A Design of NAC(Natural Admittance Controller) for Coulomb Friction Compensation

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Abstract

A natural admittance control system design is presented for a particular type of interaction controller that achieve high-performance and guarantees stability. The admittance control significantly improves performance when Coulomb friction is present in the one link robot system. The technique requires a careful choice of the target impedance. Experimental performance results are presented for a two-mass system with internal Coulomb friction.
Results demonstrate that the admittance control law is successful in rejecting internal Coulomb friction force disturbances. The controller was designed and implemented on our system that we set up one link robot system and hardware configuration system, and performance results are presented.

I. Introduction

When robot contact with environment, it is important to control force and position. The method for robot's position and force control have various control algorithms, out of these algorithm, it selects NAC(Natural Admittance Controller) that has similar to Impedance Control scheme. Natural admittance control apply that we made One-Link Robot System, it will be shown that controlled motor maintain stability about environmental reaction force and is developed the role of interaction controller than another.

Of course keeping up stability, we add Coulomb friction in controlled motor shaft, admittance controller that has robust property in spite of internal disturbance is good at rejecting Coulomb friction within One-Link Robot System. Hence, controlled motor moved desired position and velocity.

For this experiment, it set up controlled motor torque sensor's left shaft and load motor corresponding to environment torque sensor's right so we offer desired environment in robot. As control system is also using high-speed DSP chip, Natural Admittance control can be performed exactly under suggesting algorithm because it is free state from the effect of sampling rate limitation, sensor noise.

This paper consists of admittance controller scheme, One-Link Robot system and control system configuration , we analysis the performance in case of desired input is sinusoidal function while it move also environment sinusoidal velocity.

II. Admittance Controller

As admittance controller has similar to impedance controller scheme, admittance is a reciprocal of impedance. Let us consider an arbitrary 2 ports system, equations of motion in the Laplace domain for the model

$$F_m = M_m s^2 v_m + (B_m v_m + B_t v_t - B_t v_s)s + K_t(v_m - v_s) \quad (1)$$

$$Fs = M_s s^2 v_s + (B_s v_s + B_t v_s - B_t v_m)s + K_t(v_s - v_m) \quad (2)$$

with (1) and (2), it changed concerning admittance

$$\begin{bmatrix} v_s \\ v_m \end{bmatrix} = \begin{bmatrix} Y_{ss} & Y_{sm} \\ Y_{ms} & Y_{mm} \end{bmatrix} \begin{bmatrix} F_s \\ F_m \end{bmatrix} \quad (3)$$

Y_{ij} exists four admittance. it is each admittances

$$Y_{ss} = \frac{v_s}{F_s}(F_m = 0) \quad (4)$$

$$Y_{ms} = \frac{v_m}{F_s}(F_m = 0) \quad (5)$$

$$Y_{mm} = \frac{v_m}{F_m}(F_s = 0) \quad (6)$$

$$Y_{sm} = \frac{v_s}{F_m}(F_s = 0) \quad (7)$$

We can define separate numerator and denominator for all four admittances

$$Y_{mm} = \frac{Y_{mm,\,num}}{Y_{den}} \quad (8)$$

$$Y_{sm} = Y_{ms} = \frac{Y_{ms,\,num}}{Y_{den}} \quad (9)$$

$$Y_{ss} = \frac{Y_{ss,\,num}}{Y_{den}} \quad (10)$$

$$Y_{den} = \frac{Y_{mm,\,num} Y_{ss,\,num} - Y_{sm,\,num} Y_{ms,\,num}}{s} \quad (11)$$

It describes general control laws of the form in closed-loop system

$$F_m = G_f F_s - G_v v_m + F_f \quad (12)$$

F_m means the control effort(force), F_s the sensed endpoint forces, v_m the controlled motor velocity, F_f Coulomb friction, G_f force feedback gain and G_v velocity feedback gain. We must select G_v as large as possible for rejecting Coulomb friction in One-Link Robot system, that is, robot can approach environment with desired force. However, G_v is limited by sampling rate, sensor noise and other effects not included in One-Link Robot System. If G_v value is large, it is effective on remove internal disturbance but it raises stability problem when robot contact with environment. It designed admittance controller for maintaining stability with G_f. Assume G_v selected large value, desired end-point admittance is

$$Y_{des} = \frac{1}{Z_{des}} \quad (13)$$

G_f can express as

$$G_f = \frac{Y_{den} - Y_{ss,\,num} Z_{des} + G_v(Y_{mm,\,num} - Z_{des})}{Y_{sm,\,num} Z_{des}} \quad (14)$$

for solving G_f, we know admittance value

$$Y_{mm,\,num} = M_s s^2 + (B_s + B_t)s + K_t \quad (15)$$

$$Y_{ss,\,num} = M_m s^2 + (B_m + B_t)s + K_t \quad (16)$$

$$Y_{sm,\,num} = Y_{ms,\,num} = B_t s + K_t \quad (17)$$

$$\begin{aligned} Y_{den} = {} & M_m M_s s^3 + [Mm(Bs + Bt) + Ms(Bm + Bt)]s^2 \\ & + [K_t(M_m + M_s) + B_m B_s + B_m B_t + B_s B_t]s \\ & + K_t(B_m + B_s) \end{aligned} \quad (18)$$

