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Research Article

A System Diagnosis using Descriptor Model with a Constrained Dynamic Motion in a Robot Gripper

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Abstract: This research illustrates a method to diagnose a system regarding to an automatic screw or welding assembly line via the industrial robot that builds a constraint system with counterparts at the moment of working. The timely righteous estimation and judgment of the states is very important for the safe operation in time domain system. The synthesis of this problem presumes that all state variables are observable for concerned system. But it seems that it is not feasible to measure all modes of states of velocities, accelerations, forces and moments directly. A practical solution to this problem, which should be tried, is the estimation of the states or its velocities by the use of an observer which can estimate a system characteristics of linear or nonlinear states and effects as a mode, so called, " Indirect measurement". For this procedure, the mathematical model of the concerned physical system which consists of links over joints and Gripper with the end effector, is derived with the significant remarks such as friction, gravitation, and Coriolis force. This is a basic system. The concrete assignment is to design the observer that estimates the characteristics of the states and velocities based on the measurement vectors. The main artifice is to approximate the characteristics with a fictitious model that may describe the modes of system errors. As a practical and convenient fictitious model, the characteristics of nonlinear effects are assumed as approximately stepwise contact. An identity observer is obtained whose state variables are the estimate of the state variable of the corresponding "observer system". It consists of a simulated model with a correction feedback of the estimation
Keywords: Diagnosis, Observer, Mode, Indirect measurement, Descriptor Model

INTRODUCTION

From the viewpoint of the increasing-complexity and high requirement of the structure of modern control systems, the reliability of a system is strongly considered. Especially, when the interest comes to the dynamic behavior by high signal amplitude or various operating points, the safe operation is getting more and more important. This is obviously verified when a part of systems suddenly goes out of function. It can cause an entire system defect, and this is able to bring up a dangerous situation for employee and material losses. To take precautions against these kinds of troubles, many scientists in the world have been making efforts for long time. For this, it is required the inspection during the operation: certainty and system assessment. Only by this way, the sudden appearance of defects and the alteration of the processes can be founded out, and the reason for the troubles and the place are detected(Fault Detection and Isolation, FDI). It is important that the fault must be sensed early enough for avoiding the damages in the system (Fault Detection, Isolation and Accommodation, FDIA). When this process goes without man's help, it's called automated fault detection, in the other word, "System Diagnosis". Under meaning of fault, we can understand every abnormal derivations or divergences from the required process behavior and the abrupt fault is meaningful of the safe operation. The FDI process needs certain characteristics being able to give the threshold of the decision: Residuum, residue. The method of fault estimate by using the Hardware-redundancy is very costly and less practicable. The model-based methods were presented by[1]. The methods by creating the parameters, or state space estimate were given in [2]. There have been some other ways to settle the problem with fault through the consideration of the property of the robustness[3]. A practical solution to this problem was the estimation of the states or its velocities by the use of observers which can estimate a system characteristics of linear or nonlinear states and effects as a mode, so called, "Indirect measurement"[4].

In this work, for this procedure, the mathematical model of the concerned physical system which in the operation time consists of a gripper with a screw which is aimed to assemble in the part of a machine at the ends of the manipulator is derived with the significant remarks such as friction, gravitation, and Coriolis force. With the indirect measurements on Gripper, an observer is designed and is going to use for the system diagnosis through the comparison with phases.

Modeling of driver dynamic of a constrained robot gripper with a screw

In order to control and diagnose complex systems, one would like to obtain quantitative mathematical model of a system by symbolic representation involving an abstract mathematical formulation. Though a mathematical model can be adequate for a certain purpose in mind, it never describes the physical phenomenon exactly. Since the final goal of this work is to develop a diagnosis strategy, the inevitable conclusion is that the modeling problem and the diagnosis problem are not independent. Here, the necessary adequate models for the proposed diagnosis policies are built. These were comprised of the manipulator model, the environment model, and model for the interaction between Gripper and fixed body. Industrial robots are usually composed of arms connected by couplings into a kinematic chain with the links in the operation situation.The links can be either cylindrical or revolute, and are driven by given actuators [5].

