COMPARATIVE STUDY OF ALGORITHMS FOR THE MOTION CONTROL OF A ROBOT ARM

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Abstract:

This paper describes and complements a poster presentation where different algorithms are compared from experimental results. Interest is focused on the robust behaviour of simple algorithms used for the motion control of joints in robots.

1. INTRODUCTION

Within the functional structure of smart robots there are several elements whose good autonomous performance should be warranted. This is the case of robot arm joints.

Decisions about the needed behaviour of the robot arm are taken depending on environment information processed from the outputs of a set of sensors. For instance, vision involves image processing in order to identify objects as well as obstacles within the work area. Scene generation is a slow process.

Therefore, the trajectory planning strongly depends on the hipothesis that joint movements closely follow the elaborated set points (Lee, 1984). Transient inaccuracies, while the arm is following any desired trajectory could alter the configuration of the previously seen scene and should not be allowed. Variable load conditions at each joint and μP constraints in velocity (sampling rate) should also be considered. It has been proposed the use of adaptive control algorithms or, alternatively, the use of robust control algorithms, the latter being a compromise between performance and complexity (Luh, 1983; Vukobratovic, 1984). Some different strategies for adaptive control are exposed in another paper presented in this Congress (Bertran, 1986)

In this paper the characteristics of different μP based control algorithms are compared. At first, robustness is defined in the context of manipulator movements. Then, the performances of PID-like, variable structure and LQ optimal controllers are analized. Sensor needs and behaviour degradation as a sampling time fonction are specially studied. Finally, from a comparative study, a robust controller structure is proposed.

These algorithms have also been tested in dc servomotors used to drive an experimental robot arm. The importance of degraded conditions has been studied. Experimental results re-enforce theoretical previsions. In special, it is concluded that the use of partial coupling between control algorithms of the joints is advisory in order to obtain some interesting fault tolerance properties.

2. ROBUST CONTROL AND SENSOR FAILURES

In this section conditions to have a robust control algorithm, capable to support some sensor failures, are studied. Robustness is defined as the capability to hold selected properties of the system in spite of the presence of a class of perturbations (Ackermann, 1980). The perturbations of interest in the case of a robot joint control are mainly inertia variations and sensor failures. The property to be held is the dynamical behaviour of the arm and, specially, its stability margin.

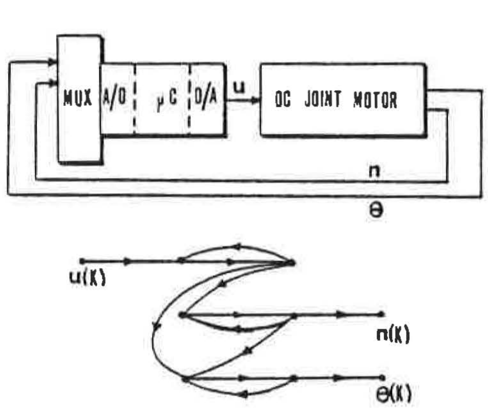

Figure 1

The dc servomotor for robot joint movement has been modelled. The model is linear and includes the mechanical dominant time constant, wich varies according to the load and the arm position, and the electrical non-dominant one. It has been considered the presence of position and speed sensors, and the model is formulated in sensor coordinates. So it results a third order discrete model with partial state measurements (Fig 1). For sake of simplicity of the algorithms, only partial state constant feedback performances are analized. Parameter design equations corresponding to the controlled system characteristic polynomial:

$$z^3 + p_2 z^2 + p_1 z + p_0 = 0$$

are:

$$p_2 = -[1+\exp(-T/\tau_m)+\exp(-T/\tau_e)]$$

$$\begin{aligned} p_1 = {} & K_v K [\exp(-T/\tau_m)- \\ & \exp(-T/\tau_e)]/[\tau_m-\tau_e] + \\ & K_p K [\tau_m-\tau_e+ \\ & \tau_e \exp(-T/\tau_e) \\ & +\tau_m \exp(-T/\tau_m)]/[\tau_m-\tau_e] + \\ & \exp(-T/\tau_m)+\exp(-T/\tau_e)+ \\ & \exp(-T/\tau_m)\exp(-T/\tau_e) \end{aligned}$$