To obtain a compensator G_f which is realizable, one must choose a target impedance Z_{des}

$$Z_{des} = M_{des} s^2 + B_{des} s + K_{des} \quad (19)$$

Substituting form Eqn (15) to Eqn(18) of (19), we obtain

$$G_f = \frac{G_{f,\,num}}{(B_t s + K_t)(M_{des} s^2 + B_{des} s + K_{des})} \quad (20)$$

(20) formula. Calculate $G_{f,\,num}$ is fourth order and $G_{f,\,den}$ is third order. Therefore, it is able to reduce $G_{f,\,num}$ order as $M_{des} = M_s$

$$\begin{aligned} Gf, num = {} & Gvs[s(Bs + Bt - Bdes) + (Kt - Kdes)] \\ & s^3[M_m B_s + M_m B_t - M_m B_{des}] + s^2[B_m B_s + B_t B_m + B_t B_s \\ & + K_t M_m - M_m K_{des} - B_m B_{des} - B_t B_{des}] + s[K_t B_m + K_t B_s \\ & - K_{des} B_m - K_{des} B_t - K_t B_{des}] - K_t K_{des} \end{aligned} \quad (21)$$

Thus, there is a best choice for desired mass in Zdes given by $M_{des} = M_s$ and can know G_f is a third-order transfer function. As $K_{des} = 0$, environment has no spring. We determine G_v and G_v value through experiment.

III. One-Link Robot and H/W System

It explains that we made One-Link Robot System configuration for achieving admittance control. As illustrated in (Fig1), One-Link Robot System consists of 750W AC Servo Motor and 400W AC Servo Motor. 750W motor is corresponding to robot and 400W motor is environment. Torque sensor measure reaction force from exerting environment while robot contact with it. Transmission dynamics (2 couplings) is connected between motor and torque sensor shaft.

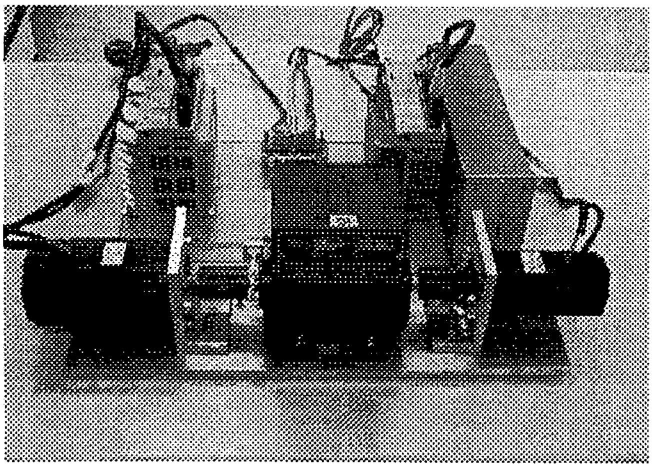

Fig1) One-Link Robot System

Each factors mean that M_m is controlled motor ine -rtia, M_e is load motor inertia, B_t is coupling damping, F_m is controlled motor force, F_s is reaction force. In experiments, we applied $F_f = 2.0Nm$ of Coulomb fri - ction to the controlled motor shaft using a rubber belt (or leather belt).

We used high-speed DSP for real-time control and DSP process and calculate data from AD converter and DA converter. The data transmit and receive through dsp-link3 between Dakar F5 carrier board and IP-carrier board. Among IP modules data transmit through IP-Bus.

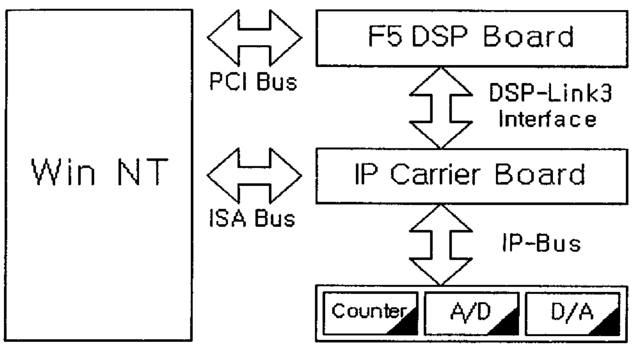

Fig2) Hardware System

IV. Result and Discussion

We describe specification about One-Link robot system that a rated torque is $\tau_{750w\_motor} = 2.39$ Nm and $\tau_{400w\_motor} = 1.27Nm$. All servo motor input velocity is $500 rpm/volt$ and 2048 incremental encoder. In case of torque sensor, capacitance is $5Nm$ and we used output voltage range $\pm 5V$ so it is $1Nm/volt$.

In hardware, we used TMS320C44 that character processes 40MIPS data and $2K \times 16bit$ SRAM, $128 \times 16bit$ cash, 32bit timer and 6~12 channel DMA processor and 6 serial ports transmit data between I/O port and processor. In AD converter, as it measure the output voltage from torque sensor, it has 12bit resolution, total 16channel and using range ± 10 volt. In DA converter, it offers desired force command and has 13bit resolution, 8 channels and generate sinusoidal function.

