UNIVERSITI PUTRA MALAYSIA

A HYBRID SAMPLING-BASED PATH PLANNING ALGORITHM FOR MOBILE ROBOT NAVIGATION IN UNKNOWN ENVIRONMENTS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

This research is dedicated to my lovely wife, Shahedeh, for her moral support and encouragement. Without her, I could not even start my study.

I also want to dedicate this thesis to my father, mother and brothers for their supports.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

A HYBRID SAMPLING-BASED PATH PLANNING ALGORITHM FOR MOBILE ROBOT NAVIGATION IN UNKNOWN ENVIRONMENTS

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The motion planning problem poses the question of how a robot can move from an initial to a final position. Sampling-based motion planning is a class of randomized path planning algorithms with proven completeness. These algorithms generate paths using random numbers and perform efficiently in guiding the robot in known environments. There are a variety of algorithms in this class with different objectives, advantages and drawbacks. The existing drawbacks of current sampling-based planners can be categorized into five categories including non-optimality of the resulted paths, instability of the results in different runs of the planner, high running time requirements in some problems, failure in difficult environments such as narrow passages and Bug traps, and inability to plan in unknown environments. Although several extensions of the sampling-based algorithms have been proposed for solving each drawback, but the lack of a randomized planner that overcomes all

abovementioned inefficiencies in a single package is evident and makes the sampling-based path planning less effective for certain purposes.

In this research, a sampling-based path planning algorithm was proposed which employs several heuristic and intelligent techniques to improve the performance of the planner in terms of quality of the resulted paths, runtimes of the planner, stability of the results in different executions, ability to solve difficult problems effectively and capability of planning in unknown environment.

First, a sensor-based path planner was designed which incorporates the heuristic rules of tabu search technique to handle uncertainty and lack of information about the environment and to prevent trapping in local minima which is quite common in online planning. This planner considers the points on the vision range of the robot's sensory system as the sampling area and uses the tabu search rules to evaluate the generated samples and select the most promising ones.

Secondly, a fuzzy logic controller (FLC) was constructed for evaluating the generated samples in order to make the planner behavior close to the human manner and solve the planning queries in difficult environments.

Afterward, a genetic algorithm-based optimization framework was designed to improve the interpretability and accuracy of the proposed fuzzy-tabu controller by optimizing the parameters of the FLC and also some of the planner's parameters in order to improve the quality of the generated paths and runtimes of the planner and also to decrease the variation of the results in different runs of the planner. The

genetic optimizer also evaluates the fuzzy rules and selects those rules that directly affect the performance of the planner and ignores irrelevant and erroneous fuzzy rules.

Finally, an adaptive neuro-fuzzy inference system (ANFIS) was designed which constructs and optimizes a fuzzy logic controller using a given dataset of input/output variables in order to increase the optimality and stability rates of the proposed path planning algorithm. The simulation and comparison results indicate the superiority of the proposed algorithm. The proposed Tabu-based path planner successfully guides the robot in unknown environments without trapping in encountered local minima. The designed fuzzy-Tabu controller effectively solves the path planning queries in difficult environments like mazes, narrow passages and Bug traps without any failure. After optimizing the proposed fuzzy model by means of genetic algorithm, the resulted planner produces shorter paths in shorter runtimes with limited variations in results of different runs of the planner. Finally, the proposed ANFIS-generated FLC successfully improves the optimality and stability of the proposed planner. The average runtime was less than 4 seconds while the optimality of the generated paths was more than 95% with less than 0.1 standard deviations for path length and runtime.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ALGORITMA PERANCANGAN PATH HIBRID BERASASKAN PENSAMPELAN UNTUK ROBOT MOBILE NAVIGATION DALAM PERSEKITARAN TIDAK DIKETAHUI

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Masalah perancangan gerakan menimbulkan persoalan bagaimana robot boleh bergerak dari awal untuk kedudukan akhir. Berasaskan Persampelan perancangan gerakan adalah kelas algoritma perancangan laluan rawak dengan kesempurnaan terbukti. Algoritma ini menjana laluan menggunakan nombor rawak dan melaksanakan cekap dalam membimbing robot dalam persekitaran yang dikenali. Terdapat pelbagai algoritma di dalam kelas ini dengan objektif kelebihan, dan kelemahan yang berbeza. Kelemahan yang sedia ada perancang berasaskan persampelan semasa boleh dikategorikan kepada lima kategori termasuk bukan optimaliti-laluan menyebabkan ketidakstabilan keputusan dalam berjalan berbeza perancang, tinggi keperluan masa berjalan dalam beberapa masalah, kegagalan dalam persekitaran yang sukar seperti yang sempit petikan dan perangkap Bug, dan ketidakupayaan untuk merancang dalam persekitaran yang tidak diketahui.