In this work only cylindrical shaft will be considered. For the purpose of modeling, the three interacting parts such as the actuators, the transmission, and the links will be studied first separately and then, the complete model will be built. The actuators are the devices that make the links move. The dynamic behavior of joint system can be modeled by analogy to [6] as follows.

$$\Theta, \quad X = \begin{bmatrix} V \\ \Omega \end{bmatrix} = J(q)\dot{q}, \quad \bar{\lambda}$$

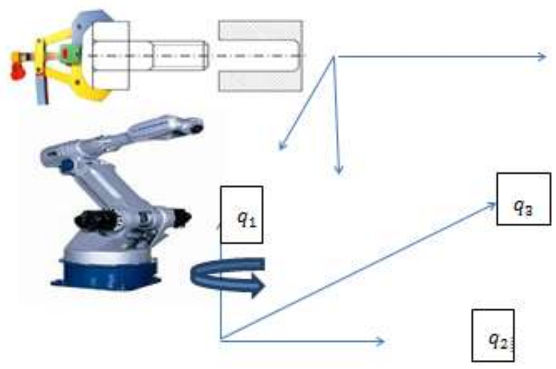

Fig. 1: Aconstrained robot system

The task is to drive a screw by a screw driver held by the end effector with a known motion. Fig. 1 shows a top view of the moving screw fixed by end effector, where the speed screw relative to the reference frame is. The task frame is chosen to have a non-varying orientation. This makes the description of the motion of the screw easer. The u-axis of the task frame points toward the motion of the screw, whereas the z-axis has the same direction as the screw. A screw motion consists of two components: A rotation and a translation about and along the center line. The two components are coupled by the pitch of the screw.

Mathematical Descriptor Modeling with Geometric and kinematic constraints

In 1985,McClamroch published a paper [7] to introduce the idea of modeling constrained robots as singular systems of differential equations. That was the first time that constraints imposed on the motion of robots are stated explicitly in an equation form. The obtained model in the joint space is composed of a differential equation that rehearses the dynamics of the arm

$$M(u)\,\ddot{q} + C(q, \dot{q}) = \Phi + J^{T}(q)\,\xi^{T}(X)\,\bar{\lambda} \quad \text{.........................(1)}$$

and an algebraic equation corresponding to m imposed constraints

$$\theta(X) = 0 \quad \text{...(2)}$$

where, $X \in R^{6}$denotes the position (position and orientation) of the end effector expressed in the reference frame;θ: $R^{6} \rightarrow R^{m}$ is twice continuously differentiable, and the constraintsjacobian is defined by

$$^{T} = \frac{\partial\theta(X)}{\partial X} \quad \text{..(3)}$$

The term of Φ illustrates the input force vector at the jointst and $J \in R^{6x6}$ presents the diagonal motor inertia matrix. The Lagrange multipliers $\bar{\lambda} \in R^{m}$ are in this case the magnitudes of the contact or reaction forces between the end effector and the constraining environment.

$C(q,\dot{q})$ is the vector of centrifugal, Colioris, and the gravitational torques and ü is the vector of the joint acceleration. Thisart of modeling describes in a useful and correct form the robot interaction with its environment. It stresses the role of writing down constraint equations in finding the contact forces. The differential and the algebraic equations can be cast together in a descriptor form, where the contact force is then considered as a state. Geometric-constraint Equation (2) defines a constraint surface that the end effector (gripper) has to maintain contact between the even and uneven surfaces in a screw, in other precise words it describes the geometry of a surface. It is called, then, a geometric-constraint equation. Geometric-constraint equations (2) may be differentiated once with respect to the time to get

$$\frac{d\theta(X)}{dt} = \frac{\partial\theta(X)}{\partial X}\frac{dX}{dt} = 0 \quad \text{.......................................(4)}$$