We used AC servo pack but servo pack is sensitivity. It is difficult to offer high input voltage in 750W and 400W motors. In addition, 2 servo motors operate same direction because it is BEMF.

Fig3) is concerned about environment that is $Vpp = \pm 0.3V$ and start voltage is 0.3v. $V_{400W\_motor} = 0.3\sin\omega_t + 0.3$ operates

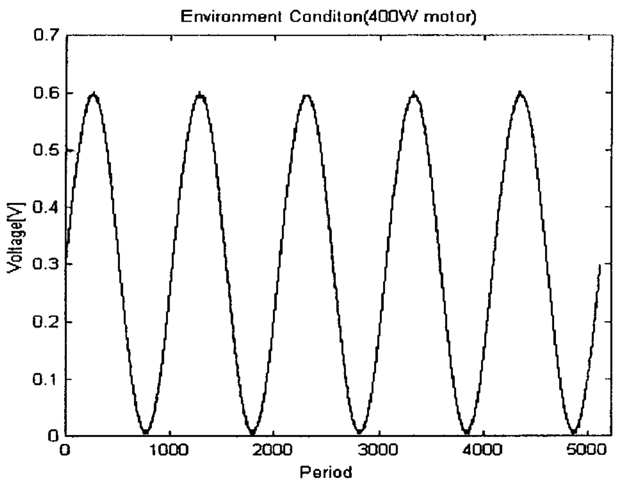

Fig3) Environment Condition

Only 750W servo motor operate sinusoidal velocity in open-loop system, input voltage vs torque sensor output display. 750W input voltage is $v_{750W\_motor} = 0.5\sin\omega_t$

+0.5 operates

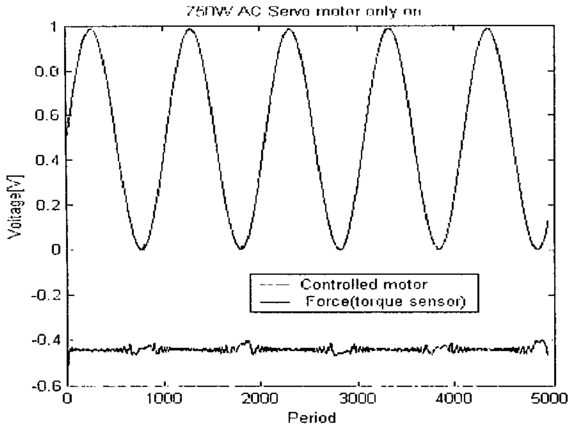

Fig4) Controlled motor vs Torque sensor

On the contrary, 400W operate sinusoidal velocity in open-loop system, input voltage vs torque sensor output

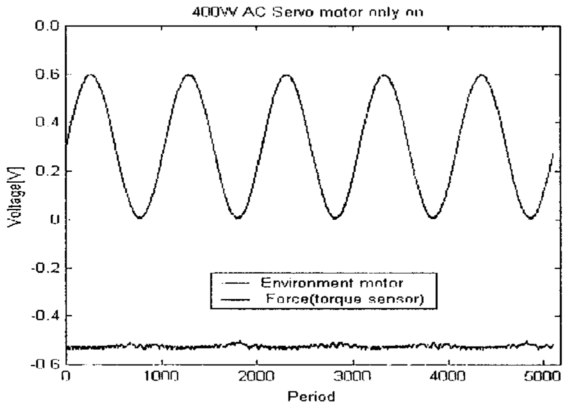

Fig5) environment vs Torque sensor

As following Fig6) is shown torque sensor output result that desired force and environment inputs sinusoidal function in One-Link Robot System

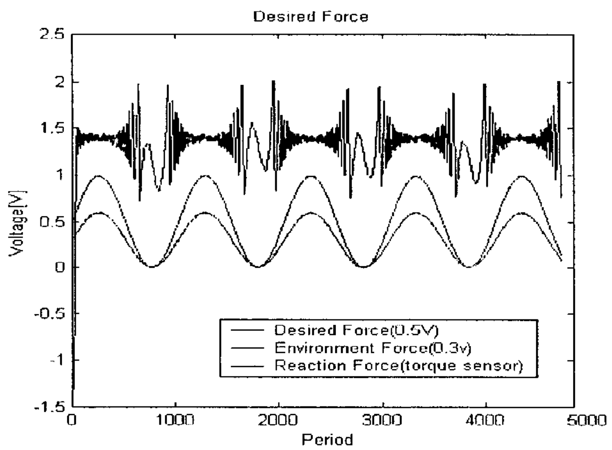

Fig6) Desired-Force

V. Conclusion

This paper focused on the implementation an admittance controller that it is successful in rejecting internal Coulomb friction in spite of disturbance in system. Typically, force feedback gain is limited by contact stability, it is difficult to find velocity-feedback and force-feedback gain as low compensator results in poor friction rejection and large gains cause contact instability. Controlled motor moved desired force well while preserving stability.

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