$$\begin{aligned} p_0 = {} & -K_v K [\exp(-T/\tau_m)- \\ & \exp(-T/\tau_e)]/[\tau_m-\tau_e] + \\ & K_p K [\tau_e \exp(-T/\tau_m) - \\ & \tau_m \exp(-T/\tau_e)+ (\tau_m-\tau_e) \\ & \exp(-T/\tau_m) \exp(-T/\tau_e)]/ \\ & /[\tau_m - \tau_e] - \\ & \exp(-T/\tau_m) \exp(-T/\tau_e) \end{aligned}$$

Therefore p_2 is independent of the values of K_p and K_v.

Loci of stable performance (mapping the $|z|=1$ contour of the z-plane) have been plotted in the (p_0, p_1) coefficient plane (Fig. 2) for two different situations:

a) Sampling time: $T = 0.2\ \tau_m$
b) Sampling time: $T \ll \tau_m$

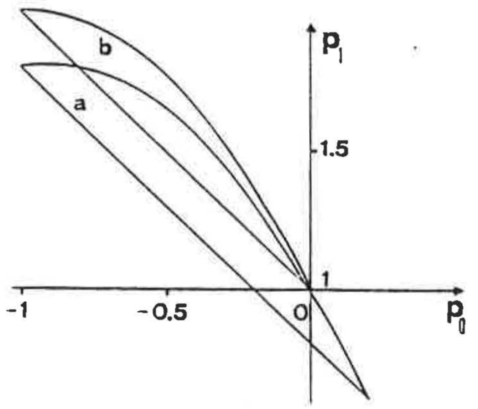

Figure 2

Due to the variations of τ_m, a) and b) should be considered as the limit cases for actual situation in the joint. In both cases it is also considered that $T \gg \tau_e$.

Stability loci can be transferred to

the $\{K_p, K_v\}$ parameter plane (Fig. 3), using the simplified design relations:

$$K_v\ K \approx -\ p_2\ \tau_m/[\tau_m - T]$$

$$K_p\ K \approx (\tau_m/T)\ [p_2 + p_1 + T/\tau_m - 1]$$

with

$$p_2 \approx -2 + T/\tau_m$$

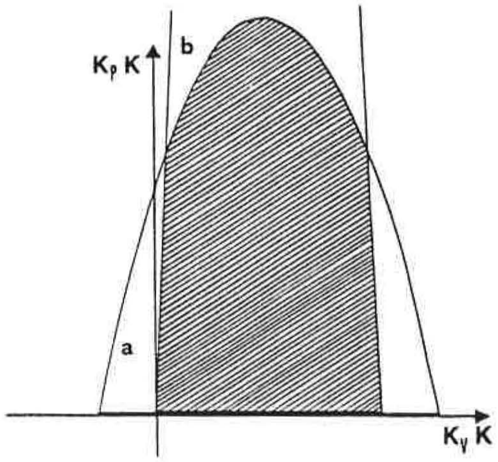

Figure 3

From Fig. 3 values for K_v and K_p can be selected that represent a good compromise between dynamic characteristics and τ_m variations (shaded area). Also it is posible to choose values in order to hold stability in front of the speed sensor failure. However, the position sensor failure unstabilizes the system.

A way to stabilize the system if the position sensor fails is to reconstruct the position (θ) from the still measured speed values (n):

$$\theta(kT) = T\ n(kT) + \theta([k-1]T)$$

This reconstruction and the selection of an appropiate pair of emergency values for K_v and K_p can stabilize the system inmediately after such a failure, avoiding undesired joint movements.

In Fig. 3, the intersection of $K_v=0$ and the stability zone decreases from a) to b). Therefore, using incomplete state feedback, when a lower sampling time is chosen a poor robustness of the system can result. This seems a paradoxical conclusion, and means a compromise between system stability in front of structural variations (T of moderate to high value) and the classical system stability in normal conditions operating with its nominal parameters (T of low value).

