UNIVERSITI PUTRA MALAYSIA

A NEURAL NETWORK SOLUTION TO SINGULAR CONFIGURATION IN TRAJECTORY TRACKING OF A SERIAL ROBOT

ALI T. HASAN

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By

ALI T. HASAN

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

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DEDICATION

A Special Dedication To

My Family

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

A NEURAL NETWORK SOLUTION TO SINGULAR CONFIGURATION IN TRAJECTORY TRACKING OF A SERIAL ROBOT

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ALI T. HASAN

September 2009

Chairman: Associate Professor Napsiah Ismail, PhD

Faculty: Engineering

Singularities and uncertainties in arm configurations are the main problems in kinematics of serial robots. The complexity in the solution arises from robots geometry and non-linear equations (trigonometric equations) occur when transforming between Cartesian and joint spaces where multiple solutions and singularities exist. Mathematical solutions for the problem may not always correspond to the physical solution and methods of solution depend on the robot configuration.

In this research, a trajectory tracking approach is proposed for a 6 Degrees Of Freedom (DOF) serial robot manipulator. The proposed solution is carried out through two stages. First the kinematics model of the Fanuc $M710i$ robot was solved using the D-H method to show the exact location of singular

configurations of the robot, and then Artificial Neural Networks (ANNs) are trained to overcome these arising problems. Solving the Inverse Kinematics (IK) of serial manipulators by using ANNs has two problems, one of these is the selection of the appropriate configuration of the network and the other is the generating of suitable training data sets.

In this research, although this is very difficult in practice, training data were recorded experimentally from sensors fixed on each joint to overcome the effect of kinematics uncertainties presence in the real world such as ill-defined linkage parameters, links flexibility and backlashes in gear train. Off-line training was implemented for the experimentally obtained training data.

Two networks configurations from the literature were tested and developed following the recommendations of the original authors, then compared to find the best configuration to be used. First the effect of orientation of the tool was examined (as one of the networks does not considered the effect of orientation while the other network does), and then the effect of the Jacobian matrix to the solution for the both configurations was examined.

Performance comparison shows that when the effect of the orientation of the tool was considered in the solution with the Jacobian matrix effect, better results in terms of precision and iteration during training the ANN were obtained.

The effect of the network architecture was also examined in order to find the best network configuration to solve the problem. A network with all the parameters considered together in one network has been compared to six different networks, where the parameters of every joint were considered independently. Results obtained show that having one network considering all the problem's parameters together give a better response than using 6 different networks representing the parameters of each joint apart from other joints.

The resultant network with the best configuration was tested experimentally using new different set of data that has never been introduced to the network before, this data set was meant to pass through the singular configurations, in order to show the generality and efficiency of the proposed approach.

Experimental trajectory tracking has shown the ability of the proposed Artificial Neural Networks approach to overcome the disadvantages of using some schemes like the Fuzzy Learning Control for example that only remembers the most recent data sets introduced, as the literature has shown.

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

PENYELESAIAN RANGUAIAN NEURAL UNTUK TATARAJAH SINGULARITI BAGI PENJEJAKAN TRAJEKTORI ROBOT SERIAL

Oleh

ALI T. HASAN

September 2009

Pengerusi: Prof. Madya Datin Napsiah Ismail, PhD

Fakulti: Kejuruteraan

Singulariti dan ketidakpastian dalam konfigurasi lengan adalah masalah utama dalam kinematik robot bersiri. Kerumitan dalam penyelesaian timbul daripada geometri robot dan persamaan taksekata (persamaan trigonometri) terjadi apabila perubahan antara satah Kartesian dan ruang sambungan di mana penyelesaian berbilang dan singulariti wujud. Penyelesaian matematik untuk masalah ini mungkin tidak selalunya selaras dengan penyelesaian fizik dan kaedah-kaedah penyelesaian bergantung pada konfigurasi robot.

Dalam penyelidikan ini, satu pendekatan penjejakan trajektori telah dicadangkan bagi enam darjah kebebasan pergerakan (DOF) pengolah robot bersiri. Penyelesaian yang dicadangkan dijalankan dengan dua peringkat. Pertama model kinematik robot Fanuc $M710i$ diperolehi menggunakan kaedah D-H untuk

menunjukkan lokasi sebenar konfigurasi singular robot, dan kemudian Rangkaian Neuro Buatan (ANNs) telah dilatih bagi mengatasi masalah yang muncul.

Menyelesaikan kinematik songsang (IK) pemutar belit bersiri dengan menggunakan ANNs mempunyai dua masalah, satu daripadanya adalah pemilihan konfigurasi rangkaian yang padan dan yang lain ialah penjanaan set-set data latihan yang sesuai.

Dalam penyelidikan ini, data latihan telah direkodkan secara eksperimen daripada pengesan yang ditetapkan pada setiap sendi untuk mengatasi kesan ketidakpastian kinematik yang hadir di dalam dunia sebenar seperti parameter rangkaian yang tidak ditakrif dengan baik, hubungan kelonggaran dan tendangan dalam gear latihan. Latihan luar talian telah dilaksanakan secara eksperimen untuk memperoleh data latihan.

Dua konfigurasi rangkaian daripada pembacaan telah diuji dan dibangunkan mengikut cadangan penyelidik asal, kemudiannya dibandingkan bagi mencari konfigurasi terbaik untuk digunakan. Pertama, kesan orientasi alat telah diperiksa, dan kemudian kesan matriks Jacobian untuk penyelesaian bagi kedua-dua konfigurasi juga telah diperiksa.

Perbandingan prestasi menunjukkan bahawa apabila kesan orientasi alat dipertimbangkan dalam penyelesaian dengan kesan matriks Jacobian, keputusan lebih baik dari segi ketepatan dan lelaran semasa latihan ANN dialami.

Kesan seni bina rangkaian telah juga diperiksa bagi tujuan mencari konfigurasi rangkaian yang terbaik untuk menyelesaikan masalah. Satu rangkaian dengan semua parameter dianggap bersama dalam satu rangkaian telah dibandingkan dengan enam rangkaian berbeza, di mana parameter bagi setiap sendi dianggap secara bebas. Keputusan yang diperolehi menunjukkan bahawa mempunyai satu rangkaian dengan mempertimbangkan kesemua parameter masalah bersama menunjukkan gerak balas yang lebih baik daripada menggunakan enam rangkaian berbeza yang mewakili parameter bagi setiap sendi yang bersendiri.

Rangkaian yang dihasilkan dengan konfigurasi terbaik telah diuji secara eksperimen dengan menggunakan tiga set data baru berbeza yang tidak pernah diperkenalkan kepada rangkaian sebelum ini, set data ini telah ditetapkan untuk melalui konfigurasi singular, dengan tujuan untuk menunjukkan keluasan makna dan kecekapan bagi pendekatan yang telah dicadangkan.

Eksperimen penjejakan trajektori telah menunjukkan keupayaan pendekatan Rangkaian Neuro Buatan cadangan untuk mengatasi kelemahan dalam menggunakan skima-skima seperti kawalan pengajaran Fuzzy contohnya yang hanya mengingati set data yang paling mutakhir diperkenalkan, seperti yang ditunjukkan dalam pembacaan.

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I certify that a Thesis Examination Committee has met on the 29th of September 2009 to conduct the final examination of Ali T. Hasan on his thesis entitled " A Neural Network Solution To Singular Configuration In Trajectory Tracking of A Serial Robot " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

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.

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ALI T. HASAN

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