$$\xi(X)\dot{X} = 0 \quad \text{...(5)}$$

Where, $X \in R^6$ denotes the position of the end effector showed in the reference frame and here, constraints described by Equation (4) are called kinematical constraints. Though, they define implicitly the geometry of a constraining surface, they give explicit information about constrained motions. The more general form of Equation (4) and (5)is considered in this work. This constraints equation is said to be rheonomic since it depends explicitly on time. Using this form increases the range of tasks. Over these notations, most of the industrial robots can be seen as open kinematic chain. The links of a robot are connected usually in series by means of revolute or prismatic joints. The joint variables constitute a generalized coordinate system, which is used to describe the kinematics and dynamics of the robot. The dynamic model which mainly expresses the relation between the input forces and the resulting motions can be easily written down in a state-space form as

$$\begin{bmatrix} I & 0 \\ 0 & M \end{bmatrix}\begin{bmatrix} \dot{q} \\ \ddot{q} \end{bmatrix} = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix}\begin{bmatrix} u \\ \dot{u} \end{bmatrix} + \begin{bmatrix} 0 \\ I \end{bmatrix}\Phi - \begin{bmatrix} 0 \\ C \end{bmatrix} \ldots\ldots\ldots\ldots\ldots(6)$$

Here, the terminology is the same as before. The state of the robot is completely described by q and $\dot{q}$.

Now, if the robot comes in contact with an external object, then the kinematical chain which forms the robot becomes closed. This happens in cases when it is desired that the robot applies forces on a certain object, tracks a given contour, or cooperate with another robot to perform a task. The natural way to model the situation is to consider the dynamics of the subsystems separately and then bind them together though a kinematical model. In the easiest case when the external object is stationary and rigid, I.e., with no dynamics, then the system (robot, external object, and constraint) can be described by Equation (6) together with the constraint equation

$$\underbrace{\begin{bmatrix} I & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & 0 \end{bmatrix}}_{E}\begin{bmatrix} \dot{q} \\ \ddot{q} \\ \dot{\bar{\lambda}} \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \xi T \\ 0 & 0 & 0 \end{bmatrix}}_{A}\begin{bmatrix} q \\ \dot{q} \\ \bar{\lambda} \end{bmatrix} + \begin{bmatrix} 0 \\ I \\ 0 \end{bmatrix}\Phi + \begin{bmatrix} 0 \\ -C \\ \theta \end{bmatrix} \ldots\ldots\ldots\ldots(7)$$

Where the Jacobian ξ is defined as equation (3) andthe interaction between the robot and the external object is through the constraint force λ.It is noticed that form (6) is a peculiar one, since its matrix pencil sE– A is singular. The descriptor model of a robot in its task frame constrained by kinematical constraints of the from

$$W^T \begin{bmatrix} V \\ \Omega \end{bmatrix} = \zeta(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where $W^T \in R^{6xK}$, $\zeta \in R^K$ and Mdenotes the number of constraints.V and Ωstand for the translational and rotational velocities in the task space. The Equation can be given as

$$\underbrace{\begin{bmatrix} I & 0 & 0 \\ 0 & M & 0 \\ \psi & 0 & 0 \end{bmatrix}}_{E}\begin{bmatrix} \dot{X} \\ \ddot{X} \\ \dot{\bar{\lambda}} \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & I & 0 \\ 0 & 0 & \xi T \\ 0 & 0 & 0 \end{bmatrix}}_{A}\begin{bmatrix} X \\ \dot{X} \\ \bar{\lambda} \end{bmatrix} + \begin{bmatrix} 0 \\ I \\ 0 \end{bmatrix}\Phi + \begin{bmatrix} 0 \\ -C \\ \zeta \end{bmatrix} \ldots\ldots\ldots\ldots\ldots(9)$$

Where (10)

A constrained robot with an actuator dynamics and joint elasticity are

$$L\,\dot{\mathbf{m}} + R_m\, m = Ku \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

$$J\,\ddot{\Theta} - S(G_r q - \Theta) = m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

