UNIVERSITI PUTRA MALAYSIA

AN INTELLIGENT SYSTEM APPROACH TO THE DYNAMIC HYBRID ROBOT CONTROL

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By

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Dedication

This study is dedicated to
my parents, Dr. Md. Yeasin M,B;B,S & Mrs. Johura Yeasin
my wife, Mrs. Shafina Hasan
&
my daughter, Miss. Mashruka Mahmud

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LIST OF ABBREVIATIONS

$V_i^l(t)$	Activation function
b_i^l	Bias term
A_i^{i-1}	The homogeneous transformation
$\Im$	Concept space
ρ	Distribution
η	Learning constant
λ	Learning rate (step length)
α	Reward or penalty
ε	Threshold
$\Delta\theta$	Finite change in joint angle
$\theta(t)$	Generalized coordinates position/orientation
$\tau_i(t)$	Torque time function
ANN	Artificial Neural Networks
BDJP	Bounded Deviation Joint Path
BNN	Back-propagation Neural Networks
C	Cartesian space
C-space	Configuration-space
CAM	Center of Area Method
CCD	Cyclic Coordinate Descent
CRS	Cellular Robotic System
CSMOS	COgnitive Sensor Motor Operation Study
DAC	Digital-to-Analog Converter
DAI	Distributed Artificial Intelligent
DIS	Distributed Intelligence System
DOF	Degrees Of Freedom
DSP	Distributed Problem Solving

F^C	Force described by the coordinate frame C
FLC	Fuzzy Logic Controller
GA	Genetics Algorithms
I	Joint space value
J^T	Jacobian Transpose
K	Stiffness matrix
LECOSO	LEarning COntrol SOftware
MOM	Mean of Maximum
MRAC	Model Reference Adaptive Control
MSE	Mean Square Error
n	The number of robot joint
PI	Proportional plus Integral
PID	Proportional plus Integral plus Derivatives
$P_n(t)$	World coordinates position/orientation
$q(t)$	End effector trajectory
$q^*(t)$	Desired end effector trajectory
R_F	Force sensor calibration matrix (6x1)
SLNN	Single Layer Neural Networks
W-space	Work-space
W_i	ith column of weight vector

Abstract of dissertation submitted to the Senate of Universiti Pertanian Malaysia in fulfillment of the requirements for the Degree of Doctor of Philosophy.

AN INTELLIGENT SYSTEM APPROACH TO THE DYNAMIC HYBRID ROBOT CONTROL

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The objective of this study was to solve the robot dynamic hybrid control problem using intelligent computational processes. In the course of problem- solving, biologically inspired models were used. This was because a robot can be seen as a physical intelligent system which interacts with the real world environment by means of its sensors and actuators. In the robot hybrid control method the neural networks, fuzzy logics and randomization strategies were used.

To derive a complete intelligent state-of-the-art hybrid control system, several experiments were conducted in the study. Firstly an algorithm was formulated that can estimate the attracting basin boundary for a stable equilibrium point of a robot's

kinematic nonlinear system. From this point the Artificial Neural Networks (ANN) based solution approach was verified for the inverse kinematics solution. Secondly, for the intelligent trajectory generation approach, the segmented tree neural networks for each link (inverse kinematics solution) and the randomness with fuzziness (coping the unstructured environment from the cost function) were used. A one-pass smoothing algorithm was used to generate a practical smooth trajectory path in near real time. Finally, for the hybrid control system the task was decomposed into several individual intelligent control agents, where the task space was split into the position-controlled subspaces, the force-controlled subspaces and the uncertain hyper plane identification subspaces. The problem was considered as a blind-tracking task by a human. The task involved three levels of coordination: learning level, skill level and adaptation level. These control levels are coordinated amongst themselves forming the Distributed Artificial Intelligent (DAI) system. The DAI control system has three basic modules; 1) the force control module, which involves the Jacobian transpose computation to determine the joint force/torque, and, a PI fuzzy gain tuning rule, for the adaptive damping control scheme which allows automatic response to surface stiffness, 2) the position control module, which involves the neural networks' kinematic solution used for the real time performance, and 3) the identification of the unknown constrains hypersurfaces module, which uses a simple linear fuzzy estimation procedure. This adaptive dynamic hybrid control method solved the servo and motion planning control level. The characteristic of the proposed controller was a one-step-ahead feedback controller due to the physical control of the robot arm before identification of the unknown surfaces. The experimental and simulation tests of these experiments had shown that the complex dynamic parameters can be estimated through the intelligent assessment procedure of the system dynamics.

