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Intelligent Control of Sensor Based Robotic System

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***Abstract:*— With the advent of computers in the field of programmable automation, control of production process has assumed new dimensions. As a matter of fact, robot is indispensible in such production systems. Effective control of such systems requires special sensory devices to interact with the environment in a more meaningful and flexible manner. To achieve this objective, factory of future should imbibe human intelligence at all levels of manufacturing, particularly robot motion/force control. This will result in improved product quality and hence customer satisfaction. Online feedback of sensory information is the basis for the development of more intelligent robot that comes closer to the performance of human arms. This information when coupled with new control strategies will definitely guide the robot to perform its intended function with highest accuracy and precision. But in such complex systems as in robotic system, it is often difficult to coordinate sensory information with the control task. This is due to the undesirable feedback delays or fundamental sensor limitations. Against this backdrop, the present work focuses on toying with the idea of exploring new control strategies namely "Intelligent Control Approaches" that refer both to the control design approach or philosophy and to implementation techniques that emulate certain characteristics of intelligent biological systems .**

Keywords:----- **Control schemes, Feedback control, Intelligent control, Robot control, Robot sensors, Robotic system.**

I. INTRODUCTION

Many robot manipulators are used in factories these days. One of the most important and fundamental task of the robot manipulators is position and force control. Most of the industrial robots, however, are used only for positioning of objects, since there are some problems in realizing force control for practical uses. Recently, robot manipulators have been expected to perform more sophisticated tasks than just the positioning of objects, even in factories. In order to realize some sophisticated tasks, such as grinding, deburring, wiping, or assembling of objects with the robot, a proper amount of force has to be applied with a proper tool feedrate. As a matter of fact there are difficulties not only in designing an effective robot controller, but also in obtaining the desired force and the desired feedrate for the tasks [1].

Endowing the robot with sophisticated sensors results in an intelligent robot that could understand and interact with the environment in a more flexible and intelligent way. The feedback information from sensors when coupled with new control strategies will effectively guide the robot to the designated task without much difficulty and with the stated precision and accuracy. The successful application of robotic systems to tasks in uncertain environment typically requires the use of special sensors for task related control feedback. Such sensors might for example, provide tool position or force information relative to an object being manipulated. In order to make robot control decisions in a task referenced space, it is typically necessary to transform the sensor outputs to the decision space, compute task relative error signals and finally compare joint level commands using appropriate coordinate transformations and control algorithms.

Control is the act of affecting a dynamic system to accomplish a desired behaviour [2]. The newly coined term intelligent control refers to the control design philosophy of implementing and emulating human intelligent characteristics. With the result, new and innovative control schemes such as 'Fuzzy Control, Neural Network Control, Neuromorphic Control' systems have come into force in the arena of robotic engineering.

II. PROBLEM STATEMENT

The design of a control system for a robotic machine can be very straightforward or can be extremely difficult depending on a number of factors. These are:

a) the geometric design of the machine
b) the specification of speed, accuracy, etc
c) the degree of definition of the task – i.e., how well structured the task is
d) the presence or not, of external disturbances
e) the degree to which the machine may be modeled dynamically
f) the method of teaching a machine

These factors, are of course interrelated so that, for instance a) will have a major influence on b), and so on. For simple applications such as pick and place operations, design of control system is very simple in that the start and end points of operations are being taught by an operator and

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robot remembers these positions and repeats the same sequence of motions when it is called for [2].

At the other end of the control spectrum are the advanced computer controlled arms which are now being designed for tasks such as automatic assembly. In such machines, full coordinated control of each degree of freedom is to be effected by "sophisticated control algorithms" which will take into account the kinematics and dynamics of the system and compute the forces and torques necessary to drive the end – effector (EE) along desired trajectories in the working space.

The control computers will have access to sensory information, of forces encountered in accomplishing the task, for example, or visual images which may be processed to provide knowledge of the environment. The control algorithms may be required to make use of this information in generating command signals for the limb servos. From the above it is evident that one of the severest constraints imposed upon control system is the very short time available in which to perform the algorithm if this must be accomplished in real – time. In control analogy terms, the robotic system in this case may be described as multivariable, interacting, non – linear, time – varying and partially modeled [3]. Efforts have been made in that direction to develop an efficient and effective control system that will address the shortcomings of present day control schemes. With the result, the emergence of newly coined idea "Intelligently Controlled" robots.

In view of the importance attributed to the new control strategies coupled with sensory information, the current research focuses on creating an 'intelligent robot' endowing with advanced controlled features and artificial intelligence. In such machines, full coordinated control of each degree of freedom is to be effected by sophisticated control algorithms.