Where S and G_r are the square regular diagonal stiffness and gear–reduction matrices s and q elements in diagonals respectively. $\ddot{\Theta} \in R^6$ is the acceleration vector of the motor shaft. The dynamics of constrained robot is given in its minimal form as

$$\underbrace{\begin{bmatrix} \dot{\boldsymbol{m}} \\ \dot{\boldsymbol{\Theta}} \\ \ddot{\boldsymbol{\Theta}} \\ \dot{\boldsymbol{q}} \\ \ddot{\boldsymbol{q}} \end{bmatrix}}_{\dot{\tilde{x}}} = \underbrace{\begin{bmatrix} -L^{-1}R_m & 0 & 0 & 0 & 0 \\ 0 & 0 & I & 0 & 0 \\ J^{-1} & -J^{-1}S & 0 & -J^{-1}SG_r & 0 \\ 0 & 0 & 0 & 0 & I \\ 0 & M^{-1}G_rS & 0 & -M^{-1}SG_r^2 & 0 \end{bmatrix}}_{A}\underbrace{\begin{bmatrix} m \\ \Theta \\ \dot{\boldsymbol{\Theta}} \\ q \\ \dot{q} \end{bmatrix}}_{\tilde{x}} + \underbrace{\begin{bmatrix} L^{-1}K \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}}_{B}u + \underbrace{\begin{bmatrix} -L^{-1} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}}_{N_n} n \ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

$$y = \underbrace{\begin{bmatrix} 0 & 0 & 0 & I & 0 \end{bmatrix}}_{C}\underbrace{\begin{bmatrix} m \\ \Theta \\ \dot{\boldsymbol{\Theta}} \\ q \\ \dot{q} \end{bmatrix}}_{\tilde{x}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

The nonlinear effects can be thought of as unknown input to the linear system. Hence, it is wise to considered associated observers. The necessary and sufficient requirements for the existence of such observers are in the work of Mueller[11]. Applied to free robots joint elasticity or to constrained robots, the measurement of joint position and contact forces does not suffice. Most of their states and their derivations have to be measured to estimate the nonlinear effects by this method. Transformed system of constrained robot is given by Equation (9).

It is normally convenient for further operation to write the equation above via state space notation with $x(t) = [q \quad \dot{q}]$ including the nonlinearities of the motion created by any defects in system.

$$\dot{x}(t) = Ax(t) + Bu(t) + N_R n_R(x(t)) + N_u n_u(t) \ldots\ldots\ldots(15)$$

The equation of the measurement is given by

$$y = Cx(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

where, A is $(N_n \times N_n)$ dimensional system matrix which is responsible for the system dynamic with $N_n = 2nn$, $u(t)$ denotes r dimensional vector of the excitation inputs due to gravitation and unbalances, and C presents $(m_e \text{ x } N_n)$ dimensional measurement matrix, respectively. Here, the vector $n_R(x(t))$ and $n_u(x(t))$ characterizes the n_f dimensional vector of nonlinear functions due to the fault such as friction and unexpected input from task respectively. N_u and N_R are the input matrices of the linear and the nonlinearities, and the order of N_R is of $(N_n \text{ x } n_f)$. It is presupposed that the matrices A, B, C, N_R, the vector $u(t)$ and $y(t)$ are already known.

