CHAPTER 1

INTRODUCTION

In the present work the robot dynamics and control problem have been visualized from a relatively new perspective which the conventional and classical methods failed to provide due to their highest levels of abstraction. The bond graph modelling technique has added a new dimension in the evolution of better control strategies for complex robotic systems.

1.1 Introduction to Bond Graphs

The scope of application of bond graphs in system modelling is continuously on the rise. Bond graph theory is based on the fact that physical systems in all domains have one abstract quantity in common i.e. energy and its time derivative, power. Bond graphs are used to reprersent pictorially and in an efficient manner the energy exchange, storage and dissipation or transformation among interacting physical systems. Usefulness of bond graphs in system modelling and simulation lies in the precise way the assumptions of system model and their modifications are incorporated. By this approach all kinds of lumped physical systems can be modelled with the help of a small number of basic ideal elements over different energy domains, namely, electrical, mechanical, hydraulic, pneumatic, magnetic, fluid, thermal and others in a unified manner. In all the domains two conjugate variables can be defined such that their product denotes power. These variables are given the generalized names: "effort" (e) and "flow" (f). The bond graph techniques help in selection of state variables, derivation of system equations and their solutions systematically. The whole procedure may be automated if advantage is taken of the existing computer programs such as COSMO-KGP [11] or ENPORT [65,66] etc. Computer programs like TUTSIM [50,14] and CAMP [19,38], which are based on continuous system simulation languages, may also be used for this purpose. The growing acceptance of bond graph techniques, for their power in modelling, analysis and simulation of physical systems, may be observed from the bibliography by Bos and Breedveld [6].

To improve the readability of the thesis, bond graph mnemonics are briefly explained along with suitable references in Appendix A.

1.2 Introduction to Dynamics and Control Aspects of Robots

Theoretical investigations on various types of robotic manipulators have conclusively revealed that the dynamic equation of a manipulator plays a very important role in the design of suitable control laws for the robot, and in the evaluation of its kinematic design. In order to servo the manipulator's joint actuators to accomplish a desired task the knowledge of the kinematics and dynamics of a manipulator is necessary. In general, the motion control problem of a manipulator consists of 1) obtaining dynamic models of the manipulator and 2) using these models to determine control laws or strategies to achieve the desired system response and performance. These dynamic models provide the control algorithm the information for controlling the manipulator's actuators such that the complicated effects of inertial, centrifugal, Coriolis, gravity and friction forces can be compensated when the robot is in motion.

A number of techniques for dynamic modelling and control of robotic manipulators have been proposed. Methods for forming these dynamic models of robotic mechanisms in principle may be classified into three basic groups:

1. Techniques based on Lagrange-Euler (L-E) equations.
2. Techniques based on Newton-Euler (N-E) equations.
3. Techniques based on Bond Graph modelling.

In addition to the above techniques for the dynamic modelling of robotic manipulators, two recursive approaches have also been developed. One is called the Newton-Euler recursive formulation [47], and the other Lagrangian recursive formulation [24]. Much of the effort was devoted by the previous investigators in developing computationally efficient schemes for the joint torques/forces for the purpose of realizing a real-time controller for robots using L-E or N-E formulations.

These dynamic equations of robotic manipulators are highly nonlinear and complex and the inertial characteristics of the manipulators significantly depend on the payload. When L-E and N-E formulations are used to determine these dynamic equations, unnecessary calculations are involved in the elimination of interbody constraint forces and torques. Thus a significant amount of computational effort is required to solve the equations, making it less attractive for on-line control schemes. This computation is a bottleneck in control schemes, because it involves a large number of floating point additions and multiplications. As pointed out by Hollerbach [24] that any minor improvements in efficiency may be achieved to the recursive formulations as they stand today. For dynamic modelling and analysis, most of the investigators are currently seeking methods which 1) are easy to formulate 2) are easily convertible into computer algorithms and codes and 3) lead to efficient numerical solutions. Closed-form models are attractive from both the dynamic modelling and control engineering points-of-view.