3. COMPARATIVE STUDY OF ALGORITHMS

3.1. Hardware implementation

As is shown in the top of the poster, the equipment used to experiment the different control algorithms is composed by:

- A µC AIM 65.
- Interface hardware: 8-bit A/D & D/A converters, multiplexers (Bertran, 1983).
- Drivers for the joint motors.

3.2. PID regulator

The regulator experimented firstly, in order to have a reference for the comparison of results, has been the well known PID regulator, using the Ziegler-Nichols rules to tune the regulator parameters. The use of empirical rules, longer experience and minimum sensor needs are the main advantages of this regulator.

The presence of a pole in the origin of the s-plane in each joint model, makes unnecesary the I effect of the regulator. On the other hand, the D effect is normally no required due to the dominance of a single pole (introduced by the mechanical components in the arm).

This regulator is poor in order to compensate non-linear effects in the joint. Dead-bands due to the dc motor and mechanical linkages are traduced to steady-state positional errors.

The reinforcement of the I effect in order to try to reduce these errors produces a limit-cycle, with mean value equal to the desired final position (see poster).

In spite that it has been used the first-order difference method (Houpis, 1985) to obtain a discrete PID regulator (μC control), and that this method is theoretically restricted to systems with a sampling period that locates the poles and zeros in a zone around ±30° from the positive real axis in the z-plane, this regulator has demonstrated a good robustness when sampling period is increased over τ_m (see poster).

3.3. Optimal Linear Regulator

This kind of regulator has higher sensor needs, due to it's based on a variable-state feedback. As it is shown in the poster, measured variables have been position and speed. As much with this choice as if the speed sensor is substituted by a dc motor current one, this regulator has a certain degree of fault-tolerance: If some positional loop element is damaged, the joint do not becomes an integrator (the behaviour of the open loop motor) as in the PID regulator case, because it is very easy to detect the presence of speed or current variations without positional ones. In this case, a fast solution is to nullify the motor set-points in order to avoid ballistic problems in the arm.

On the other hand, the choice of a performance index that wheigts speed and position deviations hides the pole placement. Contradictory results between optimization and good dynamics have been obtained as is reflected in the poster. The use of the typical pole-assignement method becomes more attractive from the designer point of view.

3.4. Variable structure control

This kind of regulator has the same sensor needs than the Optimal Linear Regulator. The control law is discontinuous, and depends on the chosen structure. In our case we have chosen a dual control action regulator.

The main advantage of this control is its insensitivity with respect to inaccuracies in the system model (Young, 1978; Bengiamin, 1984).

Considering only the mechanical time-constant, the decision about the control signal is taken in function of the measured values of both position and speed. Switching line is shown in Fig. 4.

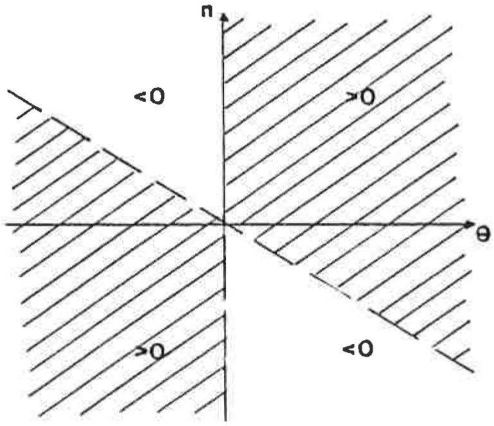

Figure 4

Experimental results (see poster) have demonstrated a good robustness in front of system parameter and sampling time variations. But if sampling time is increased the control action is taken with a delay versus the desired switching line. So an unestable motion could be followed. Another restriction to the use of this regulator is that none of the sensors can fail, because then it is impossible to decide the appropiate control action.

3.4. Sensor failures

In front of an speed sensor failure variable structure control should be avoided as emergency algorithm. Then robustness can be warranted at a

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joint controller level by selecting appropiate sampling time T and gain K_L (see section 2).

The use of some degree of redundancy is necessary only in case of position sensor failure. Of course, robustness can be re-enforced if two position sensors are located at each joint. To minimize sensor needs, this redundancy can be implemented and used at a coordination level, in order to generate a backup position signal submitted to the joint controllers (see poster).

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