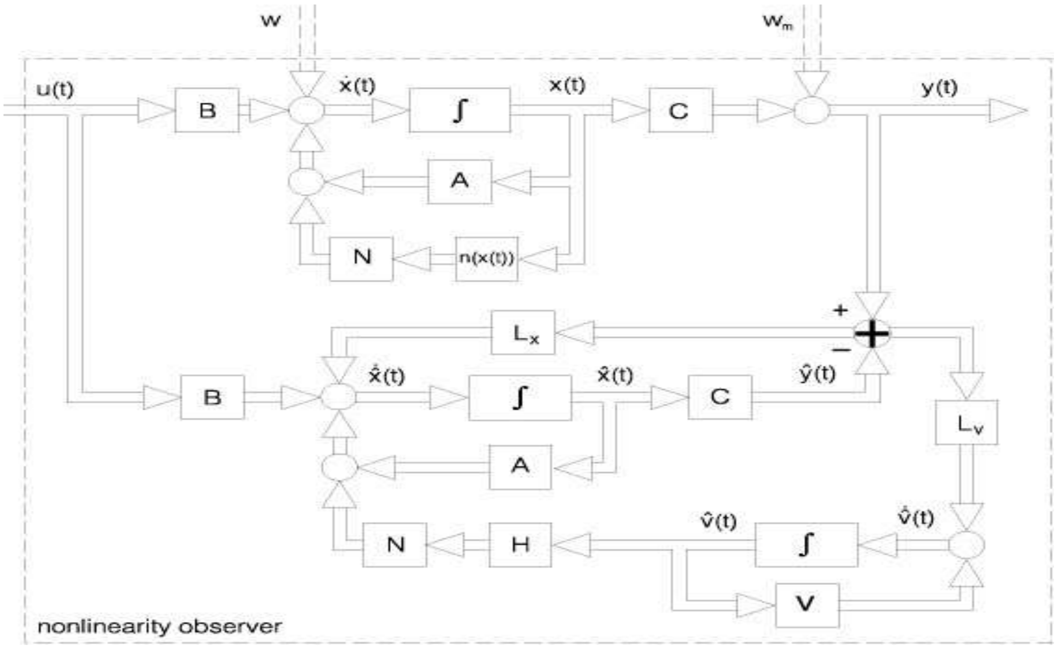

Fig.2: Nonlinear observer

DESIGN OF AN ESTIMATOR FOR THE FAULT

Now it remains to reconstruct the unknown linear vector $n_u(x(t),t)$ and nonlinear vector $n_R(x(t),t)$ which mentions the disturbance force caused by a fault such as torque unbalance and frictions which may come from any processes. The basic idea is to get the signals from $n_R(x(t))$ approximated by the linear fictitious model, see [8, 9].

In terms of the fictitious model an observer [9] is designed to get a signal

$$.\dot{v}_1(t) = \dot{V}_1 v_1(t), \dot{v}_2(t) = \dot{V}_2 v_2(t) n_u(x(t)) \approx Hz(t) \ldots\ldots (17)$$

Where, the matrices V_1, V_2 and H are of appropriate dimensions.

The meta system and the fictitious model states is characterized by

$$\begin{bmatrix} \dot{x}_i(t) \\ \dot{v}_1(t) \\ \dot{v}_2(t) \end{bmatrix} = \underbrace{\begin{bmatrix} A - L_x C & N_R H_1 & N_u H_2 \\ 0 & V_1 & 0 \\ 0 & 0 & V_2 \end{bmatrix}}_{A} \begin{bmatrix} x_i(t) \\ v_1(t) \\ v_2(t) \end{bmatrix} + \begin{bmatrix} I \\ 0 \\ 0 \end{bmatrix} u(t) \qquad (18)$$

$$y = [C \quad 0 \quad 0] \begin{bmatrix} x \\ v_1 \\ v_2 \end{bmatrix}$$

An identity observer is a dynamic system whose states variables are the estimates of the state variables corresponding observer system. It consists of model with a detection of unknown system inputs between real and estimated measurements:

$$\begin{bmatrix} \dot{\hat{x}}_i(t) \\ \dot{\hat{v}}_1(t) \\ \dot{\hat{v}}_2(t) \end{bmatrix} = \underbrace{\begin{bmatrix} A - L_x C & N_R H_1 & N_u H_2 \\ -L_{v1} C & V_1 & 0 \\ -L_{v2} C & 0 & V_2 \end{bmatrix}}_{A_o} \begin{bmatrix} \hat{x}_i(t) \\ \hat{v}_1(t) \\ \hat{v}_2(t) \end{bmatrix} +$$

$$\begin{bmatrix} I \\ 0 \\ 0 \end{bmatrix} u(t) + \begin{bmatrix} L_x \\ L_{v1} \\ L_{v2} \end{bmatrix} y(t) \ldots\ldots\ldots\ldots (19)$$

For the guarantee of the observer ability of estimator, the requirement

$$rank \begin{bmatrix} -\lambda I_{N_n} - A & -N_{v1} H_1 & -N_{un} H_2 \\ 0 & \lambda I_{s1} - V1 & 0 \\ 0 & 0 & \lambda I_{s2} - V_2 \\ C & 0 & 0 \end{bmatrix} \ldots\ldots\ldots (20)$$

$$= \dim(x(t)) + \dim(v_1(t)) + \dim(v_2(t))$$
$$= N_n + n_f + 2n_f \quad \forall \lambda \in C^+ \qquad \text{.....................} (19)$$

