NEW HIERARCHICAL METHOD FOR PATH PLANNING OF LARGE-SCALE ROBOTS

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***Abstract*— In this paper, a new coordination method based on non-linear hierarchical control for large-scale robots is presented. The large-scale system is considered as combination of subsystems so that each subsystem has interaction with others. The procedure is to use interaction prediction principle with optimal control for each subsystem. At the first level, applying optimal control principle to each subsystem with guessed interaction variables results in Two Point Boundary Value Problem (TPBVP). By solving TPBVP the new interaction parameters are generated. At the second level, the resulted interactions are exchanged between subsystems and the interaction variables are improved within interaction prediction principle. Difference between guessed and achieved interaction in each step is used in general cost function to coordinate subsystems. Hence continuing the algorithm causes to converging the interactions to each other. The new method results in less time by parallel processing for each subsystem, and has less sensitivity for different initial guess in comparison with centralized use of optimal control for large-scale robots because of using small sized sub-systems which is a step toward real-time planning of mobile manipulators, also the proposed method has the ability to solve problems with inseparable cost functions which is an important benefit for robots path planning in presence of obstacles and specified path for end-effector. The method is simulated and verified by previous work in this area. The simulation results show effectiveness of proposed method for large-scale robots. The approaches validity is checked via simulations and experiments with a 2-link nonholonomic mobile manipulator named Scout.**

***Keywords*— Hierarchical control, Large-scale systems, Optimal control, Mobile robot, Nonholonomic.**

NOMENCLATURE

M(q) : Inertial matrix of manipulator.
$C(q,\dot{q})$:Centrifugal and coriolis matrix of manipulator.
τ, U: control inputs to joints or wheels (N.m, N).
q: generalized coordinates of manipulator.
X_i: state variable of i'th sub-system.
ϕ: head angle of nonholonomic mobile base (rad).
θ_r, θ_l: angular displacement of right and left wheels respectively (rad).
θ_1, θ_2: angular displacement of first and second joints of manipulator respectively (rad).
Z^i: interaction vector of i'th sub-system.
J: cost function.
k: weight of convergence.
l_i : inseparable part of cost function of each sub-system.
h_i: separable part of sub-system's cost function.
h: overall cost function.
H: hamiltonian of general system.
R,Q: weighting matrixes of states and control variables.
η: states related to velocities.
λ_i: adjoin vector of ith sub-system.
x^*: desired state vector.
p_i: lagrange multiplayer of i'th sub-system.

I. INTRODUCTION

Today's robotic applications go toward using high DOFs robots with complex construction. They are desired because of much larger workspace and high amount of manipulability but as the order of system increases, the path planning and control become more difficult, because of high amount of dynamic equations, constraints and dynamic interactions. High DOF robots as Large-scale systems are which contain a number of interdependent components with special functions, share resources, and are governed by a set of interrelated constraints and goals (Mesarovic *et al.,* 1970).

Although during the past decades, a great deal of attention has been given to the problem of motion planning of robots, but a few authors have studied the complex robotic systems (Sadati and Babazadeh, 2006). Different methods are used for optimal path planning of robotic manipulators can be categorized into two main groups; direct methods and indirect methods (Chettibi *et al.*, 2004). Generally, direct methods result in approximate solution, and they are not suitable for systems with a large number of DOFs because they are quite inefficient due to the large number of parameters involved and may cause to numerical explosion (Korayem *et al.,* 2009). On the other hand, indirect methods are based on Pontryagin maximum principle (PMP) which solves the optimal control problem exactly (Korayem *et al.,* 2009). The optimality conditions are expressed as a set of differential equations and lead to a two point nonlinear boundary value problem (TPBVP). This boundary values problem is solved by numerical techniques. But solving nonlinear boundary value problems are numerically ill conditioned problems (Kirk, 1970). The main difficulty of these problems comes from sensitivity to initial guess and long time of computations. Also, as the order of the system increases, these difficulties become more critical.

Mohri et al. have used indirect method for trajectory