Role of Computer in Control System of a Robot

We usually call computer controlled robot. Initially computers in robots were used to perform 'fixed functions' for the control of robot arm. That is there was little or no scope to interact and influence the external world. Computer functions mainly include motion and sequence control. Controller must able to remember positions, trajectories and sequence of motion and reproduce the same in working cycle. Best known examples include point – to – point control (drilling) and continuous path control (milling and grinding).

Fig. 1. illustrates the schematic of a robot motion control block diagram. As depicted in Fig. 1, the robot is directed through a sequence of motions. RMC is one form of overall robot controller. Other components of robot control are: teaching functions, communication with the factory, peripheral device control and sensory data analysis (see Fig. 2).

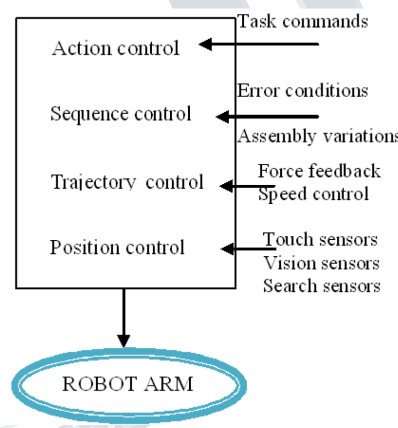

Fig. 1. Robot Motion Control (RMC)

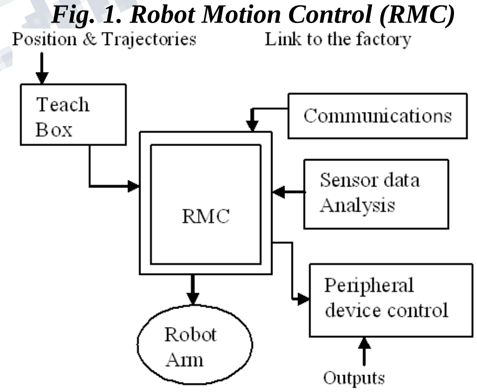

Fig. 2. Overall robot controller block diagram

Robot Sensory Devices

Any discussion of robotics must address sensors and the role they play in robotic applications. Robot without sensors is like a human being without eyes and ears. Equipping the robot with sensors will improve its

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adaptability, i.e., orientation in a changed situation, in a workevelope and hence it can interact with an environment in a more affable manner. Robots employ both external and internal sensors. External sensors are used for robot guidance in a work environment. Internal sensors deal with the detection of variables such as arm joint position used for robot control. Exterior sensors deal with the detection of variables such as range, proximity, and touch. They are used for object identification/handling. Position of robot joint can be determined with the aid of position sensors such as potentiometer, encoder, etc. and its velocity can be estimated by a tachometer coupled inside a joint. The information from these sensors has to be made to flow continuously in order to interact with the ever – changing environment [4]. Using the concepts of “input” and “output”, one can understand how sensors play critical roles in both open and closed control loops (see Fig. 3).

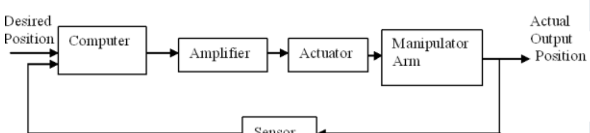

Fig. 3. Closed loop control sensor

Of course, closed loops are the most useful, where sensor input from the environment can be fed directly back to a control or actuator. This input to the control portion of the system can then drive the actuators to change the sensor environmental stimuli to whatever values have been previously determined as correct. Sensor technology is a necessary ingredient in any control – type application. Without the feedback from the environment that sensors provide, the robot system has no data or reference points, and thus no way of understanding what is right or wrong with its response. It is obvious that for a robot to do its work, it needs to be controlled by input provided by sensing changes in its actions. Even the most elementary robot doing a pick and place operation is enhanced if some kind of sensor provided to let it know when and where to pick and place.

Robot Control Schemes

The robot control can be effected by two modes of control systems. These include “open loop control system” and “closed loop control system”. When the control system employs feedback elements (sensors) to control the given operating variable, such control system is known as ‘closed loop control system’. On the other hand, if the control is accomplished without the aid of feedback elements such a system is known as ‘open loop control’ system. In the sense, no attempt has been made to make error zero in open loop control system.

The fundamental elements of tasks performed by robot manipulators are (1) to move the end – effector (EE) with or without a load, along a desired trajectory and (2) to exert a desired force on an object when the EE is in contact with it. The former is called *position control* (or trajectory control) and the latter *force control.*

As is clear from the Figure 4, in closed loop system, the sensor is attached to the robot arm directly and the actual position error is fed back to the control system. Unlike the closed loop control system, open loop has no feedback. Open loop can be applied in the case where the accuracy of control is not high and a stepping motor is used. No feedback and no detector/sensor in the circuit and the structure is simple as illustrated in Fig. 5. The accuracy of driving system is directly influenced by the accuracy of the stepping motor.