And the requirement of the control ability

$$rank\left[\lambda I_{N_n} - A \quad B\right] = N_n \text{ .... } (20)$$

must be satisfied. The output equation for the measurement is presented as follows.

$$\hat{y}(t) = \begin{bmatrix} C & 0 & 0 \end{bmatrix} \begin{bmatrix} x(t) \\ v_1(t) \\ v_2(t) \end{bmatrix} \text{ ....} (21)$$

where matrices L_x and L_v are the gain matrix of the observer. The above Eq. (11) means that the observer consists of a simulated model with a correction feedback of the estimation error between real and simulated measurements. The matrix A_o has $(N_n + n_f$ x $N_n + n_f)$ dimensions and represents the dynamic behavior of the elementary observer. The asymptotic stability of the elementary observer can guaranteed by a suitable design of the gain matrices L_x and L_v which are possible under the conditions of detect ability or observer ability of the extended system. To enable the successful estimation under the asymptotic stability, the eigen value of the considered observer (A_o) must be settled on the left side of the eigen value of the given system (A_e) to make the dynamic of the observer faster than the dynamic of the system. The fictitious model of the fault behaviors is able to be designed using integrator model[9, 10] based on the chosen crack model as follows. The observer gain matrices L_x and L_v can be calculated by pole assignment or by the Riccati equation [4] as follows.

$$AP + PA^T - PC^T R_m^{-1} CP + Q = 0 \text{ .... } (22)$$

$$L_v \begin{bmatrix} L_x \\ \cdots \\ L_v \end{bmatrix} = PC^T R_m^{-1} \text{ .... } (23)$$

The weighting matrix Q and R_m has to be suitably chosen by the trial and errors.

SIMULATION AND RESULTS

Here, the screw is held by the end effector while the body in which it will be inserted is fixed with known position and orientation. It is assumed that the initial position and orientation of the screw agree with those of the nut and it is constrained by the contact of them. Hence, the task reduced to tracking desired translational and rotational motions while maintaining the contact forces and torques to zero.

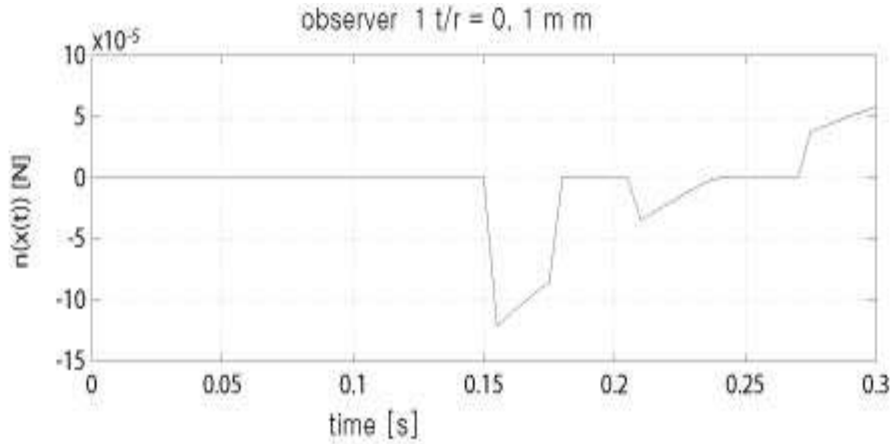

Fig. 3: Estimated nonlinear effect acting on the Gripper

The Fig.3 shows the typical nonlinear effect acting on the Gripper by the tangential friction which is represented with λ = - sgn(t) μ. In this case, the foreword moving of the end effector is cancelled for the safety operation

