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A Reactive Obstacle Avoidance Method for Autonomous Mobile Robots

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Dedication

This thesis is dedicated to my beloved Parents, who have raised me to be the person I am today;

Wonderful grandmother, for her love and support;

Sister and brothers, for their encouragement;

Wife and daughter, who have been with me every step of the way through good times and bad;

Thank you all, I love you!

Declaration

I certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for higher degree to any other university or institution.

Signed:.......................

Muhannad A. Mujahed

Date:.......................

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ملخص الرسالة

حظي الرجل الآلي المتحرك ذاتيا (الذكي) اهتماما كبيرا في السنوات الأخيرة الماضية، بالخصوص مع تطور وانتشار التطبيقات المتعددة التي يكون وجود الإنسان فيها خطر أو صعب مثل البحث والإنقاذ، التنظيف، أو الاستكشاف. معظم هذه التطبيقات تتطلب العمل في بيئة مجهولة، غير محددة، أو بالغة التعقيد.ابتكار تقنية ملاحة (navigation) فعالة تستطيع تسيير الرجل الآلي بطريقة آمنة في مثل هذه الأماكن ما زال عملية صعبة ومشكلة تحتاج البحث.

في هذه الرسالة تم تطوير وتنفيذ (implement) طريقة جديدة لتجاوز العوائق بشكل متفاعل (reactive)، تسمى ملاحة الفجوة الأقرب (Closest Gap Navigation)، للرجل الآلي الذي يتحرك في بيئة معقدة ومزدحمة بالعوائق. الإبداع في هذه التقنية يتمثل في إيجاد وسيلة جديدة لتحليل الفجوات أمام الرجل الآلي من شأنها تقليل عدد هذه الفجوات بالمقارنة مع الطريقة المتبعة في التقنية المعروفة في هذا المجال: (Nearness-Diagram Navigation)، خصوصا في السيناريوهات المعقدة. بالإضافة إلى ذلك، تم أخذ العرض أو النطاق الزاوي (angular width) للفجوة المختارة بعين الاعتبار. أدى ذلك إلى تخفيف التأرجح في حركة الرجل الآلي (oscillations) و تقليل التعقيدات الحسابية، أيضا تم الوصول إلى أداء أكثر سلاسة (smoother). هذه التقنية الجديدة تضبط قانون التحكم المقترح في تقنية ال (Smooth Nearness Diagram Navigation) من أجل إيجاد مسارات أكثر أمنا للرجل الآلي بالأخذ بعين الاعتبار نسبة التهديدات (العوائق) على جانبيه ودفعه أو حرفه بصوره أشد كلما اقترب من العائق أكثر. لذلك، مشكلة التوقف التام (deadlock) التي تحصل في الممرات الضيقة، عندما يكون هناك عوائق كثيرة في جانب من جوانب الرجل الآلي وعوائق قليلة في الجانب الأخر، قد تم حلها دون التأثير على سلاسة التحرك.

يضاف إلى ذلك، في هذه الرسالة أيضا تم دمج طريقة تحليل الفجوات، المقترحة في تقنية ملاحة الفجوة الأقرب (CG method) مع تقنية الهروب المماسي (Tangential Escape method). هذا الدمج، والذي سمي تقنية ملاحة الفجوة الأقرب المماسية (Tangential Closest Gap Navigation)، أدى إلى مسارات أسرع وأقل تأرجحا (less oscillatory) للرجل الآلي. أيضا، تم اشتقاق أوامر التحكم بحيث يكون النظام المتحكم مستقرا وقد تم إثبات ذلك باستخدام نظرية ليابونوف (Layapunov)، والتي تضمن أن الرجل الآلي يصل أي هدف ممكن وصوله.

هذه الرسالة تقدم أيضا تحسينات أخرى على تقنية ملاحة الفجوة الأقرب المماسية (TCG method). التقنية المطورة، والمعروفة بتقنية ملاحة الفجوة الأقرب المماسية السلسة (Smooth Tangential Closest Gap Navigation)، تأخذ بعين الاعتبار كل العوائق الواقعة ضمن مسافة آمنة حول محيط الرجل الآلي (تكون معرفة مسبقا)، وليس فقط العائق الأقرب، في حساب أوامر التحكم. وبذلك، هذه التقنية قادرة على توليد مسارات أكثر سلاسة للرجل الآلي، خصوصا عندما يكون شكل العوائق غير مضلع. بالإضافة إلى ذلك، هذه التقنية تقوم بتحسين درجة أمان المسارات المتولدة باستخدام ال (TCG method) من خلال حفظ مسافة آمنة بين الرجل الآلي والعوائق بينما يسير بجانبها في الممرات الواسعة. بالنسبة للمرات الضيقة، الرجل الآلي يتحرك فيما بين العوائق الموزعة على جانبيه الأيمن والأيسر.

قمنا بتقديم نتائج المحاكاة (simulation) والتجارب العملية من أجل عرض سلوك التقنيات المقترحة وإظهار قدرتها بالمقارنة مع تقنيات وطرق أخرى.

Abstract

Autonomous mobile robots have been given a lot of interest in the last few years, particularly with the evolution of application fields where human presence is dangerous or difficult such as search-and-rescue, cleaning or exploration. Most of these applications require operation in unknown, uncertain and densely cluttered environments. Developing a satisfactory navigation method that can drive a mobile robot safely in these environments is still a challenging problem.

In this thesis, a new reactive obstacle avoidance approach, entitled Closest Gap Navigation (CG), for mobile robots moving in cluttered and complex environments was developed and implemented. The novelty of this approach lies in the creation of a new method for analyzing openings in front of the robot that highly reduces their number as compared with the well known Nearness-Diagram Navigation (ND) technique, particularly in complex scenarios. Moreover, the angular width of the chosen (selected) gap with respect to the robot vision is taken into consideration. Consequently, oscillations are alleviated, the computational complexity is reduced and a smoother behavior is achieved. Our technique adjusts the motion law proposed in the Smooth Nearness-Diagram Navigation (SND) method to generate safer paths for the robot by considering the ratio of threats on its sides and applying stricter deviation against an obstacle as it gets closer to the robot. Hence, the problem of deadlock occurring in narrow corridors, with high threats on one side and low threats on the other, is solved without affecting the smoothness behavior.

In addition, in this thesis the new method for analyzing gaps, proposed in the Closest Gap (CG) approach, is integrated with the Tangential Escape (TE) scheme. This combination, named Tangential Closest Gap Navigation (TCG), results in faster and less oscillatory robot paths. Moreover, motion commands are derived with proven stability in the Layapunov sense for the whole control system, which ensures that the robot reaches any reachable goal.

Also, this thesis introduces further enhancements for the Tangential Closest Gap Navigation (TCG) approach. The enhanced method, entitled Smooth Tangential Closest Gap Navigation (STCG), considers all obstacle points falling within a pre-defined safe distance of the boundary of the robot, not just the closest one, in calculating the motion commands.

Hence, this technique is capable of generating smoother robot paths, particularly for non-polygonal obstacle shapes. Furthermore, it improves the safety of paths generated by the TCG through keeping a safe distance between the robot and obstacles while following their contour in wide corridors. For narrow corridors, the robot moves between the obstacles on both sides of the robot heading direction.

Simulation and experimental results are presented to show the performance of the proposed approaches and to demonstrate their power as compared with other methods.

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