Force control

Many of the tasks we wish to perform using robot manipulators require control not only of the position of the manipulator but also of the force exerted by its EE on an object. Assembly, polishing, deburring, opening and closing a door, and turning a crank are typical examples of such tasks. In the sense, the robotic manipulator has to maintain contact with the environment. The manipulator controller has then the dual objective of ensuring a desired motion of the EE and of the EE exerting a specified force – torque on the contact surface. Two methods have been developed for force control [5]: *impedance control* and *hybrid control*.

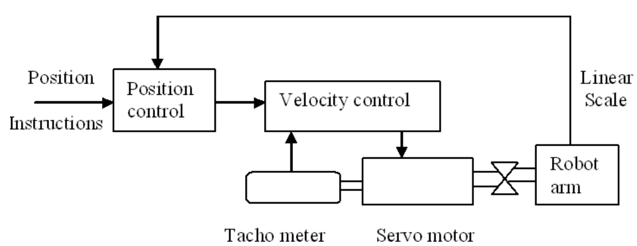

Fig. 4. Closed loop control system

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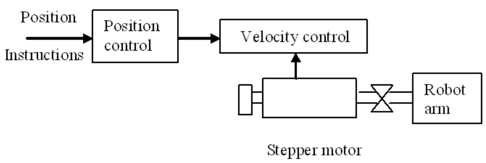

Fig. 5. Open loop control system

In order to control force to an object and position on the surface of the object simultaneously with a robot manipulator, a hybrid position/force controller seems to be a proper controller. The basic idea of the hybrid control is separate directions for the force control (orthogonal to the constraint surface of the object) and for the position control (moving along the constraint surface in a Cartesian coordinate system).

New Control Strategies

Several investigators have discussed the possibilities for the application of neural networks in robot control. The basic theme of all such discussions is that of using the network to learn the characteristics of the robot/sensor system, rather than having to specify explicit robot/sensor system models.

Neural network control of robot manipulator

Artificial neural networks (ANNs) are used to solve the problems of identification and control of complex nonlinear systems by exploiting the nonlinear mapping abilities of the NN. The most popular control scheme is one which uses NN to generate auxiliary joint control torques to compensate for the uncertainties in the computed – torque based primary robot controller that is designed based on a nominal robot dynamic model. This is accomplished by implementing the NN controller in either a feedforward or feedback configuration and the NN is trained online (see Fig. 6).

And the improved version of one of such systems is a learning control approach that utilizes the cerebellar model arithmetic computer (CMAC) neural network model. In the controller, the network is used as a feedforward term in place of an explicit system model. Network training is performed at the end of each control cycle based on online observations of the system input/output relationships, and independent of the immediate control goals. The learned information is then used at the beginning of each control cycle to predict the commands required producing desired changes in the feedback parameters. Information learned during previous movements is generalized automatically to achieve new control goals. As a result the technique is applicable to control of complex nonlinear systems performing nonrepetitive operations.

The learning controller so developed is capable of learning the kinematics of robot/video camera systems interacting with parts moving on a conveyor assuming only minimal qualitative priori knowledge of the robot/video/conveyor characteristics. As a result of this feature, CMAC network based learning controllers are easy to design for a particular application and easy to accommodate system changes [6].

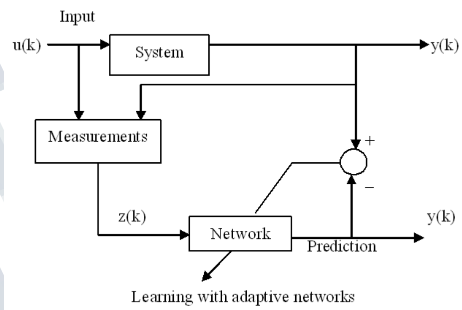

Fig. 6. Artificial Neural Network control system

Hierarchical Hybrid Neuromorphic control scheme

The neural network makes use of nonlinearity, learning, parallel processing, and generalization capabilities for application to advanced intelligent control. The neural network control has advantageous over conventional control approaches, especially in nonlinear systems including uncertainty in the environment. In force control one must consider not only system dynamics but also the characteristics of the environment as they affect the control loop. However, it is difficult to consider them. In such cases, the applicability of neural network based controller called neural servo controller (NSC) will solve the aforesaid problems with ease.