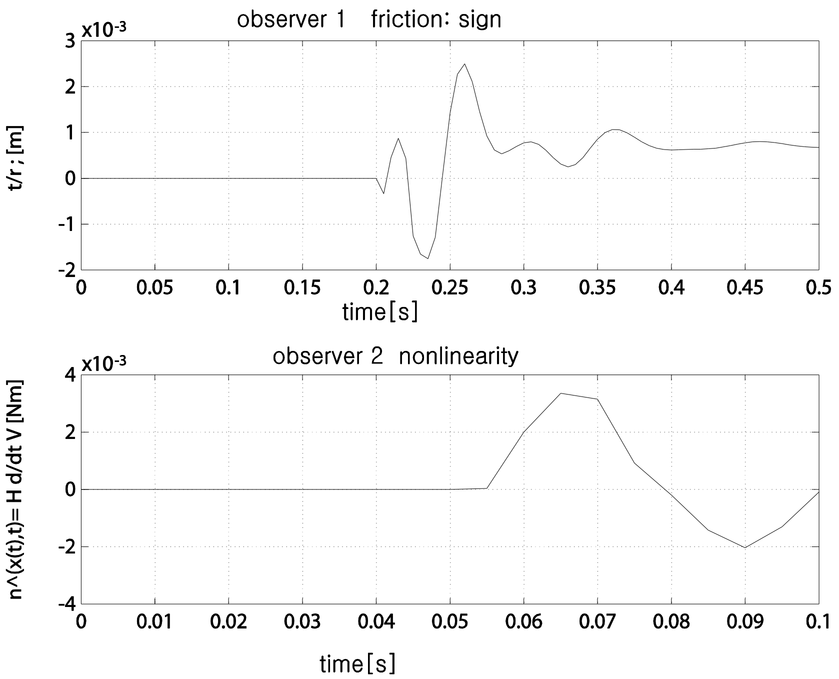

Fig. 4: Estimated nonlinear effects acting on the first motor(upper)and second motor(under)

The results in the Fig. 4 describe the fault existence on the first and on the 2nd motor under the influence of the high friction coming up from the unbalanced insertion of a screw in the runtime operation. This denotes that any defect is happened on the contact surface.

CONCLUSION

This thesis has dealt with modeling and diagnosing of constrained industrial robot. The considered constraint arises during the contact of arobot with an external object in its environment. Such a situation happens mainly if a robot is desired to apply forces and torques on an external surface for finding out in machining processes, or if it is used to mate parts with limited clearance. To address this problem, a model for free robots that takes into account actuator dynamics and joint elasticity is built first. The new interpretation made it possible to carry over the method to constrained robots at the end effector held by inserting a screw. In the second part of this thesis an estimator in terms of an observer has been presented. Simulation of selected examples indicates remarkable results for diagnosis of systemformachining.

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REFERENCES

1. Beard RV; Failure accommodation in linear system through self recognition. Report MVT-71-1, Man Vehicle Laboratory, MIT, Cambridge, 2005.
2. Patton RJ,Kangetehe SM; Robust fault diagnosis using eigen structure assignment of observers. In Patton R, Frank P, Clark R editors; Fault Diagnosis in Dynamic Systems, Prentice Hall, Herausgeber, 1984.
3. Iserman R; Identification Dynamis chersysteme, Band I and II, Spring Verlag, Berlin, 1984.
4. Mueller PC; Estimation and Compensation of Nonlinearities,” Proceedings of 1st Asian Conference, Tokyo, 27-30 July, 1994: 228-234.
5. Park RW; The finite-element modeling of dynamic motions of a constraint wind turbine and the system diagnosis for the safety control. Engineering,2013; 5(12): Article ID:41071,5 pages
6. Park RW; Estimation of a mass unbalance under the crack on the rotating shaft. ICASE, 2000; 2(4): 228-234.
7. McClamroch NH, Huang HP; Dynamics of a closed chain manipulator. American Control Conference, 1985: 50-54.
8. Park RW; Crack detection, localization and estimation of a depth in a turbo rotor. KSME International Journal, 2000; 14(7): 732-729.
9. Park RW, Mueller PC; A contribution to crack detection, localization and estimation of a depth in a turbo rotor,” ASCC Proceedings, 1997; II: 427-430.
10. Park RW, Cho S; Noise and fault diagnosis using control theory. Proceeding of 13th Korea Automation Control Conference, ICASE, International Session Paper, Seoul, 6-11 July, 1998.
11. Hou M, Mueller PC; Design of observers for linear system with unknown inputs. IEEE Transaction on Automatic Control, 1985; 37(6): 871-875.