Walaupun sambungan beberapa algoritma berasaskan persampelan telah dicadangkan untuk menyelesaikan setiap kelemahan, tetapi kekurangan perancang rawak yang mengatasi semua ketidakcekapan tersebut di atas dalam pakej tunggal adalah jelas dan membuat perancangan pensampelan berasaskan jalan kurang berkesan untuk tujuan tertentu.

Dalam kajian ini, kami mencadangkan jalan perancangan berasaskan pensampelan algoritma yang menggunakan heuristik dan beberapa teknik pintar untuk meningkatkan prestasi perancang dari segi kualiti laluan menyebabkan, runtimes perancang, kestabilan keputusan hukuman yang berbeza, keupayaan untuk menyelesaikan masalah yang sukar berkesan dan keupayaan perancangan dalam persekitaran yang tidak diketahui.

Pertama, seorang perancang laluan berasaskan penderia telah direka yang menggabungkan kaedah-kaedah yang heuristik teknik gelintaran tabu untuk menangani ketidaktentuan dan kekurangan maklumat tentang alam sekitar dan untuk mengelakkan memerangkap di minima tempatan yang agak biasa dalam perancangan dalam talian. Perancang ini menganggap mata pada julat penglihatan sistem deria robot sebagai kawasan persampelan dan menggunakan peraturan gelintaran tabu untuk menilai sampel yang dijana dan pilih yang paling cerah.

Kedua, pengawal logik kabur (FLC) telah dibina untuk menilai sampel dijana untuk membuat tingkah laku perancang berhampiran dengan cara manusia dan menyelesaikan pertanyaan perancangan dalam persekitaran yang sukar.

Selepas itu, satu genetik-berasaskan algoritma pengoptimuman rangka kerja telah direka untuk memperbaiki yang interpretability dan ketepatan yang pengawal yang dicadangkan kabur-tabu dengan mengoptimumkan parameter FLC itu dan juga beberapa parameter jururancang untuk meningkatkan kualiti di laluan runtimes dan dijana perancang dan juga untuk mengurangkan perubahan keputusan dalam berjalan berbeza perancang. Pengoptimasi genetik juga menilai peraturan kabur dan memilih kaedah-kaedah yang secara langsung menjejaskan prestasi perancang dan mengabaikan peraturan kabur tidak relevan dan salah.

Akhirnya, penyesuaian kabur neuro inferens sistem (ANFIS) telah direka yang membina dan mengoptimumkan pengawal logik kabur menggunakan dataset diberikan pembolehubah input / output untuk meningkatkan kadar optimaliti dan kestabilan algoritma perancangan laluan yang dicadangkan.

Keputusan simulasi dan perbandingan menunjukkan keunggulan algoritma dicadangkan. Perancang laluan yang dicadangkan Tabu berasaskan berjaya membimbing robot dalam persekitaran yang tidak diketahui tanpa memerangkap dihadapi minima tempatan. Yang direka kabur-Tabu pengawal berkesan menyelesaikan laluan merancang pertanyaan dalam persekitaran yang sukar seperti mazes, laluan sempit dan perangkap Bug tanpa sebarang kegagalan. Selepas mengoptimumkan model kabur yang dicadangkan melalui algoritma genetik, perancang menyebabkan menghasilkan laluan yang lebih pendek dalam runtimes pendek dengan variasi yang terhad dalam keputusan berjalan yang berbeza perancang. Akhirnya, cadangan ANFIS dijana FLC berjaya meningkatkan optimaliti dan kestabilan perancang yang dicadangkan. Runtime purata adalah kurang dari 4

saat manakala keoptimum laluan yang dijana adalah lebih daripada 95% dengan kurang daripada 0.1 sisihan piawai bagi panjang jalan dan runtime.

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I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

WERIA KHAKSAR

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