The hierarchical hybrid neuromorphic control system is a hybrid system of the neural network and AI technologies for hierarchical intelligent control and comprises two levels: a "learning" level for the long –term learning of the control process and an "adaptation" level for the short – term adaptation of dynamic process. The learning level has a hierarchical structure: recognition and

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planning for the control strategy of robotic manipulation. Plural neural networks are used at learning level as nodes of decision tree reasoning. Those neural networks are trained using the training data by a prior knowledge in order to transform various sensory data from numerical quantities to symbolic qualities, to perform "sensor fusion" and to produce "meta knowledge". Vision, weight, force, touch, acoustic and other sensors are used. Then the planning level performs reasoning for the strategic plans of robotic manipulation such as task, trajectory, force and other plans. Thus the learning level can reason unknown fact from a prior knowledge and detected information. On the other hand, the adaptation adjusts the control law to the current status of the dynamic process. In particular, the nonlinearities, their compensation, and the uncertainty of the environment must be dealt with by the neural network. Thus, the neural network in the "adaptation" process must work more rapidly than that in the learning process. Figures 7 and 8 illustrate the concept and hierarchical intelligent control of a robot arm [7] – [8].

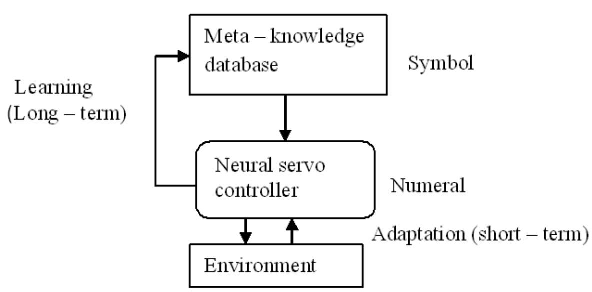

Fig. 7. Concept of hierarchical intelligent control

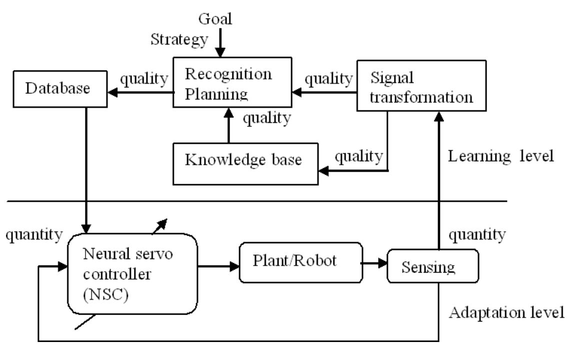

Fig. 8.Hierarchical intelligent control system

Adaptive Fuzzy control of robot manipulators

Dynamic control of robot manipulators is one of the most important topics in robotics. Various modern control strategies have been discussed so far. These controllers are generally designed assuming an exact knowledge about the model structure and do not include nonlinear friction, backlash and other uncertainties in robot systems. The PD (proportional – derivative) control with feedforward torque compensation is the most promising and effective controller for the model – based robot controllers. However, it needs the full inverse dynamics of the robot and the compensation is time – consuming. That is to say, if there exists large amount of uncertainties, the method will probably fail.

To surmount the above problems new control strategies have been developed. These include neural networks, to drive the feedforward torque because of their learning capability and universal approximating capability, and the fuzzy system. It has been shown that fuzzy systems are also universal approximators and capable of learning. In conventional fuzzy control of a robot manipulator, the robot dynamics and other parameter modeling are carried out with a set of fuzzy rules. It is noticed that for a conventional fuzzy system, the number of rules grows exponentially when the number of input variables increases. Whereas in a decentralized fuzzy control system, this problem will not arise at all. This is due to the fact that a simple input – output form is adapted. And hence, the number of fuzzy rules in the system is greatly reduced [9].

The successful application of the fuzzy control depends on the parameters and the structure of the concerned fuzzy rule system. Fuzzy modeling of robot dynamics will depend upon Lagrange – Euler and Newton – Euler formulation. Once we model the system, and then apply Genetic Algorithm (GA) for optimization of parameters of fuzzy model. GA is a stochastic optimization technique mimicking the natural selection, which consists of three main operations, namely, reproduction, crossover, and mutation. After parameter optimization, then design a fuzzy controller. The feedback fuzzy controller has a PID (proportional – integral – derivative) – like structure and is able to adjust its parameters when the uncertainties in the robot system vary. The adaptive method is driven by the gradient method based on a quadratic performance index that is widely adopted in optimal control. Fortunately, the algorithm depends on neither the inverse dynamics nor the full perturbation model of the robot. It has been shown that

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the gradient method based learning method can work well if the sensitive model of the controlled system is available.

III. CONCLUSIONS

In the present work, the impetus is given to the sensor based robotic system with a view on the most commonly used sensors in robotics engineering and their role in efficient control of a robot manipulator. When it comes to the control of a sensor based robotic system, conventional control schemes have found to be ineffective in view of nonlinearity of parameters, computational complexity and dynamic modeling of a robotic system. In such cases, new control strategies such as *neural network based control*, *hybrid neuromorphic control* and *decentralized adaptive fuzzy control* would definitely fit the case for effective control of sensor based robotic system. Besides, conventional control systems – closed loop and open loop control systems – for position control and velocity control were also given due consideration in the present study.

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