Abstrak dissertasi yang dikemnukakan kepada Senat Universiti Pertanian Malaysia bagi memenuhi syarat-syarat untuk memperolehi Ijazah Doktor Falsafah.

PENDEKATAN SISTEM CERDIK TERHADAP MASALAH KAWALAN ROBOT HIBRID DINAMIK

Oleh

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Objektif kajian ini ialah untuk menyelesaikan masalah kawalan hibrid dinamik robot dengan menggunakan proses-proses pengkomputeran cerdik. Dalam penyelesaian masalah, model-model berinspirasi biologi telah digunakan. Ini adalah kerana robot dapat dilihat sebagai sistem cerdik fizikal yang berinteraksi dengan persekitaran dunia nyata melalui penderia dan penggeraknya. Kaedah kawalan hibrid robot ini menggunakan strategi-strategi rangkaian saraf, logik kabur dan perawakan.

Untuk memperolehi sistem kawalan hibrid cerdik yang lengkap, kajian ini menjalankan beberapa eksperimen. Pertama, satu algoritma yang dapat mentaksir sempadan asas bertarikan untuk titik keseimbangan yang stabil bagi sistem tak linear

kinematik sesebuah robot telah dirumus. Pendekatan penyelesaian berdasarkan Rangkaian Saraf Buatan (Artificial Neural Networks - ANN) dibentuk untuk penyelesaian kinematik songsang. Kedua, untuk pendekatan generasi trajecktori cerdik, rangkaian saraf pokok teruas untuk setiap paut (penyelesaian kinematic songsang) kerawakan dengan ketidakjelasan (mengendalikan persekitaran tak berstruktur daripada fungsi kos) telah digunakan. Satu algorithma perataan satu-laluan digunakan untuk menjana laluan trajecktori yang praktik dan rata dalam masa hampir nyata. Akhir sekali, untuk sistem kawalan hibrid, tugasan untuknya telah dibahagikan kepada beberapa agen kawalan cerdik individu, iaitu ruang tugasan dipisahkan kepada subruang kawalan kedudukan, subruang kawalan daya dan subruang pengenal pastian hipersatah yang tak tentu. Masalah ini dianggap sebagai tugasan menjejak buta oleh seseorang manusia. Tugasan ini melibatkan tiga tahap penyelarasan: iaitu tahap pembelajaran, tahap kemahiran dan tahap adaptasi. Tahap-tahap kawalan ini diselaraskan dengan sendirinya dan membentuk Sistem Kecerdasan Buatan Tersebar (Distributed Artificial Intelligent - DAI). Sistem kawalan DAI mempunyai tiga modul asas, 1) modul Kawalan Daya yang melibatkan pengiraan alih Jacobian untuk menentukan daya gabungan dan satu peraturan penalaan gandaan fuzzy PI, untuk skim kawalan radaman yang menghasilkan gerak balas automatik kepada kekakuan di permukaan; 2) modul kawalan kedudukan yang melibatkan penyelesaian kinematik rangkaian saraf yang melibatkan penyelesaian kinematik rangkaian saraf yang digunakan untuk prestasi masa nyata; 3) pengenal pastian kekangan yang tidak diketahui modul hiperpermukaan yang menggunakan prosedur taksiran ketidakjelasan linear yang mudah. Kaedah kawalan hibrid dinamik yang adaptif ini memberi penyelesaian pada servo dan tahap kawalan rancangan gerakan. Ciri pengawal yang dicadangkan adalah satu pengawal suap-balik satu langkah ke hadapan disebabkan kawalan fizik lengan robot sebelum pengenal pastian permukaan yang tidak diketahui. Ujian eksperimen dan simulasi eksperimen-eksperimen ini telah menunjukkan bahawa parameter dinamik yang kompleks dapat dijangka melalui prosedure taksiran cerdik dinamika sistem tersebut.