For industrial robots and manipulators with high requirements on speeds and tracking accuracies, the control problem becomes quite complex. As pointed out earlier that in the control law formulation, a precise knowledge of the manipulator parameters and a detailed description of the dynamic model are required. The variation of payloads, unknown joint resistances and modelling errors give rise to uncertainties in manipulator dynamics. The performance of the control system is ultimately governed by the fidelity of the mathematical model used to describe the manipulator dynamics. The existing controller schemes are adequate for simple pick-and-place tasks, for which industrial robots are often used, where only point-to-point motion is of concern. However, in tasks where precise and fast tracking of trajectories under different payloads are required, the existing robot control systems are severely inadequate.

With increased demand on manipulator performance there is a need for improved control techniques which can take care of the above difficulties and are capable of achieving high-speed operations and accuracy.

1.3 Scope of the Present Work

From the above discussion, it is felt that most of the investigators are currently seeking methods to handle the robot dynamics in developing a suitable control law. In the present work the dynamics and control aspects of robotic systems have been studied from a relatively new perspective. The bond graph modelling technique has been used because of its flexibility in modelling and uniqueness in formulation of the system equations.

The first phase of the study is devoted to deriving scalar closed-form effort expressions for the desired state of motion to be used as feedforward for robotic manipulators.

In the second phase, a new approach is presented for the evolution of a robust controller for robotic systems which can take care of parameter variations, uncertainties and modelling errors and is capable of fast and precise tracking of trajectories under different payload conditions in joint coordinate and in cartesian coordinates. The scheme has the advantage of avoiding all the problems of model-based controller.

In the third phase, estimation of computational burden for the implementation and realization of the robust controller is presented.

1.4 Summary of Chapters

A brief review of related literature is presented in Chapter 2. The survey is restricted only in the areas of kinematics, dynamics and control. Many areas like sensors, locomotion, path-planning, etc. are out side the scope of the present work.

In the first part of Chapter 3 an unambiguous notation is introduced for different vectors. Although the form seems elaborate, still it probably is the minimal symbolism which is able to denote all velocities. The bond graph modelling for a particular robotic system is presented as an example. A general procedure is presented for the determination of the modulated transformers for the serially connected link structures using vector notation. The method for the derivation of driving effort expression by minimizing the elimination of number of internal reactions for a four bar mechanism as an example system is presented. The symbolically generated equations for all the state variables of a five degrees of freedom revolute robot are presented. The procedure for deriving the closed-form expressions from the symbolically generated equations is discussed.

In Chapter 4 an intuitive approach to design a robust robot controller by an "overwhelming system" for fast trajectory tracking is presented. The concept is developed using a single mass system and applied to general robotic system. The effect of "compensating elements" on the overwhelmer and the significance of "padding system" to remove differential causality is discussed. Using the methodology developed , the proposed controller along with a three degree of freedom revolute robot with unmodelled parameters has been simulated for tracking joint trajectories in the presence of uncertainties. Various simulation results are presented.

In Chapter 5, the overwhelming controller proposed in the previous chapter is elevated to tackle the precise and fast path tracking problem of manipulators in cartesian coordinates in the presence of various uncertainties. Here it is shown that the inverse kinematics problem which is very much involved in path tracking with its inherent drawbacks can be avoided and the forward kinematic transformation can solve the fast tracking problems. The effect of compound control, integral feedback and adaptive integral feedback control have been studied. Simulation results are shown for all these cases. The tracking quality shows that the proposed scheme is superior to any existing control schemes.

In Chapter 6, estimation of the computational burden involved in the realization of the overwhelming controller is presented. A proposition for implementation of the scheme is presented.

Chapter 7 contains a summary of the results and conclusions arrived at various stages of this work. The future scope of the work is also discussed.

In Appendix A the mnemonics of bond graphs are presented. Appendix B presents the closed-form driving effort expressions and are represented in a form suitable for computer algorithms.

The work concludes with a list of references arranged in alphabetical order as per the last name of the author.