًا نواجه نموذجاً يعتمد بشكل كبير على نماذج التعلم الآلي المركزية أو المدخلات البشرية، وكلاهما مليء بالعيوب. بينما أظهرت الذكاء الصناعي بعض الوعود، فإنها تتطلب مشاركة البيانات الخام، مما يهدد خصوصية البيانات ويمكن أن يدخل العديد من الثغرات الأمنية. ردًا على هذه التحديات، نقدم إطار عمل رائد يدمج التعلم الاتحادي والشبكات العصبية للرسم البياني لتحسين مهام الكشف عن الأجسام والربط بين البيانات في الروبوتات المستقلة. يتيح هذا النهج للروبوتات التعلم من البيانات المحلية دون التضحية بالخصوصية، وإدارة البيانات المهيكلة كرسوم بيانية، مما يعزز قدرتهم على فهم بيئتهم. النتائج الأولية من تجاربنا تدل على أن يتفوق بشكل كبير على الطرق التقليدية، خاصة في سيناريوهات الدفاع الحقيقية والمعقدة. هذه الخطوة الجديدة ليست فقط تضمن خصوصية البيانات، بل أيضا تعزز القدرات القرارية بشكل كبير، مما يمهد الطريق لعصر جديد للأنظمة الروبوتية المستقلة في تطبيقات الدفاع والأمن.

وكيل الروبوت، دمج البيانات ، نقل التعلم ، التعلم الإتحادي ، شبكة عصبية رسومية ، شبكة عصبية رسومية متحدة ،أنظمة الروبوتية , الأمن.

List of abbreviations and acronyms

GNN	*Graph neural network*
GCN	*Graph convlotional Network*
GAT	*Graph Attention Network*
GraphSage	*Graph Sampling and Aggregating*
FL	*Federated Learning*
FedAvg	*Federated Averaging*
MPAG	*Multi-Party Gradient Aggregation*
MPA	*Multi-Party Averaging*
FedProx	*Federated Proximal Algorithm*
FedGNN	*Federated Graph Neural network*
DARs	*Decentralized Autonomous Robots*
Non-IID	*Non-Independent and Identically Distributed*