CHAPTER I

INTRODUCTION

A robot is an automatic apparatus or device that performs functions ordinarily ascribed to human beings, or operates with what appears to be almost human *intelligence* (adapted from Webster's Third International Dictionary). The theory and practice of *intelligent* and *robotics system* are currently one of the most trendy and promising areas in computer and system science and engineering, and will certainly play a primary role in future industrial automation. Robotics is the science and art of designing and using robots. Robot can be seen as a physical intelligent system which interacts with the real world environment by means of its sensors and actuators. Generally it consists of three principal subsystems; an *intelligent perception subsystem*, an *intelligent action subsystem*, and an *intelligent task planning subsystem.* The intelligent perception subsystem recognizes a situation of the real environment by means of visual, force and tactile sensing. The intelligent action subsystem takes care of proper kinematics and dynamics action by means of avoiding obstacles, gripper positioning and orientation, path planning. The intelligent task planner subsystem provides information on "*how to do and when?*" about a task. To achieve an integrated intelligent robotics control system these subsystems must be able to be fused together.

Robotic manipulators became widely used in industry during the 1980s for tasks such as spray painting, spot welding, and simple pick-and-place operations. Now-a-days modern industrial automation demands that “agile” assembly line be incorporated. In this scenario, robots will eventually become the most dominant device in an industrial automation arena. Their use for more demanding tasks has prompted its research to a wider range of technical problems, such as combined force and motion control for constrained tasks like grinding and deburring (Raibert and Craig, 1981), (Kazerooni, 1986). With the introduction of these modernistic robot tasks, new research problems have arisen concerning their kinematics, dynamics and control. With more complex robot tasks, the problems of kinematics, dynamics and control of the robot have become more difficult over the more conventional tasks of pick-and-place operations.

The basic difficulty in controlling a robot manipulator arises from the fact that the dynamic equations describing the manipulator motion are inherently non-linear and highly coupled. This is due to the dynamic coupling effects between the objects and varying effect of inertia of the link. It was proven that real-time adaptive robot control is extremely difficult (Atkeson and Reinkensmeyer, 1990). Present day control systems can be said to be more challenging in terms of computational burden and real-time responses. The complexities of the mathematical model make the robot control task a difficult and challenging one. However, robots have to work in the real world, and the real world cannot be modelled with concise mathematical expressions.

Thus, any equations that is to be derived must always have these real world problem in mind. Equations of motions for a system of rigid bodies have previously been based on physical laws of Lagrangian mechanics and Newtonian mechanics. This has led to the development of the two main approaches to dynamic equations of motion for manipulators; the Lagrange-Euler equations and the Newton-Eulers equations. The nature of these solutions were too slow for real time consideration, due to the velocity product terms which needed triple summation for each joint torque (Kahn, 1969), (Uicker, 1967). When these were taken in conjunction with the joint torque computation for n joints, it has resulted in $O(n^4)$ operations (which was a real computational bottle-neck).

In recent years, there has been rapid changes of specialization in the field of intelligent control for a complex plant in building a smarter machine. Infact, the notion of machine intelligent or intelligent controls had now become an engineering discipline. The study of intelligent machines and neurosciences are current active fields of research. Research in learning automata, neural nets, and brain modelling have given insight into learning vis-a-vis it's similarities and differences between neuronal and electronic computing processes. Research in Fuzzy Logic Theory has developed methods for decision making in the face of uncertainty. Modern control theory has developed precise understanding of stability, adaptability, and controllability under various conditions of feedback and noise. What is lacking is a general theoretical model of intelligent systems which ties all of these separate fields